Response style differences between left- and right-handed individuals

Lynn Wright

A thesis submitted in fulfilment of the requirements of the
University of Abertay Dundee for the degree of Doctor of
Philosophy

May 2005

Response style differences between left- and right-handed individuals

Lynn Wright

A thesis submitted in fulfilment of the requirements of the
University of Abertay Dundee for the Degree of Doctor of
Philosophy

May 2005

I certify that this thesis is a true and accurate version of the thesis approved by the examiners.

Signed……………………………….. **Date** 20/10/05
(Director of studies)

Acknowledgements

I would like to thank Scott Hardie for his supervision, guidance, help and encouragement throughout my thesis. I would also like to thank him for his friendship and constant reassurance yet again that everything would be fine. Thanks too for his monkey fascination, without this the idea for the intial study would not have happened. I should also thank Scott for putting up with my constant stressed states and no matter how busy he was he always made sure that I was ok. Without him I could not have completed this work and therefore I am very grateful.

Secondly, I would like to thank Karen Wilson for all of her help. Her knowledge of all things technical and her constant checking that things made sense and piecing everything together have been invaluable. I would also like to thank her for her continued friendship (26 years now S!!! ☺) and also for her shopping addiction which allowed us to step away from the world of PhD's when we needed it!!

I am indebted to these two people and I offer them a huge amount of thanks.

Thanks to Charlie Cranmer for constantly being my 'cack' guinea pig when I was setting up experiments. Although this was often stressful for him he still went through with it. Thanks also to Noelle McAra for putting up with me in the office over the last few years and for always reassuring me that this would get done (along with providing me with words when my mind went blank).

Thanks also to my parents for supporting me through yet another few years at University. I promise that this will be the last time….honest. Without them this would not have been possible and I am forever grateful.

Thanks to Paul Rodway for his advice and thank you to all of the people who have taken part in my experiments over the last few years. I am particularly grateful to all of the left-handers who put up with me hounding them.

I would like to acknowledge and thank Fife Council for awarding me the Williamson Bequest during my studies.

Additional thanks to Lisa Clark, Lynne Davies and Lindsay Stewart for their help.

I would also like to thank Dr Leona Elder and Dr Louise Phillips for making my viva a pleasant experience and for their useful discussions and ideas.

Finally, thanks to the T-Gang and the GD’s. Without you the whole experience would have been much less fun and a much harder task……honest ☺   TNO!!!

Contents

Chapter 1 : Laterality and the evolution of handedness 1

List of figures

List of tables

List of appendices

Publications

Hardie, S., Hancock, P., Rodway, P., Penton-Voak, I., Carson, D., & Wright, L., (2005). The enigma of facial asymmetry: Is there a gender-specific pattern of facedness? *Laterality*, *10* (4), 295-304.

Rodway, P., Wright, L., & Hardie, S. (2003). The valence-specific laterality effect in free viewing conditions: The influence of sex, handedness and response bias. *Brain and Cognition, 53*, 452-463.

Wright, L., Hardie, S. M., & Rodway, P. (2004). Pause before you respond: Handedness influences response style on the Tower of Hanoi Task. *Laterality, 9* (2), 133-147.

These can be found after the appendices.

The published papers have been removed from this e-theses due to copyright restrictions.

Abstract

This thesis explores differences in response style between left- and right-handed individuals. Evolutionary and comparative backgrounds suggest that we should expect left- and right-handers to show differential responses in some similar situations and for the behaviour of left-handers to be adaptive and not necessarily pathological. Exploration of genetics, pathology and culture show that hand preference is best understood in terms of a genetic susceptibility modulated by experience. Consideration of how to measure and categorise handedness revealed that there is no universally accepted method and so a new inventory was developed, utilising the main accepted measuring scales (Annett, 1970; Oldfield, 1971 and Peters, 1998). A series of experiments was conducted in order to explore the potential differences in response style. Chapter 4 looked at response to a novel task: the 3-disk Tower of Hanoi and found that left-handers took significantly longer to start the task and solved it in significantly fewer moves than right-handers. In Chapter 5, the role of emotional processing was explored and it was found that both left- and right-handers showed broadly similar identification of facial emotions, although there were some sex and valence effects. This suggests that the differences in response style were probably not caused by differential lateralised emotional processing (and negative emotional 'interference') differences. Chapter 6 investigated the role of planning and type of task and found that in common with the findings of Chapter 4 when completing a manual sorting task there was a handedness effect, with right-handers showing a significantly quicker latency to start the task. However, spatial tasks showed mixed effects and sequencing tasks showed no significant differences. It was hypothesised that novelty of task might be the cause and this was further explored in Chapter 7. This chapter looked at the influence of stress and anxiety as well as the role of novelty. A further study using the Tower of Hanoi showed a similar but non-significant first move difference on a 'simple' version (3-disk) of the task but not the more complex (4-disk) version. However, state anxiety (Speilberger, 1983) was found to be significantly higher for left-handers on the simple task (when it was novel) but not for the 4-disk and non-novel versions. This suggests that task complexity and novelty may be important factors in understanding differences in response style between left- and right-handers. These findings are discussed in terms of the literature and suggestions are made for future studies.

Chapter 1 : Laterality and the evolution of handedness

1.0. Aims of the thesis

One of the most overt forms of lateralisation is handedness. Handedness has been tested widely in both humans and animals and a variety of similarities and differences have been reported between left- and right-handers (these will be discussed throughout the thesis). One key study central to this thesis concerns differences in response styles between left- and right-handed monkeys. Cameron and Rogers (1999) reported that left-handed marmosets took significantly longer to approach a novel object than right-handed marmosets. This pattern was also found in chimpanzees (Hopkins & Bennett, 1994). These findings suggest that there are fundamental differences shown in the way that these primates interact with the world that are related to handedness. However, very few human studies have reported differences between left- and right-handers' behaviour and their interaction with the world. Therefore this thesis will investigate the response styles of human left- and right-handers towards a variety of different novel tasks. Possible underlying cognitive and behavioural differences will be investigated.

1.1. Handedness

Around 10% of the human population are right-handed (e.g. Annett, 1985) although this figure is now often quoted to be as high as 14% in many cases because the intolerance of left-handedness in society has greatly subsided in recent years (Coren, 1992). There is much debate on how handedness should be defined and measured however most people still define themselves as either left-handed or right-handed (Provins, 1997). Men and younger people are reported to have higher levels of non-right-handedness (Amunts, Jäncke, Mohlberg, Steinmetz & Zillies, 2000) and around 33% of the population exhibit some form of mixed-handedness (a mixture of preferences between the left and right hand for performing a number of actions rather than ambidexterity where a person can perform actions equally well with either hand). Consistent right-handedness and consistent left-handedness is estimated to be around 64% and 4% respectively (Amunts et al., 2000).

However, humans appear to be unique in this trait, as comparative research shows that this preference differs vastly in primates. Indeed, Lehman (1993) argues that monkeys, apes and prosimians show very little bias towards either left- or right-handedness. It has been argued that handedness in great apes would allow us to gain a valuable insight in to the evolution of human handedness but there is much debate about whether handedness and more specifically a population bias towards right- or left-handedness actually exists in this group.

The origins of and the proposed reasons for human handedness (especially a bias towards the right hand) have often been debated. It is often assumed that handedness is solely a human trait and the argument resides over whether handedness is genetic or whether it is learned through environmental influences (see chapter 2 for details of these arguments). However, in order to explore the evolutionary issues of handedness further we have to look back to our closest relatives, the apes, and evaluate their laterality and handedness patterns.

1.2. Comparative lateralisation in primates and other animals

1.2.1. Primates

The existence of primate handedness has been debated for a long time. If handedness and laterality evolved a long time ago then we should look for signs of it in our closest evolutionary relative, the chimpanzee (they share around 99% of their genetic make-up with humans, (Corballis, 1991)). It is often supposed that if human handedness is similar to that of primates then it is probably inherited along with some subtle environmental influences (primate handedness would not have been subjected to educational or social influences that could have influenced their handedness) (Harris, 1993). Non-human primates (particularly chimpanzees) are not only similar to humans genetically but also anatomically and physiologically (Vauclair, Fagot & Depy, 1999). Chimpanzees also have similar motor and perceptual processing to humans (Vauclair et al., 1999). Thus, it is important to examine animal models of behaviour in order to be able to understand similar human processes and thus it is important to study animal handedness (and more specifically non-human primate handedness) in order to compare human handedness. However, there is support for the existence of lateralisation in a number of animals other than primates and some of these examples will be discussed later.

It is generally accepted that apes and monkeys show some form of handedness but the question of handedness being species specific is debated (MacNeilage, Studdart-Kennedy & Lindblom, 1987). MacNeilage et al. (1987) add that although population level asymmetries appear to exist in non-human primates, that the demand of the specific task can have an effect on hand preference. Ward, Milliken and Stafford (1993) report that lower primates (such as lemurs) appear to hold food with their left hands but hold and swing on tree branches using their right hands. This suggests that they have more strength in their right hands but does not indicate whether the hand used to hold the food is also used to manipulate it. It is also unclear which hand Ward et al. are suggesting is more skilled. Westergaard and Suomi (1996) reported that rhesus macaques showed a right hand preference for the manipulation of tools but they did not find this effect in capuchin monkeys. However, capuchin monkeys showed more definite hand preferences as individuals than the rhesus macaques did and this was the case particularly among adult primates. MacNeilage et al. (1987) backed up this finding by suggesting that many primates (particularly apes) use their right hands for manipulating objects and to perform fine motor skills.

Hopkins (e.g. 1994; 1999) has researched laterality in chimpanzees for a number of years and reports that chimpanzees as a population group have a right hand bias. He classifies handedness using a frequency system. In order to do this he observes and calculates the number of times a chimpanzee uses each hand to perform a series of actions. However, calculating only the frequency of hand preference has been criticized by some researchers (e.g. Marchant & McGrew, 1996). Therefore, Hopkins, Cantalupo, Freeman, Russell, Kachin and Nelson (2005) examined chimpanzee handedness using a series of different measurements including bouts of handedness as well as frequency measures and also examining handedness using both continuous and categorical scales of measurement. Hopkins et al. found that when different scales of measurement were used that a population level bias of right-handedness still existed among chimpanzees.

Other studies have reported that handedness exists at the population level in a number of non-human primates. The most widely researched groups are chimpanzees but a number of studies evaluating the hand preferences of, among other primates, gorillas and orang-utans have also been carried out. Colell, Segarra, & Sabater-Pi (1995) reported that chimpanzees displayed a right hand preference for a number of activities including object manipulation and reaching. Bard, Hopkins and Fort (1990) reported that chimpanzees mainly showed right hand preferences and these preferences became stronger as the chimpanzee got older. Lutz-Maki and MacNeilage (1991) reported that 77% of their chimpanzee sample exhibited right hand preferences (however the group only consisted of 13 animals where 2 of the others exhibited left hand preferences and the other exhibited no preference at all). It appears that a substantial body of evidence exists in favour of a right hand population bias among chimpanzees however, a number of researchers have failed to find an existing right hand bias. Palmer (2002) questioned Hopkins' findings and reanalysed Hopkins' data (along with data from a number of other studies) and reported that there were unusual patterns in the data and that the validity of the findings could be questioned. Palmer concluded that there was no concrete evidence of right-handedness at the population level among chimpanzees. Palmer proposed that the problem lay with the distribution of hand preference among the chimpanzees and the number of observations made. He found that hand preference became more ambiguous as the number of observations increased, that is as the sample size increased and the number of times each individual was observed performing specific actions the more mixed the hand preference became (often with almost equal numbers of left and right hand actions). Boesch (1991) reported that there was no population asymmetry in reaching or grooming in chimpanzees. Dimond and Harries (1984) reported that there was no population asymmetry in a group of chimpanzees, gorillas and orang-utans and McGrew and Marchant (1997) reported that there was no evidence of right-handedness at a population level among chimpanzees. According to Boesch (1991) an important factor that has to be taken in to account when considering hand preference in chimpanzees is age. Boesch reported that right hand preference was higher amongst younger chimpanzees than it was in adults. However, Byrne and Byrne (1991) countered this by reporting that there was no effect of age on hand preference in apes and more specifically in gorillas. This conflicts with the previous findings of Bard et al. (1990) who stated that there was a right hand bias among chimpanzees and that this preference got stronger as the chimpanzee got older.

Hopkins et al. (2005) challenged the findings of Palmer (2002) and in particular the point that handedness became more ambiguous as the number of observations and sample size increased. Hopkins reported that his sample consisted of three sub samples of which he had combined the data and thus each group in itself displayed a population level right hand preference before being merged. However, the choice of analysis carried out by Palmer (funnel analysis) lost this effect and thus he concluded that there was no right hand bias among the group. Hopkins et al. (2005) add that sensitive and reliable measures of hand preference have to be used in order to pick up effects and if these are used then most individuals will show nearly exclusive left or right preferences for individual actions.

The findings for gorillas have been a little more consistent in that many studies report that there is a lack of a population bias of handedness among this group. Annett and Annett (1991) reported that there was an even distribution of left-handed and right-handed reaching in gorillas. Byrne and Byrne (1991) studied a group of gorillas in the wild and found that there was no population asymmetry overall but there was a slight trend towards right-handedness for action movement (for example they reported that around two-thirds of gorilla preferred the right hand for preparing vegetables to eat). They also reported that there was no bias at all for foraging behaviour. Shafer (1988) examined handedness in groups of gorillas in the wild and in groups of captive gorillas (which were zoo born) and found that there was only a population asymmetry towards right-handedness in the group that was zoo born (16 right-handed gorillas compared to 2 left-handed gorillas). The group of wild gorillas did not show a population level asymmetry as 8 of the gorillas were left-handed and 9 were right-handed. Thus it appears that overall right-handedness is more common than left-handedness among gorillas but not significantly so that it can be regarded as dominant within the gorilla population. Also, it has to be taken in to account, as can be seen from Shafer’s (1988) study, that the habitat of the primate might also be important as many of the findings that have reported existing population level asymmetries have all involved captive primates. From this is might be presumed that the importance of the findings with captive primates is that they often imitate their caregivers and therefore a bias in their hand preferences is likely.

One problem with researching handedness in non-human primates is that the groups that conclusions are drawn from are often very small and therefore it is difficult in many cases to make valid claims. For example, Bresard and Bresson (1983) reported that chimpanzees and orang-utans exhibit a right-hand preference over a series of manipulation tasks. However, the study only consists of 1 chimpanzee and 1 orang-utan and therefore the results are lacking in power and validity. Similarly, Cunningham, Forsythe and Ward (1989) reported that orang-utans demonstrated a right hand preference for reaching and object manipulation but a left hand preference for touching their bodies. However, the sample again only consisted of a single orang-utan and thus the validity of making such claims is weak.

In summary, there have been several problems with acceptance of the position of a dominant hand preference in the chimpanzee population. Palmer (2002) argued that there are sampling biases in the data and therefore any evidence of population handedness is weak. McGrew and Marchant (1997) added that Hopkins' data is collected using captive chimpanzees and therefore assumptions cannot be made to the population in general. McGrew and Marchant (2001) argue that apes reared in captivity are influenced by the humans around them and in many cases they will develop a right hand preference through social learning. However, Hopkins and Cantalupo (2005) add that there is no evidence that states that hand preference differs between groups of wild chimpanzees compared to those who are raised in captivity. Hopkins and Cantalupo compared five different hand preference behaviours (scratching, grooming, eating, picking things up and holding) in captive and wild chimpanzees using data from a number of previous studies (see Hopkins & Cantalupo, 2005 for details of these). They reported that there were no large differences between the hand preference behaviours of the captive groups and the wild groups for any of the behaviours except for 'holding'. They also reported that there was a high incidence of ambiguous hand preference in both the captive and the wild chimpanzee groups. Groups of captive chimpanzees are often larger than groups of wild chimpanzees and thus the numbers of right-handed chimpanzees are often cited as being higher in the captive group (Hopkins & Cantalupo, 2005). However, when these numbers are transformed into ratios the split of left- and right-hand preferences are similar between the captive and wild groups (often cited as 2:1 in favour of a right hand preference). Marchant and McGrew (1996) reported that there is no population level handedness among wild chimpanzees. However, this conclusion was reported using only two studies of chimpanzees and there was much debate on whether a sensitive enough measure of hand preference was used. Hopkins and Cantalupo (2005) state that in order to be able to directly compare the hand preferences of groups of wild and captive chimpanzees a similar measurement of handedness must be used which is sensitive enough but also which is flexible enough to accommodate differences in context between the two groups.

An additional factor which has to be taken in to consideration when examining hand preference is whether the behaviour is unimanual or bimanual (whether the individual uses one hand to perform the action or two, see Chapter 3 for further discussion). It is often debated which hand is the leading or dominant hand in a number of bimanual actions and thus there are often some discrepancies across studies for this reason. For example, in the human literature participants are often asked how they sweep with a broom. Some questionnaires ask which hand is at the top of the broom (e.g. Annett, 1970) while others ask which hand is at the bottom of the broom (e.g. Raczkowski & Kalat, 1974). The argument is that the hand at the top of the broom is the hand that controls the direction and thus this is regarded as the dominant hand (Annett, 1970) however, others regard the hand at the bottom of the broom as the dominant hand as that is the one that pushes the broom harder and requires more strength (Raczkowski & Kalat, 1974). In other cases the researcher does not report which hand does the holding and which hand manipulates the object (Steiner, 1990). Therefore it is important to consider whether a task is unimanual or bimanual in order to examine strength of handedness. Hopkins and Rabinowitz (1997) compared unimanual and bimanual strategies using a honey dipping task used to fish for termites. They found that there was population level right-handedness for bimanual actions (when holding the stick with two hands) but not for unimanual actions (when using a single hand to fish for termites). MacNeilage et al. (1987) propose that a dominant hand preference in non-human primates is most apparent in those who can stand bipedally. MacNeilage et al. propose that non-human primates have a slight left hand bias and state that the evolution of bipedalism may have shaped this hand preference. When the animals were quadrapedal then the right front limb was probably used for support and the left hand (front limb) used for picking food or catching insects. However, when the animals evolved to be able to stand on two legs the right hand possible developed the skill to manipulate and co-ordinate objects.

However, as has been previously mentioned, the type of task that is being carried out may play an important part on hand preference (also see Chapter 3). Westergaard, Kuhn, and Suomi (1998) examined hand preference in humans and rhesus monkeys. They studied the reaching behaviour of humans and rhesus monkeys from a bipedal position (on two legs with both hands free) and also from a quadrapedal position (on all four limbs with no hands free). Westergaard et al. found that the human participants exhibited a population-level preference for the right hand regardless of their posture. However, rhesus macaques showed a population-level preference for the left hand when quadrapedal but they exhibited a shift toward the right hand when bipedal. Westergaard et al. reported that there is a correlation between right handedness and bipedal reaching and propose that bipedalism may be an attributing reason for why there is a species-level of right-handedness in humans.

While it is debatable whether animals show an overall population-level handedness similar to humans, Fagot and Vauclair (1991) state that it is clear that non-human primates exhibit population level handedness for numerous behavioural measures. Fagot and Vauclair define handedness as a routine action that is non-specific. In other words, every day actions with which the animal uses their hands to perform. In order to get the most honest handedness measurement from non-human primates (such as baboons) Fagot and Vauclair (1988) state that the first few trials on a new task are the most important.

Warren (1980) studied a series of old world monkeys (such as baboons and macaques) and described their manual preferences as being divided equally between those with a left hand preference and those with a right hand preference. He also added that in order to examine hand preference that the task that was used to measure the laterality was of vital importance as it could alter preferences depending on what it was (for example if it required 2 hands in order to manipulate it). Also, the novelty of the task is also important because an accurate measure of hand preference would not necessarily be recorded if the primate was practiced in the task thus a naïve primate would give the most accurate data.

MacNeilage et al. (1987) reported a different set of findings from that of Warren (1980). MacNeilage et al. reported that there was an existing population level of asymmetry among various groups of primates. For example, they reported that prosimians (such as lemurs) displayed a left hand preference for actions that were visually guided. This finding is common amongst groups of primates (including apes according to MacNeilage et al.). MacNeilage et al. also reported that monkeys and apes appear to have a right hand preference for manipulative tasks or in tasks that require both hands the right hand acts as the dominant hand most often. MacNeilage et al propose that a left hand population bias is more likely to occur in monkeys that are in the field rather than in a laboratory setting and also in tasks that are relatively simple (they state that more complex tasks that require more manipulation would be more likely to evoke a right hand response). One final factor that MacNeilage et al. propose that could evoke higher left hand responses is if the subjects are adults rather than infant primates. This ties in with the findings of Boesch (1991) who stated that right hand preferences are higher amongst infant chimps than adults. Thus, there appears to be some form of decline in right-handedness among primates, as they get older in some cases.

It is relatively easy to measure human handedness once the definition of handedness has been established. If hand preference is being measured then the format is usually a handedness questionnaire and if hand skill is being measured then a task is performed (usually with both hands one at a time) that will allow the researcher to see which hand is more skilled and by how much (for example, Annett's peg moving task, see Chapter 3). However, the measurement of primate handedness is much more difficult. A non-human primate cannot be presented with a questionnaire and asked which hand they use to perform a series of actions. However, it is easier to get a primate to perform on a task that will give an idea of which hand they prefer to carry this out with. One frequently used method of collecting data on non-human primate handedness is to get the primate to perform a single task numerous times so that numerous observations can be calculated and analysis can be performed. Additional methods of collecting handedness data from non-human primates involve using a series of different tasks and actions and averaging the responses to these in order to calculate hand preference. These include free field reaching, restricted reaching, carrying behaviour, object manipulation, touching the face and/or body and feeding (Hopkins, 1995a, b). The items that are used to assess non-human primate handedness are important in order to get accurate measurements. Hopkins and Bennett (1994) measured hand preference in a group of chimpanzees using bipedal reaching. Chimpanzees had to reach for a suspended food incentive and the hand used to grab the food was recorded over 50 trials. In order to avoid any from of lateral bias the food was placed central to each individual. However, Marchant and McGrew (1991) state that in order to get accurate measurements of hand preference that it is not enough just to study the general reaching or touching behaviours of primates. Instead, Marchant and McGrew suggest that actions that require a degree of motor skill have to be studied in order to get a true indication of hand preference. Arguments are often presented about the classification of handedness in non-human primates and at the point at which is hand dominance applied. Hopkins and Morris (1993) use a frequency criterion of 50% where frequencies greater than 50% represent a right hand preference, a frequency of 50% represents no preference and a frequency of less than 50% represents a left hand preference. Hopkins and Bennett (1994) used a frequency paradigm in order to calculate their handedness classifications. Chimpanzees were classed as right-handed if they bipedally reached for food more than 59% of time (over 50 trials). Chimpanzees who used the right hand for reaching less than 41% of the time were considered to be left-handed and those who used the right hand more than 40% of the time but less than 60% were classed as ambidextrous.

Another inconsistency that exists is the definition among non-human primate researchers about what ‘no preference’ actually means. Hopkins and Morris (1993) suggest that chimpanzees are classed as having ‘no preference’ when they do not show any behaviour on a task or fail to show a significant left or right hand bias on a given task. Hopkins and Morris add that many studies are only interested in the subjects that display a left or right hand preference and that those with no preference are dropped from the analysis. However, they state that the results of some of these studies would be questioned in terms of their validity, as the claim of a population asymmetry without considering those with no preference would be weak.

Hopkins and Morris (1993) propose that in order to accurately test comparative models of handedness, both in humans and non-human primates, a test battery that consists of multiple tasks and a solid criterion of handedness would have to be established and be able to be applied to all species in order to draw valid and comparative conclusions.

Although many studies have argued for or against the existence of population level handedness among non-human primates, most of these studies involve apes rather than monkeys. Because apes are closer ancestors to humans then it is easier to link right-hand dominance as the preferred trait in these animals. However, numerous studies have also examined handedness in a variety of species of monkeys and mixed results have been reported. De Sousa, Xavier, De Silva, De Oliveira and Yamamoto (2001) reported that there was no population bias for right or left-handedness amongst a group of marmosets. Their handedness was measured using a food reaching task and was measured over 100 trials per monkey. Hook-Costigan and Rogers (1995) examined hand preference using motor tasks in common marmosets and reported that although there were individual biases for hand preference there was no clear population bias. Spinozzi and Cacchiarelli (2000) studied manual laterality in a group of capuchin monkeys using three reaching and discrimination tasks and found that there was a significant left-hand bias at the group level for one of the reaching tasks and also for the discrimination task while a right-hand group level bias was found for the other reaching task (this task involved visually guided reaching while the other involved reaching by touch only). Spinozzi and Cacchiarelli concluded that the hand preference can vary according to the type task presented and more specifically that both spatial requirements and visual cues affected preference in this instance. It has been proposed that the right hemisphere is involved in processing tactile information (e.g. Lacreuse & Fragaszy, 1999) and this therefore supports the left hand group level preference by the capuchin monkeys when performing a reaching task by touch only.

Westergaard (1991) examined the hand preferences of tufted capuchin monkeys and lion-tailed macaque’s in tool use and tool manufacture. He found that a dominant hand preference for tool use was found in 4 out of the 5 capuchins and in 3 out of the 4 macaques

One factor that has to be taken in to consideration, and it is one that is often proposed by McGrew, is that many reports of hand preferences among non-human primates are the result of animals held in captivity. Very few studies report hand preferences of non-human primates in the wild and when they do it is often reported that there is no population level of hand preference. Most of the studies reported above were carried out in with captive primates and therefore they have to be considered with caution. The direction and strength of hand preference in non-human primates is considered to be a very sensitive variable and susceptible to change. Fagot and Vauclair (1991) report that, for example, task complexity can affect non-human hand preference. If a complex task involves fine motor skills then it is likely that there will be a switch in hand preference or that both hands will be used across the task in order to manipulate it successfully. Another factor according to Fagot and Vauclair that can affect hand preference is the novelty of the task. In the same way that complexity has an effect the novelty can also trigger a response of uncertainty. Because the individual does not know how to manipulate a novel object or task then a system of trial and error often takes place where different attempts are made to effectively solve or manipulate the task. In doing so it is common for a change of hand preference to occur. Hopkins (1996) however, states that familiar tasks often result in a symmetrical distribution of hand preference. He adds that there is a relatively consistent use of one hand for each individual when familiar tasks are being carried out. The issue of novelty is further examined by the work of Lehman (1980), who studied hand preference in a group of stump-tailed macaque monkeys using a simple reaching task. Lehman studied which hand the monkey originally used to reach with and every time the monkey subsequently used that hand they did not receive a reward. However, every time the monkey used their opposite hand to reach with they were rewarded. Lehman found that in spite of the reward system that most of the animals continued to use the hand that they had originally used (the unrewarded hand). Lehman concluded by suggesting that monkeys are predisposed to choose which hand they prefer for a new task rather than always using the same one.

Numerous studies of prosimians have proposed that there is a population bias towards left-handedness in these animals. Larson, Dodson and Ward (1989) studied a group of 10 bushbabies and found that 7 of them had a left hand preference compared to 3 with a right hand preference. Sanford and Ward (1986) studied 8 bushbabies and found that all of them were left-handed. Forsythe and Ward (1987) also noted that there was a trend for left-handedness among lemurs. They studied a group of 33 black lemurs and found that 20 of them were left-handed and Masataka (1989) studied 22 ring-tailed lemurs and found that 20 of the group were left-handed. The biggest study to date of handedness and lemurs was carried out by Ward, Milliken, Dodson, Stafford and Wallace (1990) who studied a group of 194 mixed species lemurs and found that 47% of the group had a left-hand preference compared to 34% preferring the right-hand. However, another problem that often arises is the small sample numbers of the groups. It is not unusual for conclusions to be drawn using a sample size of less than ten in many cases (e.g. Westergaard, 1991 used 5 capuchins and 4 macaques in his study).

King (1995) reported that tamarins (*Saguinis oedipus*) exhibit population level right-handedness. However, King (1995) states that marmosets do not exhibit any handedness bias at the population level. Marmosets and tamarins are closely related but there appears to be a difference in their population level hand preference. King states that reasons for this could range from the difference in their diet or the different sized territories that they defend (the territories of tamarins are larger than those of marmosets).

Studies of various species of monkeys have resulted in fluctuating results. Some studies propose that there is a left-handed trend among monkeys (e.g. Fagot & Vauclair, 1991; Hatta & Koike, 1991), others propose that there is a right hand preference among monkeys (e.g. Westergaard & Suomi, 1996) while other studies report that there is no population bias at all (e.g. King, 1995).

1.2.2. Parrots

Corballis (1991) stated that handedness is a unique and universal human behaviour in relation to primates. Corballis (1991) proposes that the only animal that appears to show any sign of true handedness is the parrot. He states that parrots use their feet like hands and that most parrots are left footed. Rogers (1989) reported that only around 12% of parrots are right-footed and thus this pattern is the inverse of human handedness statistics. Parrot footedness is measured by examining the claw that is used to pick up food from the cage and the non-dominant claw is considered to be the one that the parrot is left perching on. Most parrots use the right hemisphere to view the food and manipulate it with the left claw. It views the food with the eye ipsilateral to the foot that they are standing on. In contrast to the left foot dominance of the parrot, Rogers and Workman (1993) reported that chickens show a right foot preference.

1.2.3. Chicks

Extensive studies have been carried out examining lateralisation in chicks. Vallortigara, Regolin, Bortolomiol and Tommasi (1996) carried out a study where they trained chicks to discriminate between two identical boxes using a pecking response– the only difference was that one box was placed on the right and the other was placed on the left (and one box contained food). The chicks were then trained using a red box and a green box (where the one on the right contained food). This time there were three conditions. In the first group the position of the boxes were alternated randomly, in the second group the position of the boxes did not change at all and the third group was a control group who continued to use the two original white boxes. The chicks had to differentiate between the two boxes based solely on their positions. Vallortigara et al. found that chicks took fewer trials during training (using the white boxes) to learn when the positive box (the box with food) was placed on their right side. This pattern also occurred when the second phase of training was carried out (using the coloured boxes which were not moved) and in the control condition. However, in the alternating condition chicks were trained to learn when the positive box (the one with the food in it) was placed on the left hand side. The approach behaviour of these chicks to the food (a positive behaviour) and the box being placed on the right hand side further reinforces the approach and positive behaviour. Chicks trained themselves very quickly to identify the pattern of positive behaviour with the right hand side.

1.2.4. Bees

Evidence exists that laterality is also present in a number of other animals. Kells and Goulson (2001) examined the behaviour of four species of bees (*B. lapidarius; B. terrestris; B. lucorum and B. pascorum*) on a series or flowers arranged in a circle. They noted the rotation behaviour of each bee around the flowers over ten trials. Kells and Goulson reported that in three of the four species that there was a significant overall tendency for the bees to rotate in a preferred direction suggesting that this may be linked to handedness. B. *lucorum* and B. *pascorum* displayed a significant anticlockwise rotation around the flowers while B. *lapidaries* displayed a significant clockwise rotation around the flowers. B. *terrestris* did not display any significant direction in rotational behaviour. Kells and Goulson state that thee findings may be linked to handedness in that the bees are choosing one direction over the other. It might be possible to assume that the two species that preferred the anticlockwise direction would be exhibiting a right-hand preference and the species choosing the clockwise preference would be exhibiting a left-hand preference due to the direction that the bee would start from. However, it could also be possible that anticlockwise could refer to the direction that the bee is heading towards (so this would be the left in this case). Kells and Goulson do not clarify which direction would be linked to left- and right-handedness respectively and thus in order to draw further conclusions this would have to be rectified in order to do this.

1.2.5. Mice and Rats

Collins (1985) carried out numerous laterality studies with mice and rats and concluded over a series of food reaching tasks that there was no population bias for handedness amongst the group. He found that in every study around 50% of mice or rats were right-pawed and the other 50% were left-pawed. However, Waters and Denenberg (1994) disagree with Collin's findings and report that the task that the mice are performing will affect the paw dominance. They state that a population of inbred mice showed a significant right paw preference (61%) on a paw preference test (Waters and Denenberg's 1994 lateral paw preference test) but there was a left paw dominance (55%) on a reaching test (using Collin's 1968 paw preference test).

1.2.6. Cats

Cole (1955) (cited in Pike & Maitland, 1997) reported that cats show a slight bias for the left paw over the right paw. However, Pike and Maitland (1997) studied paw preferences for food reaching in around 50 cats living in a household environment. They reported that 46% of the cats showed a right paw preference, 44% preferred the left paw and 10% used either paw (measurements were taken over a 10 week period). Pike and Maitland also reported that 60% of the sample used the same paw 100% of the time. Pike and Maitland conclude that cats show and equal distribution of left and right pawedness. Broadly similar findings were also reported in studies conducted by Tan, Yaprak and Kutlu (1990) and Fabre-Thorpe, Fagot, Lorinez, Levesque and Vauclair (1993), thus suggesting that cats do not show population-level pawedness.

1.2.7. Dogs

Few studies have been carried out on the laterality of dogs. However, Tan (1987) reported that domestic dogs favoured their right front paw on a single task (57% of the sample) than their left paw (18% of the sample). However, Wells (2003) found that the sex of a dog was related to their paw preference. She reported that there was a population bias in both male and female dogs but these were in opposite directions. Female dogs preferred to use their right front paws while male dogs preferred to use their left front paws on a series of tasks.

1.2.8. Amphibians

Bisazza, Cantalupo, Robins, Rogers and Vallortigara (1997) examined pawedness in toads. A piece of paper or a balloon was attached to the toad’s head (centred so that there was no side bias) and the paw with which the toad reached to remove the paper or balloon from its head was recorded. It was reported that there was a right paw bias for removing the balloon (59% of the sample used their right paw) and also a right paw bias for removing the piece of paper (55% of the sample used the right paw). Bisazza et al. carried out additional tests on different species of toads – the first example used the common European toad (*Bufo bufo*) while the following example uses the South American cane toad (*Bufo marinus*). The toads were placed upside down in water and the paw used to control the movement of the toad back to the upright position was recorded. It was found that 66% of the toads used the right paw to get back in to the upright position. Robbins, Lippolis, Bisazza, Vallortigara and Rogers (1998) carried out a similar study to Bisazza et al.'s. (1996) study with the upturned toads submerged in water. The difference this time was that the toads were turned upside down on a dry surface (such as a table) and the limb used to move the toad back the right way up was noted. Three different species of toad were tested in this study (*Bufo marinus, Bufo viridis and Bufo bufo*). *Bufo* viridis is the European green toad.   It was found that each species of toad used their hind limbs to navigate them back. Robbins et al. reported that *Bufo marinus* and *Bufo bufo* preferred to use the right hind limb to navigate them while *Bufo viridis* preferred to use the left hind limb. These findings support the work of Bisazza et al. (1997) who found that *Bufo viridis* showed a left paw preference on a wiping test while the other species showed a right paw preference. It appears that pawedness in toads not only depends on the task that they are doing but also on the species of toad (Vallortigara, Rogers, Bisazza, Lippolis, & Robins, 1998).

1.2.9. Summary of Animal Handedness

Thus it can be seen that various arguments exist for and against the presence of handedness amongst a number of animals. The biggest controversy lies amid the hand preferences of primates and most specifically chimpanzees. Since these are our closest relatives then there is a great amount of interest in whether or not they exhibit right hand dominance as a species in order to attempt to relate their hand preference to that of humans. It has been extensively reported by Hopkins that chimpanzees do exhibit right-handedness at the population level and thus the relationship between chimpanzees and humans and the dominance of right-handedness would appear simple. However, there is extensive evidence (e.g. McGrew) which states that around 50% of chimpanzees are left-handed and 50% are right-handed (although there are varying degrees of the strength of this preference across the animals). This view appears to contradict the link between human handedness and handedness in chimpanzees. If right-handedness were dominant in chimpanzees then the obvious answer would be that this preference continued to evolve after humans spilt from the chimpanzees almost 6 million years ago (see Corballis, 1989). To complicate things further, it has been argued that right-handedness in society did not become much more apparent until around 170,000 years ago (Corballis, 2002). However, it is unclear how the true dominance of right-handedness in our (human) society evolved and a number of possible reasons for this have been proposed (see further on in this chapter for some possible reasons and chapter two for genetic, environmental and pathological theories). Provins (1997) proposes that some genetic change must have occurred during evolution that shifted hand preference sharply in the favour of right-handedness. Also, MacNeilage et al. (1987) argued that there is a slight bias towards left-handedness in chimpanzees (particularly in visual reaching tasks) therefore this also complicates the straightforward relationship between handedness and primates. Previc (1991) contradicts this finding by stating that the bias of right-handedness did emerge in the great apes, however, the more extreme right hand preference that is observed in humans, Previc says, is caused by cultural and environmental influences created by humans themselves. Finally, Corballis (e.g. 1991) proposes that chimpanzees do not exhibit handedness at all and although they may use certain hands to perform a number of actions any existence of a dominant hand preference is very weak. Corballis concludes that humans are a unique group in our society as they are the only species that show population level handedness. Thus the question that is often asked is ‘Is handedness a uniquely human trait?’ and based on the evidence presented in the previous section it appears that many other species show various degrees of hand preference but it appears that only humans have a population level right-handed society. The evolution of handedness and the dominance of right-handedness will be examined and discussed in the following sections of this chapter as well as in Chapter 2.

1.3. Emergence of hand preference

Evidence suggests that the dominance of right- handedness (at almost 90%) has stretched back as far as prehistoric times. For example, in Egyptian tombs, cave paintings depicted people performing activities with their right hands and the profiles of the people in the paintings suggested that a right-handed person drew them. Additionally, analyses of numerous tools and weapons from this time also suggested that not only were they made with the right hand but also for the right hand (E.g. Corballis, 1991).

Strong evidence for right-hand dominance has been illustrated through the analysis of fossilised baboon skulls. It was concluded that the positions of the injuries on the skulls of the baboons were the results of blows inflicted by the clubs of right-handed humans (Springer & Deutsch, 1993).

Another theory for why right-handedness was dominant in society was that human handedness was caused by the way that blood flowed around the body (Harris, 1993). This idea was devised through much earlier work by Aristotle (cited in Harris, 1993) who stated that the blood supply to the right hand side of the body was purer and warmer than the blood supplied to the left hand side of the body. The reason given for this was that the vena cava (which is the larger part of the heart) supplied the right side of the body while the more restricted aorta supplied the left hand side. An alternative theory of the cause of right hand dominance was concerned with the balance of the body which was known as visceral distribution (McManus, 2002). This theory proposed that the liver was positioned more to the right hand side of the body and thus the body would not be equally balanced. Thus in order to balance the body the balance would have to be shifted to the left hand side such that the right hand and right leg would be free in order to perform actions (Harris, 1993). However, one problem with this theory is that it does not account for left-handedness and fails to explain how left-handedness exists using the theory of visceral distribution.

Therefore a number of theories have been proposed which attempt to explain firstly, how handedness evolved and secondly, why humans are predominantly right-handed. Chapter 2 will investigate genetic, environmental and pathological theories of handedness.

1.4. Brain lateralisation

1.4.1 Brain lateralisation and behaviour in animals

Lateralisation, behavioural and cerebral asymmetries have generally been argued to be part of a uniquely human set of behaviours. However, this has changed recently and numerous cases have been proposed for the existence of asymmetries in a variety of species such as frogs, toads, lizards, rats, mice and mammals. However, perhaps the most important evidence that has been reported is that of asymmetries among non-human primates. Because non-human primates are our closest living relatives and research into their cerebral organisation has been extensively carried out the results are vital in aiding our understanding of the evolutionary origins of human lateralisation.

Spinozzi and Cacchiarelli (2000) state that in order to investigate whether cerebral specialisation in non-human primates is similar to that of humans, manual performance has to be studied along with hand preference. Ettlinger (1988) proposed that manual performance is a much more effective way of examining hemispheric specialisation (particularly with respect to motor functioning) than hand preference would be.

As previously mentioned, brain lateralisation and its related behaviours such as handedness, language abilities and cognitive functioning were often thought to be solely human traits (Vallortigara, Rogers & Bisazza, 1999). However, a number of researchers have reported that the brains of many mammals, vertebrates and non-human primates are also lateralised. Vallortigara et al. (1999) state that animals are very important in order to be able to investigate hemispheric asymmetries as they provide models that can be related to human asymmetries and help trace the evolutionary pathway of cerebral asymmetry. In order to examine early brain lateralisation Vallortigara et al. (1999) state that brain asymmetries in lower vertebrates should be examined. Bauer (1993) reported that frogs had a left side dominance of the brain for vocalisations and Cantelupo, Bisazza and Vallortigara (1995) reported that some species of fish favoured the right side of the brain when fleeing from predators (this is linked to the avoidance behaviour and right hemisphere link proposed by Davidson, 1992). A number of studies have been carried out on the lateralisation of toads and it has been reported that toads display pawedness (see section 1.2.8.).

Rogers (2002) stated that it is possible that cognitive style, temperament and emotional responsiveness are connected to hemispheric lateralisation. This has been found in chicks (see Workman & Andrew, 1989, for a comprehensive review) but is also widely reported in non-human primates. Rogers states that a possible indicator of hemispheric lateralisation in primates is handedness and the preferred hand is related to the behaviour and style of the contralateral hemisphere controlling it. Thus an individual with a left hand preference would exhibit potential cognitive styles and behaviours associated with the right side of the brain such as strong emotional responses (particularly negative responses) (Davidson, 1992) and those with a right hand preference would not exhibit behaviour directly related to such a strong emotional response. Studies on non-human primates have been carried out in this area (Hopkins & Bennett, 1994; Cameron & Rogers, 1999) and these will be discussed in detail in chapter 4. To summarise these two studies here Hopkins and

Bennett examined the response behaviour in chimpanzees to novel objects and found that left-handed chimpanzees took significantly longer to approach the novel objects than right-handed chimpanzees did. Hopkins and Bennett concluded that approach behaviour and willingness to explore must be related to the left hemisphere while avoidance behaviour must be related to the right hemisphere. Similarly, Cameron and Rogers (1999) found that left-handed common marmosets took significantly longer to enter a novel room containing novel objects than right-handed common marmosets. Again this is consistent with the right hemisphere being dominant for fear and avoidance responses and the left hemisphere being dominant for approach behaviour and no fear responses. Cameron and Rogers (1999) and Hopkins and Bennett (1994) concluded that right-handed primates appear to exhibit more exploratory behaviour and show less fear and avoidance behaviour than left-handed primates. Rogers (2002) speculates that a population bias towards right-handedness may be plausible in species where survival depends on a high level of exploratory behaviour but a low level of fear and negatively associated emotions. Rogers also proposed that survival among a left-handed species group would depend on high levels of vigilance in new environments and the exhibition of high fear and stress responses towards both novel environments and objects. Rogers (1999) adds that additional factors such as gender and age can influence these findings (see Rogers, 1999, for a more detailed account).

Andrew and Rogers (2002) argue that *"the left hemisphere mechanisms provide inhibitory influences on behaviour such as fear and attack, and that the left hemisphere is used when there is a need to assess the situation before taking a decision."* (p. 111).

As previously mentioned, King (1995) reported that tamarins exhibited a population level of right-handedness while marmosets had no population bias for handedness (left- and right-handedness in marmosets is said to be around 50% each). However, Rogers (2002) states that if the two species were mixed then it may be beneficial in terms of cognitive and emotional responses to a variety of objects and situations. The left-handed monkeys in the group would be more vigilant but cautious in their approach to novel objects and situations and would therefore possibly be more likely to survive from predators. However, the right-handed group (of which the numbers would be higher if the two groups were combined) would be more explorative and also less fearless and willing to approach novel situations more readily and thus would perhaps have more chance of being caught by a predator but also would have more chance of gathering food than the left-handers.

Hook-Costigan and Rogers (1998) studied the facial expressions of marmosets and reported that there was a greater emotional expression on the left side of the face when the marmoset produced two different fear expressions but the emotional expression was more apparent on the right when the marmoset produced a social contact call. Andrew and Rogers (2002) state that this provides evidence that the left hemisphere controls the production of vocalisations in these animals

One of the most studied animals in terms of brain lateralisation is the domestic chick (e.g. Vallortigara & Andrew, 1994). Reports have found that the functions of the two hemispheres are very different in the way that they store information and how they perceive different things. Vallortigara and Andrew (1994) reported that the right hemisphere of chicks is specialised to deal with spatial awareness and novelty while the left hemisphere is specialised for its categorising ability. Andrew (1991) found that chicks are lateralised for a number of similar features to humans. He states that chicks display lateralised motor behaviour, lateralised emotional behaviour and lateralised cognitive processing. Rogers (1997) reported that chicks were able to distinguish between grain and pebbles when using the right eye only (and thus the left hemisphere) but not when they used the left eye and the right hemisphere. Another example of brain lateralisation in chicks was illustrated in a study carried out by Tommasi and Vallortigara (1999). When chicks performed a task where they had to scratch the floor with one foot while one eye was covered Tommasi and Vallortigara found that the chicks supported themselves using the foot contralateral to the eye that was covered. That is the foot used to support the chick would be on the same side as the hemisphere of the brain that was being used for vision in the contralateral eye. Andrew and Rogers (2002) report that the use of the left eye in chicks (and thus the use of the right hemisphere) is associated with fear responses, attack and copulatory behaviour. Andrew and Rogers also report that the use of the left hemisphere suppresses attack and copulatory responses.

Not only is handedness examined amongst non-human primates but hemispheric specialisation has also been found to affect behaviour in primates. Morris and Hopkins (1993) reported that chimpanzees had a right hemisphere advantage for face recognition (and this was also the case in recognising facial expressions). This pattern is similar to humans. Bradshaw and Rogers (1993) reported that the perception and production of emotions in monkeys was lateralised in the right hemisphere. Once again, this pattern is similar to that reported in humans. Hopkins and Bennett (1994) propose that it is unclear whether or not cognitive differences occur between left- and right-handed primates in the same way that they occur in left- and right-handed humans. Hopkins and Bennett proposed that right-handed chimpanzees would approach novel stimuli faster than left-handed chimpanzees based on the lateralisation of left- and right-handed humans. They state that because, in general, right-handers reflect greater left hemisphere dominance and left-handers reflect greater right hemisphere dominance and this is associated with positive emotions and approach behaviour and negative emotions and avoidance behaviour respectively that there would be a delayed response towards a novel object by the left-handed chimpanzees. Hopkins and Bennett reported that there was a difference in the approach behaviour of left- and right-handed chimpanzees towards a novel object in that left-handers took significantly longer to approach it. These findings support Davidson’s (1992) model of approach-avoidance hemispheric specialisation.

The hand used to perform a number of actions can be related to hemispheric lateralisation (Rogers, 2002). Ward and Hopkins (1993) report that prosimians often use their left hands to catch prey. However, there could be different explanations for why this is the case. Firstly, catching prey with the left hand might reflect the dominance of the right hemisphere in the role of spatial awareness of where the prey is and the judgement of its’ distance in the animal’s visual field. However, it could also be argued that the left hemisphere could be dominant in this situation as the right limb may be the important limb in the process as support limb so that the animal could successfully strike it’s prey. One problem with this work is that it assumes that hand preference and hemispheric specialisation are closely linked in non-human primates. However, Corballis (1991) states that this is a controversial assumption and that hand preference has to be considered independently of hemispheric specialisation in non-humans. Corballis also proposes that there is no population level hand preference amongst non-human primates and thus it makes it difficult to draw conclusions concerning primate handedness and hemispheric specialisation. Corballis (1991) adds that handedness in non-human primates is a much weaker form than the handedness of a human.

Another lateralised behaviour that is often cited is that of vision in relation to vigilance or anti-predator behaviour (e.g. Bisazza et al., 1997 in toads; Andrew & Rogers, 2002 in chicks;). It has been reported that when a predator is viewed in the left visual field that both human and non-human primates' aggression levels are higher than if the predator is viewed in the right visual field (Vallortigara, 2000). This behaviour has been reported in a vast number of species such as fish, frogs and lizards. Most studies of aggression focus upon male aggression however, Hews, Castellano, & Hara (2004) report that mated female lizards display similar behaviour to lizards presented in their left visual fields, which is similar to the aggressive behaviour of male lizards. This display did not occur when other lizards were presented in their right visual fields. Also, when females were displaying themselves they used the left visual field significantly more often than the right to view the males that they were displaying to. According to Vallortigara (2000) visual lateralisation is subject to some controversy as many species have their eyes placed on the sides of their heads (such as many birds, fish and reptiles). Thus, the visual system works generally in a contralateral fashion with the brain but in some species the brain works in an almost ipsilateral fashion with the visual system. Visual lateralisation in chicks has been extensively examined and it has been reported that there are different visual abilities in the left and right eyes. Andrew (1988) reported that the right eye of chicks is specialised for more detailed vision (such as patterns on stone or granite) while the left eye is more specialised at picking up emotionally charged stimuli. Regolin, Vallortigara and Zanforlin (1994) devised a detour test for chicks that was used to examine eye preference. They reported that when a chick was faced with a stimulus that was novel the left eye was used more in females. In males when the stimuli was moderately novel again the left eye was used more than the right eye but when the stimuli was completely novel males used the right eye more often. Regolin et al. conclude that it is not only that the two cerebral hemispheres of the chick show different specialisations but more specifically the chick can control its sensory input depending on the visual field that it is located in. Many animals have been reported to show a link between the left hand side and negative behaviour relating to predators. Vallortigara et al. (1998) carried out a series of studies examining the visual fields of toads and their reactions to horizontally presented worms. The worms were presented to both the left and right visual fields but only one at a time. Vallortigara et al. report that almost all of the reactions by the toad (normally in the form of a tongue strike) occurred when the worm was in the right half of its binocular field of vision. When prey approaches in the toad's left visual field the toad does not strike it until the prey has moved in to the right visual field. Vallortigara concluded that predatory behaviour is more likely to be displayed by the toad when the prey approaches from the right visual field. Vallortigara (2000) carried out an additional study that examined tongue striking amongst feeding toads. He found that toads struck other toads with their tongues most when they were in their left visual fields (this is the opposite way round from how they strike their prey). Toads are thus more likely to strike their prey when they are in the right visual field but are more likely to strike their own species when they occupy the left visual field. This behaviour has also been displayed amongst a series of other species including chicks, pigeons, baboons and lizards (Vallortigara, 2000). Lippolis, Bisazza, Rogers and Vallortigara (2002) examined fear responses among three species of toads using a toy snake as a predator. They presented the snake individually to the left and the right visual fields and found that the toad reacted more when the snake was presented on the left. Lippolis et al. concluded that this demonstrated one of the roles of the right hemisphere as instigating a fear response towards a novel stimulus. Rogers (2002) reported that agnostic responses are made towards a conspecific when in the left visual field. Rogers continues that the aggressive responses towards others when viewed in the left visual field are not results of a simple leftward bias but more specifically an agnostic reaction, which is an emotional response, controlled by the right hemisphere.

One fact that has to be taken in to consideration when considering the lateralisation of toads is that they have a binocular visual system. That is because their eyes are placed on top of their heads so that they do not have such a clearly defined left and right side as animals that have eyes placed on the side of their heads (Lippolis et al., 2002). However, as it has been noted the toad strikes prey approaching from the right and strikes other toads that approach from the left but this is not advantageous to the survival of the toad or its defence of their food sources. The toads do not react to prey on the left hand side nor do they strike other toads approaching from the right hand side and thus they are risking not only their food sources from other toads but also are endangering themselves from predators and prey who approach from the right hand side (Lippolis et al., 2002). Rogers (2002) states that it is difficult to say whether or not the left and right hemifields in toads differ in their reactive behaviour due to the closeness of the eyes and thus an ambiguous midline.

1.4.2. Visual Lateralisation

A vast body of research in conjunction with lateralisation in animals has been carried out on the visual system**.** It is a possibility that different species of animals might use their visual systems differently. However, visual asymmetry of responding to predators can cause problems. A reaction to the detection of predators in toads, for instance, only evokes a response when the predator moves to the right visual field. If the predator/prey approaches from the left visual field then the toad does not react. This can cause problems, as it might be too late if the toad waits until the predator is in the right visual field. Vallortigara (2000) states that predators should be detected and avoided with the same caution regardless of which visual field it is identified in. This problem is a bit more difficult in fish. Because fish mainly move in schools then the avoidance of predators depends mainly on the group response rather than an individual response. If the majority of fish swim in one direction then it becomes difficult for any individuals to swim in the opposite direction. Also, because fish have laterally placed eyes this can have an effect on how they deal with potential predators. One visual field (and thus one hemisphere of the brain) potentially sees most other species as a threat while the other visual field would treat the potential predator as non-threatening. This could cause major disruption within a school depending on the position of the predator. Vallortigara (2000) states that this type of population asymmetry would be more likely to be encountered among social species rather than solitary species. Magurran and Seghers (1990) reported that when fish are part of a large shoal it is common for one pair to leave the group and inspect for potential predators. If both fish inspect a potential predator then the risk of them both being attacked is shared. However, if only one fish of the pair approaches the potential predator then they put themselves at risk while freeing the other fish. This takes the form of a model of mutual co-operation among unrelated individuals. Bisazza, De Santi and Vallortigara (1999) studied predator inspection in mosquito fish with respect to mutual co-operation. They did this by positioning a mirror either at the right or left hand side of the fish in order to create an additional fish. Vallortigara found that predator inspection was more likely to take place when the mirror image was on the left rather than on the right hand side of the fish. He suggests that this way the right eye watches the predator while the left eye monitors the companion. These findings suggest that different types of social behaviour can be displayed depending on what the fish can see with each visual field and the response to perceptual information processed by each side of the brain.

Patterns of lateralisation across many different species of animals are therefore somewhat unclear and in many cases are varied. However, there seems to be certain situations where one hemisphere takes precedence over the other (for example the role of the right hemisphere in avoidance behaviour). It is proposed that animals will react to different features of the environment (such as other animals or novel objects) according to the hemisphere that is in control

1.5. Lateralisation in humans

Brain lateralisation or asymmetry, according to Byrne, Kuba and Meisel (2004), is when one side of the brain is structurally different from the other or when one side of the brain performs different functions from the other. Hews et al. (2004) add that the brain is lateralised in order to perform specific tasks.

Although the left and right hemispheres of the human brain appear to look relatively symmetrical there are a number of existing anatomical differences. These anatomical differences include the right hemisphere being slightly heavier and larger than the left hemisphere; the temporal lobes are asymmetrical with the planum temporale being larger on the left hand side in around 65 to 90% of humans (Kolb & Whishaw, 1995). Also, the right hemisphere is longer at the front of the brain than the left hemisphere while the left hemisphere extends further back than the right hemisphere. Anatomical differences can be affected by sex and handedness and a brief summary of these differences will be discussed in this chapter.

Lateralisation is a complicated process for a number of reasons. Firstly, factors such as gender and handedness can affect laterality of function and it has been frequently reported that left-handers and females are more likely to be less lateralised (in that they have bilateral control of many functions) than right-handers and males (Kolb & Whishaw, 1995). Although most behaviours or functions (such as language) are predominantly controlled by one hemisphere of the brain, this control is not exclusive and the other hemisphere will also play a role in this. Thus, although the left hemisphere is dominant in the role of language production, the right hemisphere is also involved.

Additional hemispheric asymmetries exist but these tend to be static irrespective of hand preference. For example there are lateral differences in the visual system, the auditory system and the somatosensory system. Research into the somatosensory system has examined the recognition of shapes and patterns solely by touch. It has been reported that in these types of tasks that the left hand of right-handers is better at recognising shapes and patterns through touch. Asymmetries in the somatosensory system have been investigated through the reading of Braille (both in blind and sighted individuals) and it has been reported that both blind and sighted individuals read Braille faster with the left hand (Corballis & Beale, 1983). In addition it has been reported that the recognition of Braille patterns requires spatial awareness and knowledge and thus there is an important role for the right hemisphere to play in this while the processing of the spatial information does not directly involve the left hemisphere. Other tests of the somatosensory system involve simultaneously presenting different objects to both hands at the same time and asking the participant to identify the object that they had in their hand by looking at a selection in front of them. In almost all cases the individual selects the object placed in the left hand quicker than the object that is in their right hand (showing a right hemisphere superiority). A more common asymmetry with respect to handedness and laterality is that of the motor system. Kimura (e.g. 1977) has reported that control of movement is functionally asymmetrical. Kimura (1977) studied the gestures of groups of people while they were either talking or humming and found that right-handed people tended to gesture with their right hands while they were talking but were also inclined to touch or scratch their bodies with either hand while doing this. Kimura concluded that the hand used for gesturing was the one that was contralateral to the hemisphere that is dominant for speech and therefore there was a relationship between speech and certain manual activities (see section 1.6.1. for additional information). However, it could be argued that the previous study merely indicated hand preference rather than any form of asymmetry of motor control.

Davidson (1995) states that in humans the right hemisphere is associated with negative emotions and avoidance behaviour while the right hemisphere has been associated with more positive emotions and exploration and approach behaviour. Andrew and Rogers (2002) add that the right hemisphere appears to be heavily involved in human emotion and can be associated with negative states and social withdrawal. The debate continues as to whether all emotions are processed in the right hemisphere or whether the valence of emotions is hemisphere specific such as negative emotions being processed in the right hemisphere (see chapter 5, section 5.1. for an extended outline of this). Andrew and Rogers (2002) conclude that surprising and/or painful stimuli as well as novel stimuli affect the right hemisphere more than the left hemisphere.

Byrne et al. (2004) state that there are two definitions related to individual and population level lateralisation. One definition is concerned with the behavioural aspects of lateralisation (such as the work of Rogers and Andrew 2002) while the other definition is concerned with structural asymmetries. Those interested in behavioural lateralisation tend to define a population as lateralised if more than half of that population have the same preference (i.e. if more than 50% preferred the right hand then the population would be said to be lateralised to the right for hand preference). Rogers and Andrew (2002) add that lateralisation at the individual level occurs when most people in a population are lateralised but not necessarily in the same direction thus there will be no dominant bias. Lateralisation concerning structural asymmetries can be expressed in a number of different ways. One form is known as ‘fluctuating asymmetry’. Fluctuating asymmetry refers to differences between the right and left sides of many different parts of the body. Among the things that can be measured to get a measure of fluctuating asymmetry include hand size, digit size, feet size and ear size. High fluctuating asymmetry occurs when there is a big difference between the two sides being measured and low fluctuating asymmetry occurs when the two sides are similar. Fluctuating asymmetry has been used in a number of studies to predict a number of relationships such as increased/decreased levels of fertility; sex related behaviour and health issues (such as susceptibility to certain forms of cancer) (Manning, 2002). Additionally, human faces are also asymmetrical and Smith (2000) reported that males have a larger left side of the face and females have a larger right side of the face. However, Hardie, Hancock, Rodway, Penton-Voak, Carson, and Wright (in press) did not find an effect of gender on facial asymmetry. However, Hardie et al. found an effect of handedess on facial asymmetry with right-handers having a larger left side of the face. This pattern was not found among left-handers.

1.6. Handedness and cerebral asymmetry

Most people exhibit the standard pattern of right-handedness and left hemisphere dominance for language and right hemisphere dominance for spatial abilities and emotional processing. However, individual differences do exist in the lateralisation of cognitive function (Grimshaw, Bryden & Finnegan, 1995). Bryden (1988) adds that women may be less lateralised for cognitive functions than men. Witelson (1991) states that this could be because exposure to pre-natal testosterone leads to increased lateralisation of function. However, this could be argued against as there are claims that left-handers are less lateralised than right-handers and yet it is claimed that left-handers are exposed to increased levels of testosterone in utero according to Geschwind and Galaburda’s (1985) theory (see chapter 2, section 2.5.9. for a detailed description of this theory). Grimshaw et al. (1995) reported in their longitudinal study that girls with higher pre-natal testosterone levels were more strongly right-handed and had stronger left hemisphere speech dominance where as males who had higher pre-natal testosterone levels showed higher right hemispheric dominance for emotional processing.

Davidson and Fox (1982) suggest that hemispheric specialisation in humans possibly underlie differences in various types of human behaviour (for example, affective behaviour). This view leads to the suggestion by Davidson (1992) that there is a relationship between affective states and lateralisation. He reported that positive states or approach behaviour is associated with the left hemisphere while negative states are associated with the right hemisphere. Thus the hemispheric dominance of a person can have a possible effect on their behaviour. Similar conclusions have been drawn from animal studies (see Hopkins & Bennett (1994), section 1.2.1.).

1.6.1. Language

It is also often assumed that the brain organisation of left-handers and right-handers differs dramatically. However, these differences vary across individuals and in many cases left- and right-handers are lateralised in very similar ways. One main area that has been identified as being different is the lateralisation of language. It has often been cited that non right-handers are less strongly lateralised for language than right-handers (e.g. Bishop, 1990). Studies have revealed that over 95% (and up to as many as 99%) of right-handers are left hemisphere dominant for language whereas only around 70% of left-handers are left hemisphere dominant (Green, 1995).

Corballis (e.g. 1989) has constantly proposed that handedness is specific to humans and that non-human primates do not show population level handedness. Corballis (1991) states that right-handedness is dominant among humans and any existence of handedness in non-human primates is very weak and most of the time favours the left hand over the right. The main point that Corballis makes is that the differences between the left hand and the right hand are caused by the asymmetry of structure in the brain rather than a difference in the structure of the hands.

Corballis (1991) proposes that the most important part of cerebral asymmetry is not the resultant hand preference but the left side specialisation of the brain for speech and language. Corballis leans heavily on the lateralisation of language in order to help explain why humans have asymmetric preferences. There are many functional differences between the two hemispheres of the brain but there are fewer differences between the structure of the brains of left- and right-handers. Corballis (2002) proposes that right–handedness in humans is associated with left hemisphere dominance but not for language but more specifically for vocalisation. He states that vocalisation evolved much earlier than language as it was derived from manual gestures and this eventually led to manual gestures with elements of vocalisation. Corballis reports that the left hemisphere in many species is specialised for vocalisations but only humans have a link between vocalisation and right-handedness. He adds that Broca's area is situated in the left hemisphere in humans but in monkeys Broca's area is located bilaterally. Broca's area was also reported to be situated in the left hemisphere of *Homo habilis* (Corballis, 2002) and thus a link can be made between gesture and vocalisation in humans as long as 2 million years ago. Corballis adds that although gesture and vocalisation are linked to *Homo habilis* speech probably did not originate until the evolution of *Homo sapiens* around 170,000 years ago. Corballis (2002) suggests that any right hand bias in chimps may be linked with the dominant left hemisphere that may be specialised for vocalisation and communication.

Hopkins and Leavens (1998) state that the fact that captive chimpanzees can be taught to point and do so with the right hand may be important for a number of reasons. Firstly, it may simply be a link to human right-hand dominance. Secondly, it may be linked to left hemisphere dominance for speech and communication or thirdly, chimpanzees may just imitate the humans who taught them to point (most of whom would be right-handed) and thus most chimpanzees would use the right hand with which to point.

The production of vocalisations in animals (such as rhesus monkeys – Hauser & Andersson, 1994) is lateralised in the left hemisphere in almost all cases and thus this would suggest that they would show a right side advantage. However, Hauser and Andersson found that these vocalisations were not correlated with handedness. This is not the case in humans however as it is reported that the lateralisation of speech and handedness are correlated (e.g. Knecht, Dräger, Deppe, Bobe, Lohmann, Flöel, Ringelstein, & Henningsen, 2000). Green (1995) states that 99% of the right-handed population are left hemisphere specialised for speech and vocalisation. Additionally, around 70% of left-handers are left hemisphere dominant for speech and language.

Corballis (2002) proposes that the dominance of right-handedness in our society is a consequence of the dominance of the left hemisphere for speech and vocalisation.

He states that since vocalisation emerged early on in evolution that this might have influenced hand preference. Annett (1995) suggests that this might have occurred due to a single genetic mutation that could have influenced both the left hemisphere as dominant for vocalisation and the preference of the right hand as the preferred hand. Crow, Crow, Done and Leask (1998) added that it was this event (the genetic mutation which may have created the left hemisphere as the dominant hemisphere for speech and for right-handedness) that led to the emergence of *Homo sapiens*. *Homo sapiens* were different to any of the previous *Homo* species as they had the ability of speech, whereas previous species such as *Homo habilis* had vocalisations but not speech. Crow et al. (1998) add that *Homo sapiens* had a number of additional uniquely human abilities such as theory of mind.

Corballis (2002) reports that one of the main differences between humans and chimpanzees after they split over 6 million years ago was the bipedal posture of humans. He reports that the bipedalism of humans allowed them to have their arms and hands free and be able to use them for manual expression. McNeill (1985) states that people make hand gestures during speech and that these gestures follow the pattern of their speech.

Corballis (2002) proposed that population level right-handedness evolved after the emergence of the ability of speech. Corballis states that the association between handedness and vocalisation occurred through the evolution of language. He continues that gestures made during vocalisations from animals such as apes led to the lateralisation of manual gestures and this led to a dominant right hand preference.

Thus, Corballis concludes that the dominant right hand preference in humans derives from the left hemisphere which is specialised not only for speech but also for vocalisation and gestured behaviour. As humans evolved from apes and apes communicated through vocalisations and gestures then it was the dominance of the hands in these gestures that were first noted. Corballis proposes that the synchronisation of the hands and mouth while making gestures may be what evolved to allow a right-hand preference. He added that along side the synchronisation of the mouth and hands was vocal production that was lateralised.

Kimura (1977) studied the use of the hands in gesturing and reported that right-handers gesture with their right hands but left-handers gesture with both the left and right hands. Graves and Goodglass (1982) studied the movement of the mouth while speaking and found that around 90% of the population moved the right side of their mouth more than the left side. This supports the percentage of right-handers in the population but Graves and Goodglass did not specifically look at handedness.

McManus (1999) proposes that during evolution all humans were right-handed and that left-handedness only developed due to a genetic mutation. If this was the case and all early humans were right-handed then this would suggest that the vocal elements of speech (but not speech itself) would have been evident over 2 million years ago. The main difference between humans and apes is the actual ability to pronounce words rather than just make simple vocalisations. Corballis (2002) states that the vocal tract in humans had to evolve sufficiently in order to be able to make these articulate sounds and he suggested that the first group of humans that this was possible in would probably have been *Homo sapiens* over 170, 000 years ago.

Even though humans are dominantly right-handed for a number of actions (particularly writing, eating and throwing) Corballis (2002) suggests that gesturing plays a leading role towards a strong right-handed society. The link between gesturing and language and the resulting hand preference can be supported through the examination of developing handedness in young children. Although later in life children are often influenced to use a specific hand to do certain activities hand preference in relatively young children (around the ages of 2-4 years) can be driven by the development of speech. Hand preference often settles around 4 years of age (Annett, 2002). Annett (2002) proposes that handedness settles down around 4 years of age as that is the time when a child begins to write or draw or use their hands for finer motor movements. She adds that this coincides with the time that a child perhaps attends nursery school. Annett also accepts, however, that the hand preference of some children will have been apparent before the age of 4 and in others hand preference might take much longer to settle down.

The relationship between hand preference and the dominant hemisphere for speech is not simple. This would insinuate that all right-handers were left hemisphere dominant for speech and all left-handers were right hemisphere dominant for speech. The relationship is much more complicated than this as around 70% of left-handers are left hemisphere dominant for speech (e.g. Green, 1995). Thus, gestural communication would have to be studied further where the dominant hemisphere for speech was examined alongside dominant hand preference and the hand or hands noted that were doing the gesturing. However, Corballis (2002) reports that the incidence of left cerebral dominance for language is higher than the incidence of right-handedness and thus left cerebral dominance must play a more important and superior role than right-handedness. He goes on to state that if 90% of the human population are right-handed and the incidence of left hemisphere dominance for language among right-handers is 96% and among left-handers is 70% then 93.4% of the population are left hemisphere dominant for language. This statistic is higher than the incidence of right-handers in the population itself and could also be higher if the percentage of right-handers with left hemisphere dominance is as high as 99% but could also be reduced if there is an overestimation of the number of right-handers with left hemisphere dominance for language.

Another link between handedness and language has been proposed through another genetic theory. Crow et al. (1998) stated that a link between handedness and language dominance was dependent on a genetic mutation that was only present in humans. The models of Annett (e.g. 1995) and McManus (e.g. 1999) also propose a link between handedness and language (see chapter 2, sections 2.3.3. & 2.2.4. respectively for more details of these theories).

Corballis (1991) states that one main problem with McManus' single gene theory is that handedness and cerebral dominance are determined independently of each other and this is less clear in those with the DC genotype. McManus' theory focuses on hand preference and he states that if an individual does not have a dextral (D) gene then their hand preference will be determined by chance, however, if an individual has the DD genotype then they will almost certainly become right-handed and if they have the DC genotype there is a 75% chance that they will become right-handed. However, McManus states that the alleles in this theory do not code for language dominance but he does states that there is a link between parental handedness and language lateralisation. McManus indicated that an individual with at least one left-handed parent would be more likely to have right hemisphere language dominance than those with two right-handed parents. If an individual has the DC genotype then this would be difficult to clarify as they could either have a left- or right-hand preference. Corballis (1991) states that handedness and cerebral dominance of language are related and thus the occurrence of one affects the other. Corballis (2002) goes on to state that because handedness and cerebral dominance of language are related then the relationship between the two factors is continuous rather than independent (Corballis, 2002). Knecht et al. (2000) back this up and report that as the incidence of right hemisphere dominance for language increases in an individual the degree of right-handedness decreases. That is there are very few right-handed individuals (less than 1%) with a dominant right hemisphere for language but there are a high proportion (around 15%) of left-handed individuals with a dominant right hemisphere for language. However, in terms of strongly lateralised individuals, Knecht et al. state that around 27% of extreme left-handers have right hemisphere lateralisation of language whereas only around 4% of extreme right-handers have right hemisphere dominance for language.

The single gene models (e.g. Annett and McManus) of handedness suggest that one allele codes for speech or language in some dimension (usually the cerebral dominance of speech) while the other allele is an expression of handedness (which is often left down to chance). However, Corballis (2002) proposes that the influence of handedness in humans on the production and perception of speech is thought to be relatively strong in humans and states that this is the case due to the relationship between gesturing and vocalisation and the early evolution of language in humans. Corballis (2002) adds that the genetic mutation that Crow, Annett and McManus report cites a link between handedness and vocalisation rather than creating specific asymmetries.

The specialisation of language in the left hemisphere in most of the population is linked to the dominant preference to use the right hand to perform fine motor tasks (Crow et al. 1998). Crow (2000) proposed that a gene for cerebral dominance was a critical factor in human evolution. He suggested that the specialisation of the hemispheres (and hence cerebral dominance) led to the establishment of language. However, as there are sex differences for language abilities Crow proposed that a gene for cerebral dominance would be located on the sex chromosomes. Crow adds that a mutation of this gene would be responsible for schizophrenia. Crow (1997) examined language dominance and handedness in schizophrenics. He reported that there were elevated numbers of mixed-handers among this group. Annett (2002) reports that schizophrenia is uniquely human and no other species show any equivalent to this. Annett adds that although we share around 99% of our genes with chimpanzees that any bias in humans for right-handedness, left hemisphere dominance and the onset of schizophrenia are thought to be genes that are not common with chimpanzees. As it has been reported that we are the only species capable of speech and as schizophrenia is uniquely human then there appears to be a tentative link between the two. However, Crow’s theory is based on language as opposed to speech (whereas the right shift theory is directly concerned with speech) so this cannot be directly compared. Crow concludes that schizophrenia is a disorder of cerebral dominance for language and suggests that it is due to the mutation of a gene that was associated with language over the course of human evolution.

Crow et al. (1998) stated that handedness is an overt behaviour which is correlated with cerebral dominance for language. Crow et al. examined children's abilities on a series of verbal, non-verbal and mathematical tests and divided them according to their hand skill. They found that those who had similar levels of skill between the two hands (and what Crow et al. termed as hemispheric indecision) performed worse than the other groups. Also, those who were strongly right-handed and strongly left-handed did not perform as well as those who were found to be moderately left- and right-handed. This finding supports the work of Annett (e.g. 2002) who predicted that there would be deficits on a task by those who were extreme left- or extreme right-handers. Crow concluded that those who displayed the largest deficits were those who wrote with a different hand to the one that they were more skilled with (for example someone who write with the left hand but was more skilled with the right hand). Although Crow et al.'s. results suggest that it is a disadvantage to have a more mixed preference Annett (e.g. 2002) has postulated that those who are heterozygote in her right shift theory (see chapter 2 for a detailed outline of this) will perform better than homozygotes on some cognitive tasks. Crow (2000) concludes that the degree of lateralisation establishes how quickly verbal ability will develop.

Overall, the link between handedness and language is complex and subject to a lot of disagreement and debate. It is fair to say that importance of language in humans has led to a focus of research in this area, but we await more clarity in how these skills evolved in the first place.

1.6.2. Effects of human handedness on cognition and emotion

Emotion

There is very little literature available on the effects of human handedness and emotion. Although emotion is a widely researched topic many of the studies carried out only use right-handed participants and very few studies compare any differences in emotions between left- and right-handers. For example, Bourne (2005) examined the processing of positive facial emotions but only did this with right-handed participants. Additionally, Jansari, Tranel and Adolphs (2000) examined the valence specific effect for discriminating facial expressions but again only used right-handed participants.

Much of the research that has been carried out on emotion with both left- and right-handers is the discrimination of emotional faces between the two groups (e.g. Rodway, Wright & Hardie, 2003) or similarly, rating a series emotional faces on a forced choice paradigm (e.g. van Strien & van Beek, 2000). However, many of these studies have found no clear handedness differences between left- and right-handers on how they rate emotional faces or how they discriminate between positive and negative faces. Reuter-Lorenz, Givis and Moscovitch (1983) found that there was an interaction of valence and visual field for right-handers and left-handers with inverted writing postures. This suggested that these groups had faster reaction times to negative faces that were presented in the left visual field and faster reaction times to positive faces presented in the right visual field. However, left-handers with a non-inverted hand posture displayed the opposite pattern. Also, Everhart, Harrison and Crews (1996) asked left- and right-handed participants to use a forced-choice questionnaire to identify positive and negative faces from a series of happy, neutral and sad pictures. Left-handers rated neutral faces as negative faces more when they were presented in the right visual field than when they were presented in the left visual field. The ratings of right-handers remained the same irrespective of the visual field that the face was presented in. Everhart et al. conclude that the findings of the right-handers do not support the valence specific hypothesis and the findings of the left-handers suggest the opposite from the valence specific hypothesis (in that negative emotions are identified more often in the right visual field).

Cognition

The effect of human handedness on cognition is a vast area of research. Many studies which examine cognitive abilities and handedness focus upon IQ scores and other measurements of intelligence. Many studies address the question of whether there are any intellectual differences between left- and right-handers and a series of contradictory results have been reported (Nettle, 2003). For example, Hardyck, Petronovich and Goldman (1976) examined left- and right-handers on a series of tasks including writing, intelligence, reading, spelling and attention and found that there were no clear relationships between handedness and any of these tests. A common citation is that left-handers generally have lower IQs than right-handers (e.g.

McManus & Mascie-Taylor, 1983; Bishop, 1990). However, Benbow (1986) studied a group of students who scored significantly higher than their peers in mathematics and verbal ability and found that her sample consisted of high numbers of left- and mixed-handers. There were very few strongly right-handed people in this sample but there were a considerable number of weak or moderate right-handers. Additionally, Annett and Manning (1989) reported that IQ scores were highest in right-handers who had a weak to mixed preference rather than in those with a strong right hand preference. Annett and Manning add that pattern is also found for left-handers where those with a weak to mixed left hand preference often show higher IQ scores than strong left-handers. However, these findings have been challenged by Crow, Crow, Done and Leask (1998) who reported that cognitive ability and IQ scores were lowest among those with a mixed hand preference. Crow et al. add that those who show very little difference in skill between the two hands will be those who perform worst on these tasks. However, this finding was not supported by Mayringer and Wimmer (2002) who found that performance was no worse in those with equal hand skill abilities.

Nettle (2003) states that the contradictory findings in this research might be influenced by the way that handedness is both defined and measured. For example, the distinction between hand preference and hand skill needs to be made as hand skill itself is often reported to correlate with cognitive ability. Nettle reported that cognitive ability increases as the strength of handedness increases. Therefore someone with a strong hand preference would have higher cognitive abilities than someone with a mixed hand preference. Additionally, Nettle states that right-handers have more of an advantage, as they as a group are more strongly lateralised than left-handers. Harris and Carlson (1988) add that perhaps the distinction between pathological and non-pathological left-handers would also have to be considered in order to draw valid conclusions as pathological left-handers may respond differently to non-pathological left-handers (see Chapter 2, section 2.5. for details of the pathological argument).

In addition to this researchers have proposed that left-handers can be divided in to two main sub-groups that differ in their cerebral organisation. The first group is comprised of familial left-handers (who have a history of left-handedness in their family) and non-familial left-handers (who have no history of left-handedness in the family). Hecaen and Sauguet (1971) reported that non-familial left-handers with unilateral lesions performed similarly to right-handed individuals on a series of neuropsychological tests. However, familial left-handers performed differently which led Hecaen and Sauguet to conclude that the cerebral organisation of familial and non-familial left-handers is somewhat different.

1.7. Implications for humans

Fagot and Vauclair (1991) state that population level handedness will differ depending on the type of task that is being carried out (for example whether there are more cognitive demands on a task rather than motor demands). This point is often ignored particularly in human handedness research as hand preference is often classified by quantifying the number of tasks an individual prefers to carry out with a particular hand. Thus in order to examine the variation of an individual’s hand preference it would be useful to look at the tasks according to type (e.g. cognitive) and classify hand preference for each task type.

Corballis (1989) states that it is difficult to directly compare the hand preferences of non-human primates with those of humans. He argues that non-human primates display weaker asymmetries than humans and thus in order to be able to make even slight comparisons stringent handedness criteria would need to be developed which would be applicable for both human and non-human primates. Also, a number of comparative tasks would have to be devised in order to collect valid comparative handedness data. These tasks would have to be sensitive enough to pick up any handedness effects (particularly in non-human primates) but varied enough so that all of the actions could be carried out by both the humans and non-humans.

1.7.1. Asymmetry in the motor system

On the surface our motor systems are symmetrical (Corballis, 1998). Several areas of the cerebral cortex are responsible for voluntary movement in humans. The main areas involved are the primary motor cortex, the secondary motor cortex and the premotor cortex (Hellige, 2001). All movements performed in humans are induced by the lateralised motor system (Sabaté, González & Rodriguez, 2004). The primary motor cortex of each cerebral hemisphere controls the movement of the contralateral side of the body (Kolb & Whishaw, 1995) and it is widely reported that the left hemisphere is dominant for many aspects of motor control while the right hemisphere is dominant for visuo-spatial processing and the processing of emotions (Hellige, 2001). The dominance of the left hemisphere for motor control is said to be critical for controlling both arm movements and also oral movements (Watson & Kimura, 1989). They state that speaking and gestural movements are linked and that these are both controlled by the motor cortex. However, it is thought that the left hemisphere dominance for motor control may have evolved due to the dominance of right-handedness in our society. Hellige (2001) states that hand preference or dominance indicates that one hemisphere's control of the hand is superior to the other. Kimura (1977) suggests that speech also derives from motor control. In terms of looking at the link between handedness and the human motor cortex, things are a bit unclear as Amunts, Schlaug, Schleicher, Steinmetz, Dabringhaus, Roland and Zillies (1996) report that no clear relationship between the two have been demonstrated. Amunts et al. (2000) tested whether asymmetries in hand performance (in a group of consistent-right, consistent-left and mixed-handers) were associated with anatomical asymmetries in the motor cortex. The asymmetry was measured by examining the depth of the central sulcus and it was found that consistently right-handed males showed a significantly deeper central sulcus in the left hemisphere than the right hemisphere. This asymmetry decreased for mixed-handers and decreased further for consistent left-handers. Over half of the consistent left-handed group (62%) had a deeper central sulcus in the right hemisphere than the left but this difference was not significant. There was no pattern of asymmetry found in females regardless of handedness and Amunts et al. concluded that sex differences occurred in the motor cortex but this pattern was only demonstrated in males.

1.8. Reported laterality and handedness differences

Numerous differences have been reported between left- and right-handers. Some of these differences are factual differences while other differences include cognitive and performance differences.

1.8.1. Biological/factual differences

Left-handers are often reported to die earlier, on average, than right-handers (e.g. Harris, 1993). Also, pathological models of left-handedness have proposed that left-handers undergo some form of brain damage (normally during birth) that ranges from unnoticeable brain damage where there is very little apparent difference in performance to minor brain damage which results in lowered ability on various tests of mental functioning to those who have learning disabilities caused by severe brain damage at birth (e.g. Satz, 1972) see Chapter 2, section 2.5. for a more detailed account of pathological handedness.

Left-handers have also been reported to be more susceptible to migraines, allergies and thyroid problems (e.g. Springer & Deutsch, 1993). Geschwind and Galaburda (e.g. 1985a) proposed in their biological theory of handedness that testosterone is not only responsible for left-handedness but also it plays a major role in susceptibility to immune disorders. Geschwind and Galaburda state that when foetuses are exposed to testosterone it slows down the growth of the left hemisphere and accelerates the growth of the right hemisphere (see chapter 2, section 2.5.8. for links to handedness). Geschwind and Galaburda believe that the slow development of the left hemisphere caused by the high exposure of testosterone in utero could also affect the development of the immune system. They do state, however, that the accelerated growth of the right hemisphere also leads to additional skills (and name artistic ability among them). However, the effects of the testosterone on the left hemisphere could be detrimental to the development of language in some cases (particularly as around 70% of left-handers have language lateralised in their left hemispheres (Green, 1995). Bryden, McManus and Bulman-Fleming (1994) reported in a review of Geschwind and Galaburda’s model that left-handers were more likely to show signs of asthma and allergies; however, right-handers were more likely to be more susceptible to disorders such as arthritis.

Hellige (2001) states that the brain lateralisation of left-handers is more variable than right-handers in both the degree and the direction of the asymmetry. For example Annett and Kilshaw (1983) have reported that people with dyslexia tend to be either non right-handed or people with a very strong right hand preference. However, Bishop (1990) states that the evidence of increased numbers of non right-handers among those with developmental language disorders is not strong. Bishop (1990) reported that there was no evidence in 8-year-old children that there were hand preference differences linked to language impairment.

Another difference that has been reported is that there is a higher level of non-right-handedness among gay men and women in the normal population (McCormick & Witelson, 1991). However, although minor handedness differences have been reported between the homosexual and heterosexual population the actual performances of the two groups on a variety of tasks did not differ. For example, on a finger dexterity task there was no difference between the performance of gay men and heterosexual men (Hall & Kimura, 1995).

Differences in levels of anxiety have also been reported between left- and right-handers. However, these reports have been mixed and some argue that left-handers experience higher levels of anxiety (e.g. Dillon, 1989) while others suggest that there are no differences at all between the anxiety levels of left- and right-handers (e.g. French & Richards, 1990). (Also see Chapter 4, section 4.7. and Chapter 7, section 7.2. for additional details).

1.8.2. Performance differences

Performance differences reported between left- and right-handers are often attributed to differences in intellect between the participants. These differences address the effect that handedness has on differences in cognitive abilities and most of this research focuses on IQ tests and similar tests of intelligence (see section 1.6.2. of this Chapter for a summary of this research). For example, it is often cited that left-handers have higher mathematical abilities than right-handers (e.g. Annett, 1995). O'Boyle and Benbow (1990) found that in a sample of college students who scored the highest grades on a mathematical aptitude test the number of left-handers in this sample was significantly higher than the number of right-handers. They also reported that around 50% of the students in the group who scored the highest maths scores were either left-handed, mixed-handed or were right-handed but had immediate relatives who were left-handed. O'Boyle and Benbow stated that this finding supported the argument that bi-lateralisation, rather than greater specialisation of the hemispheres, is associated with increased mathematical ability.

Therefore a number of differences exist between left- and right-handers ranging from easily observable performance differences to more complex and perhaps hidden biological differences. However, as previously stated much of this research has focussed upon addressing the cognitive abilities of left- and right-handers through a series of intelligence measures and therefore a wider measurement of cognitive ability tests in addition to the current IQ tests need to be carried out before strong conclusions can be drawn.

1.9. Conclusion

Around 90% of the population are right-handed and although this dominance has (evidently) always existed in human society it is unclear why right-handedness is the dominant preference. Evolutionary theories of handedness have shown that right-handedness has existed as far back as pre-historic times and evidence from Egyptian cave paintings and fossils supports this. However, in order to explore this issue further we have to look back to our closest relatives, the apes, and in particular, the chimpanzee with whom we share around 99% of our genes with, in order to evaluate both the development and the pattern of their handedness.

The existence of right-hand dominance in apes is a controversial area and there has been great debate as to whether dominantly right-handed societies exist. It is generally accepted that apes and monkeys show some forms of handedness however the existence of population level right-handedness is generally challenged. Hopkins (e.g. 1999) and Fagot and Vauclair (1991) report that chimpanzees exhibit right-handedness at the population level which means that right-handedness is dominant in chimpanzees. However, this finding has been widely challenged. Westergaard et al. (1998) state that the type of task being performed can affect hand preference; Ward et al. (1993) state that the posture adopted by the primate (whether they walk on two legs or four) can also affect hand preference and Marchant and McGrew (1996) state that whether the chimpanzee was raised in captivity or in the wild can also influence hand preference as those raised in captivity may be influenced by the right hand dominance of the humans around them. Marchant and McGrew also state that most of Hopkins' work is done on captive chimpanzees and therefore in order for Hopkins to make clear assumptions on population biases then more research on wild chimpanzees would have to be done. Many researchers who work with chimpanzees reared in the wild report that the split in handedness is around a 50% left-hand preference and 50% right-hand preference. A final measure that may affect hand preference in chimpanzees and other primates is how the preference is actually measured. Marchant and McGrew (1996) measure handedness by examining performance on motor tasks whereas others such as Hopkins and Bennett (1994) measure a number of tasks over around 50 trials in order to get a consistent measurement of the hand used. A number of researchers concluded that there was no evidence of population level right-handedness in chimpanzees (e.g. Boesch, 1991; Dimond & Harries, 1984; Marchant & McGrew, 1996). MacNeilage et al. (1987) proposed that there is a slight left hand bias in chimpanzees and they stated that this was due to the evolution of bipedalism as the chimpanzees probably used the right hand at the front for support when they walked quadrapedally and therefore developed a certain amount of skill in the left hand. A final point that researchers make who study handedness in chimpanzees is that a consensus has to be reached as to what ‘no hand preference’ in chimpanzees’ means as this data is equally as important to researchers but researchers define this in a number of different ways.

The lack of bias in hand preference is more prominent in monkeys. Warren (1980) stated that hand preference in old world monkeys (such as baboons) is divided equally in 50% right-hand preference and 50% left-hand preference. However, MacNeilage et al. (1987) claimed that the type of task could affect the preference and state that a number of prosimians (such as lemurs) display a left hand bias in visually guided tasks and many monkeys and apes show a right-hand preference in some tasks that require manipulation. However, very little evidence of population level handedness exists in monkeys (e.g. De Sousa et al*.,* 2001; Hook-Costigan & Rogers, 1995). Other studies have proposed that there are left hand biases in groups such as bushbabies and lemurs (e.g. Larson et al*.,* 1989; Sanford & Ward, 1986; Ward et al*.,* 1990; Masataka, 1990). Thus, it appears that there is no handedness bias overall in groups of monkeys but in apes many additional factors have to be taken in to account (such as the type of task) in order to effectively evaluate their hand preferences. It does seem in many studies that there is a right hand population bias but in many other studies the spread of hand preference is equally divided between left- and right-hand preferences. The distributions of hand preferences in primates leans steadily to a right hand preference and in very few species is there any evidence of left hand dominance and thus it is possible that this dominance has progressed throughout evolution and become even more dominant as human beings and chimpanzees split from their common ancestor.

Additionally, brain lateralisation in both humans and animals has to be investigated in order to examine the link between lateralisation and handedness. Again it is perhaps most relevant to examine the brain lateralisation of the chimpanzee in order to examine the evolutionary links between them and humans. Rogers (2002) stated that cognitive style; temperament and emotional responsiveness were all affected by lateralisation in primates as well as humans. Handedness is often used as an indicator of lateralisation both in human and non-human primates and thus both groups display a number of similar responses and temperaments based on hemispheric dominance (e.g. Davidson, 1992). That is the lateralisation of each individual may affect how they respond to an object or situation based on their cerebral dominance. For example, someone with a left-hand preference and a strong right hemisphere dominance may display a temperament that reflects some of the strong characteristics of the right hemisphere such as strong emotions and inhibitory behaviour. Differences in temperament and cognitive behaviour between left- and right-handers have been found in chimpanzees and marmosets (Hopkins & Bennett, 1994; Cameron & Rogers, 1999). This finding suggests that the right hemisphere in primates might be associated with negative emotions and avoidance behaviour. These behaviours allow us to hypothesise about humans and links can be made by citing the findings of Davidson (1992). Davidson reported that the right hemisphere of humans is associated with inhibitory and avoidance behaviour while the left hemisphere is associated with approach behaviour. These findings aid in our understanding of the brains of human and non-human primates and it can be proposed that there are many similarities between the lateralisation of the two. A similar link can also be made in terms of the lateralisation of language.

Although humans differ from chimpanzees in the fact that we have the mechanism of speech we share common lateralisation (particularly with chimpanzees) with respect to communication and vocalisation. Corballis (2002) stated that the most important part of lateralisation is the specialisation of the left hemisphere for language. This has been found to be the case in both chimpanzees and humans. Corballis linked our left hemisphere specialisation for language and vocalisations back to primates and stated that the cerebral specialisation of language and hand preference evolved through manual gestures coupled with vocalisations in *Homo habillis* around 170,000 years ago. There have been objections to these findings and Hauser and Andersson (1994) stated that vocalisations were not correlated with handedness but they report that this link has been reported in humans. Thus, in conclusion a tentative link between hemispheric dominance of vocalisation and hand preference in chimpanzees can possibly be attributed to the evolution of the left hemisphere for language and right hand dominance. This however is a much-debated issue.

Therefore, examining handedness and lateralisation in chimpanzees and other animals gives us an invaluable insight in to how both the brain and hand dominance has evolved. A number of handedness differences have been found to exist in primates and these often involve response style and/or temperament. However, studies concerning particular cognitive behaviours and styles of interaction with the world in humans are sparse and many human handedness studies report factual differences such as left-handers are more prone to migraines or have higher allergy levels. However, the differences found in temperament and response styles in primates suggest that fundamental differences do exist with how left- and right-handers interact with the world and thus these possible differences in humans need to be investigated. Additional theories on the causes and consequences of handedness are examined in Chapter 2 and these will take in to account genetic, environmental and pathological theories. Chapter 3 will then investigate how handedness is categorised and measured and Chapter 4 will examine response styles of left- and right-handers towards a novel object. This thesis will be developed in accordance with these findings.

Chapter 2 : What causes human right-handedness? The role of Genetics, Culture and Pathology

2.0. Aims of the Chapter

Chapter 1 outlined the relationship between handedness in humans and other animals and associated brain lateralities. While it is the case that the roots of human right-handedness may be debated, it is certainly clear that unlike other animals, humans have population level right-handedness. This chapter seeks to examine theories related to how this pattern may be brought about and maintained. More specifically this chapter will look at a number of different theories that attempt to explain what 'causes' or influences a person to have a left-hand preference or a right-hand preference. These include genetic theories, environmental and cultural arguments and pathological theories and arguments.

2.1. Traditional Theories

"*Nearly 90% of humans are right handed. That is, they prefer the right hand for most tasks requiring a single hand and the right hand dominates in tasks involving both hands, such as unscrewing the lid off a jar*." (Corballis, 1991, p82).

The preferred hand of an individual is regarded to be the one with which they are most skilful in activities such as writing and drawing (e.g. Annett, 2002). A variety of evidence suggests that the incidence of right-handedness at almost 90% has stretched back as far as prehistoric times. For example, in Egyptian tombs, cave paintings depicted people performing activities with their right hands. An analysis of tools and weapons from this time also suggested that not only were they made with the right hand but also for the right hand (Springer & Deutsch, 1993). Contrary to this, it was originally thought Ancient Egyptians were predominantly left-handed because cave paintings showed a number of profiles of humans and animals facing the right and it was suggested that it was more natural for right-handers to draw left profiles (Springer & Deutsch, 1993). However, Corballis (1991) proposed that the dominance of the right-handed profile might have been related to the belief that the right side is sacred. This aside, it was accepted that by the time of the Bronze Age right-handedness was established (3000-100 B.C), as many tools and weapons of that time were almost exclusively manufactured for right-handers (Corballis, 1991). In further support of this, an analysis of the locations of the fractures in fossilised baboon skulls concluded that injuries were the results of blows inflicted by humans using clubs in their right hands (Springer & Deutsch, 1993). This suggests that population level right-handedness has been a characteristic of human behaviour for at least the last few thousand years.

Some theories of handedness were popular in the 19th Century. One of the main theories was Visceral Distribution, meaning 'displacement of internal organs' (McManus, 2002). It was argued that the position of the organs in the body such as the liver resulted in some form of imbalance in many people and resulted in them being tilted slightly to the right. Thus, it was suggested that we balance better on the left foot and this therefore leads to us becoming more right footed and in consequence right handed (Langford, 1995). It was argued that left-handedness might result from an opposite centre of gravity but no evidence has been produced to support this point. For example, Browne (1648) (cited in Langford, 1995) dismissed this by saying that "*left-handers and right-handers have been found in whom the position of the liver is at variance with the strong emphasis placed on its location in this theory*" (p18). He also said that apes, whose livers are on the right, show no distinctive preference for one hand or the other, thus he concluded, why should the position of our livers play any part in determining our handedness? Another popular theory was Carlyle's Sword and Shield Theory (cited in Springer & Deutsch, 1993), which suggested that soldiers held their shields with their left hands to protect their hearts and thus, held their weapons with their right. Therefore, more skill was gained with the right. But, as with the theory of Visceral Distribution, no attempt was made to explain left-handedness or why humans still predominantly used their right hands.

The right side has also been reported as being seen as sacred and the left as unclean. In fact, according to Barsley (1970), there are over one hundred favourable mentions of the right hand in the Bible and about twenty five unflattering mentions of the left (Corballis, 1991). This supports the idea that right-handedness has long been regarded as being more important than left-handedness.

In summary, traditional views of handedness indicate that the right hand was not only the dominant one but that it was also the accepted one by most people. Whilst the left hand was considered to be anything from sinister, evil or unclean, the right hand was considered sacred. These traditional views, however, can be argued against effectively and none of them satisfactorily explain how we arrive at our individual hand preferences.

2.2. Genetic theories and explanations of handedness

Many arguments exist as to whether handedness is genetic or not. Among those who argue that handedness is genetic are Hepper (Hepper, Shahidullah & White (1991); Hepper, McCartney & Shannon (1998) and Hepper, Wells and Lynch (2005)) who looked at handedness in foetuses; Annett (e.g. 1972; 1985; 1995, 2002) and Annett & Kilshaw (1983) who argued that there is a ‘right shift’ in the human population which causes most humans to have a right hand bias, plus McManus (1985) who outlined an opposing genetic theory to Annett’s (although some argue that both Annett’s and McManus’s theories are essentially very similar and this will be discussed later in this chapter). More recently the genetic random-recessive model of Klar (1996) has been added to this debate, which, like the models of Annett and McManus, is a single-gene model. The final models that will be discussed are the gene-culture models of Laland, Kumm, van Horn and Feldman (1995) and James and Orlebeke (2002), which take genetic arguments into consideration, but maintain that there has to also be an element of cultural influence in determining handedness. Most recently an additional genetic theory by McKeever (2004) was proposed and this will be covered briefly.

There is much debate in handedness research as to whether it is an inherited trait. Blau, 1946 said, “*Preferred laterality is NOT an inherited trait. There is no evidence to support the contention that dominance, either in handedness or any other form is a predetermined human capacity*” (cited in Springer & Deutsch, 1993, p132). Some theories propose that left-handedness is a natural variant while others propose that it is abnormal or pathological (Annett, 2002). According to Annett (2002), those theories that propose that left-handedness is normal are best explained through genetics. She adds that even if some left-handers are pathological left-handers that their hand preference can still be explained through genetics.

Early genetic models of handedness proposed that the preferred hand would be determined by the action of a single gene (The Mendelian Model). This gene would either be a dominant R allele and code for right-handedness or a recessive l gene and code for left-handedness. Thus, it was assumed that an individual who inherited an R allele from one parent and an l from the other would be right-handed. Left-handers would be those who inherited the l allele from each parent (Springer & Deutsch, 1993). This model, however, cannot account for the fact that 54% of offspring of left-handed parents are right-handed (e.g. Green, 1995). It also assumes that two left-handed parents will produce only left-handed offspring through the transmission of the l allele and this is firstly, too simplistic a model and secondly, these findings are clearly not the case.

Many are sceptical when considering the evidence for genetic models of handedness and cerebral dominance. Because the simplest genetic model cannot be effectively demonstrated for handedness (the Mendelian model) then it is questioned whether or not handedness can be a purely genetic mechanism (Klar, 2003). The most convincing evidence that could be provided to indicate that handedness is influenced by genetics, according to Klar (2003) would be the discovery of some form of handedness gene but so far there is no evidence of this. Others who have opposed genetic models include supporters of pathological explanations of left-handedness (E.g. Bakan, 1971) and those who support biological explanations (e.g. Geschwind & Galaburda, 1985a). These will be discussed during this chapter.

When considering the case for and against genetic models of handedness three major arguments against genetic models are often proposed. Firstly, hand use can be culturally changed and in many cases (particularly those who were originally left-handed) has been changed (even though some may not be aware of this if it happened at a young age). Secondly, around half of children born to two left-handed parents are right-handed and therefore if left-handedness has a genetic component and this is the recessive, non-dominant gene for hand preference then it would seem unlikely that two left-handed parents would have such high incidences of right-handed children. Thirdly, despite sharing the same genes, 18% of identical (monozygotic) twins have discordant hand preferences, that is, one twin has a right-hand preference while the other twin has a left-hand preference. If handedness is genetic and these twins have the same genes then it is proposed that they would almost certainly have the same hand preference. These arguments have led many psychologists to believe that handedness must be specified by a combination of genetics and environmental and cultural influences. These issues will be discussed in conjunction with the proposed genetic theories that are outlined in this section.

2.2.1. Pre-natal Handedness

Evidence suggests that hand-preference is apparent even when a child is still in the womb. De Vries, Visser and Prechtl (1985) observed that the embryo makes its first whole body movements around 7 weeks gestation and at 9 or 10 weeks it makes movements with the left or right arm. They argue that this is the first sign of lateralised behaviour in the foetus. Hepper, Shahidulah and White (1991) studied ultrasound observations of foetuses from 12 weeks onwards. Prior to this, behavioural asymmetry research had only been carried out (on people) after birth, as it had been argued that because hand preference becomes more apparent around the age of 2 then there was little point in looking at it any time before that.

However, Hepper et al's findings challenged this assumption by showing that some form of hand preference did exist before birth and found that foetuses can be seen to suck their thumbs at around 12 weeks in the womb (see figure 2.1.). They predicted that if lateralisation was present before birth then most foetuses should show a right thumb sucking bias (in relation to right-hand dominance in the population). Hepper et al. looked at the act of thumb sucking for around 15 minutes each in the ultrasounds of 282 foetuses noting the preferred thumb. Thumb sucking was defined as having the thumb in the mouth with simultaneous mouth movements made by the foetus. Twenty foetuses were observed on three different occasions to check the reliability of the preferred thumb and these observations were done at least three weeks apart. Hepper et al. found a clear right thumb sucking bias both overall and for each individual age group (finding around 90% of them consistently sucked the right thumb compared to around 8% who consistently sucked the left thumb). They concluded that a bias for right thumb sucking seemed to be present from around 15 weeks gestation (and in a few cases from around 12 weeks) and explained this by stating that some amount of physical and motor development is needed for thumb sucking and up until 15 weeks this had not developed sufficiently in the foetus. Out of the 20 foetuses that were observed 3 times, 17 of them consistently sucked their right thumbs and one of them consistently sucked their left thumb. The other 2 foetuses sucked their right thumbs in two out of the three observations and their left thumb during the other. It therefore appears that, overall, thumb sucking remains stable and consistent during the gestation period. These data concur with the statistics for the proportion of left- and right-handers in society (i.e. when the population is split into either left or right-handers approximately 10% are left-handed and 90% right-handed).

Figure 2.1: Shows a foetus sucking the left thumb around 21 weeks (http://pregnancy.about.com/cs/ultrasounds)

Hepper, McCartney and Shannon (1998) expanded upon the work of De Vries et al. (1985) and studied the frequency of foetuses' left and right arm movements in utero in order to see if there was any difference in their occurrence. They observed 87 foetuses each at 10 weeks gestation, only recording the number of single left and right arm moves when both arms were visible. In order to count as a single arm movement all other parts of the foetus' body had to remain still. Hepper et al. (1998) pointed out that at 10 weeks gestation "*the foetus is free floating in the uterus and thus its body position does not influence its movements*" (p532). If a foetus had more recorded arm movements with one arm, it was recorded as preferring that arm (i.e. more movement with the right arm equals a right preference), and if it displayed equal numbers of left and right arm movements then it was classified as having no preference. 75% showed a higher number of right arm movements, 12.5% showed a higher left arm preference and 12.5% showed no overall preference. Hepper et al. also looked solely at the foetuses that exhibited either a left or right preference and found that 85.7% exhibited a right arm preference and 14.3% exhibited left arm preferences. Again this correlates with the figures that around 90% of the population are right-handed and around 10% are left-handed. Hepper et al. also reported that they looked at the number of arm movements displayed by each foetus over the course of half an hour and each foetus displayed around the same number of arm movements in that time. They found that there was no difference in the number of arm movements between the three groups. The work of Hepper et al. (1991) and Hepper et al. (1998) presents a strong case that there appears to be some form of genetic link to hand (or arm) preference in foetuses. The displayed behaviour in utero rules out most cultural or environmental factors. However, the lying position of the foetus could have an effect on arm movements, as could more than one foetus in the womb.

These findings were further supported by recent follow-up work from Hepper, Wells and Lynch (2005) who showed that aged 10-12 years the hand preferences largely followed their pre-natal preferences. They also reported that males who sucked their left thumbs prenatally were more likely to switch to be right-handed children than females who sucked their left thumbs prenatally.

Other studies that have examined lateralisation in foetuses and newborn infants have looked at head turning preferences. Ververs, de Vries, van Geijn and Hopkins (1994) carried out ultrasound studies on the position of foetuses' heads relative to their bodies from around 12 weeks gestation until birth. They found that around 38 weeks gestation the foetus showed a preference for having its head turned right relative to its body. Goodwin and Michel (1981) found that in newborns the majority of the infants prefer to lie with their heads turned to the right. Thus, Hepper et al. (1991) proposed that if foetal thumb sucking was linked to handedness then this should relate to the infants' head turning preference after birth. Goodwin and Michel (1981) and Michel and Goodwin (1979) argued that an infants' head position after birth reflects on the position of the foetus intrauterine and therefore this could be linked to the developing hand preference of the child.

Hepper et al. (1991) examined this idea further and looked at the thumb sucking preferences of 101 foetuses at 32 weeks gestation and then followed up 1/3 of the foetuses as newborns (aged between 2 and 4 days old). They examined their head turning preferences to see if there was a correlation between the thumb sucking preference (hand preference) and head turning as Michel and Goodwin (1979) and Goodwin and Michel (1981) had suggested. Hepper et al. tested the infants in their own cots and placed them lying on their backs. They ensured that there were no objects or distractions present that might bias the infants' head turning. The infants' head was held in the middle by an examiner and then let go. The side that the infant turned its head to was noted by the examiner, every infant tested turned its head either to the left or to the right (turning the head was defined as turning it at least 30 degrees from the midline). Of these 32 newborns as foetuses 28 (88%) of them were observed sucking their right thumbs. It was found that 23 (82%) of these 'right-handers' turned their heads to the right and 5 (18%) of them turned their heads to the left. 4 of the foetuses out of the 32 had a left thumb sucking preference (12%) and as newborns it was found that 3 of them turned their heads to the left (75%) and one to the right. In total, therefore, 81% of the sample had a corresponding thumb sucking preference as foetuses with head turning preference as newborns. Hepper et al. (1991) concluded that foetal hand preference might be related to head turning preference in newborns. Again this forms a case for a genetic basis to handedness, as thumb sucking in foetuses is not subject to any form of cultural or environmental influence.

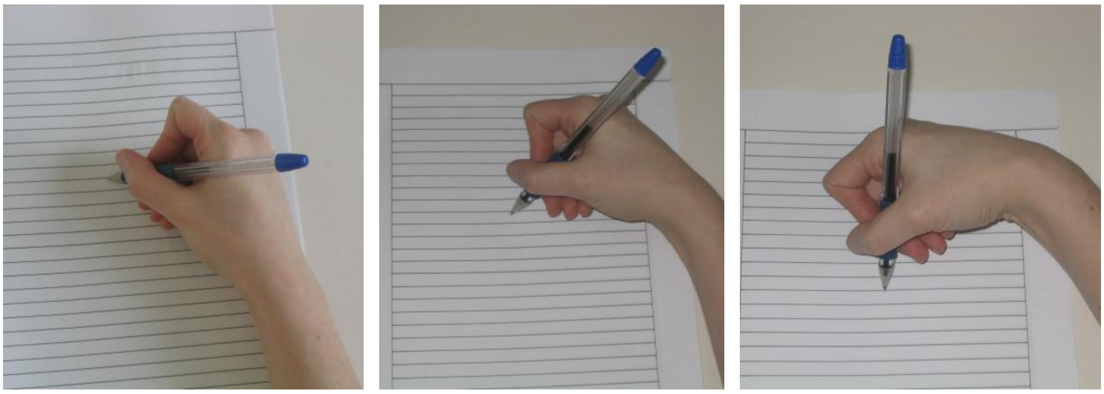
In summary, there is clear behavioural evidence to support the idea of a genetic component to handedness. Hepper et al. (2005) suggest that laterality in early gesture must be influenced by spinal cord reflexes and not a consequence of brain laterality (as the brain lacks a cortex at these early stages) and so may stimulate brain organisation, leading to laterality effects. This is counter to the mainstream view that brain lateralisation leads to behavioural asymmetry (e.g. Geschwind & Galaburda, 1985a; Harris, 1983).

2.2.2. The Levy-Nagylaki (1972) 2 gene-4 allele Model

Levy and Nagylaki (1972) outlined a genetic model of handedness and cerebral dominance for speech. The model proposed that there were two genes and four alleles responsible for language and handedness. The first gene was responsible for expressing cerebral dominance for language. This gene had two alleles one for left hemisphere language dominance (L) and the other for right hemisphere language dominance (l). The second gene determined whether the preferred hand was contralateral or ipsilateral to the hemisphere that was dominant for language (with alleles (C) and (c) respectively). Thus those with the genotype LLCC would be left hemisphere dominant for language and their dominant hand would be their right hand. This would be the most common genotype.

Levy and Nagylaki also proposed that writing posture (i.e. either an inverted posture or a non-inverted posture for holding a pen – see figure 2.2) was a possible indicator of the genotype of a person’s cerebral dominance for language. They suggested that those with an inverted writing posture (found more commonly in left-handers than in right-handers) had more control via the ipsilateral pathways and those with a non-inverted postures were more likely to be controlled via the contralateral hemisphere. Thus as many left-handers adopt an inverted writing posture then this would suggest that those who do will be, according to Levy and Nagylaki, left hemisphere dominant for language. The percentage of left-handers who are left hemisphere dominant for language varies between 60 – 70%. Green (1995) cites Wada test statistics which suggest that “*around 70% of left-handers have language in the left hemisphere, 15% in the right and 15% have a bilateral representation across both hemispheres*” p73. Levy and Nagylaki (1972) suggest that around 60% of left-handers write with an inverted posture and 40% write with a non-inverted posture. This means that the figures concur fairly well with the majority of left-handers being left hemisphere dominant for language and writing with an inverted posture. Over 95% of right-handers have their left hemisphere dominant for language (e.g. Carlson, 2001). Levy and Nagylaki propose that those with a non-inverted posture would be more likely to be controlled by the hemisphere contralateral to their writing hand and this corresponds with the findings that almost all right-handers write with a non-inverted posture.

Left hand non-inverted   Left hand parallel   Left hand inverted/’hooked’



Right hand non-inverted   Right hand parallel   Right hand inverted/’hooked’

Figure 2.2: Non-inverted, parallel and inverted or ‘hook’ postures shown by the left and right hand.

Problems

However, a number of problems have occurred with this model. Bishop (1990) questions whether writing posture can be used to identify the genotype for cerebral dominance. Several studies back this suggestion up. Peters and McGrory (1987) studied dichotic listening and writing posture and found that there was no difference in response between those with inverted postures and those with non-inverted postures. Volpe, Sidtis and Gazzaniga (1981) examined the hypothesis that left-handers' dominant hemisphere for language can be identified by their writing posture by means of a Wada test and failed to support the predictions of Levy and Nagylaki (1972). Similarly, Ajersch and Milner (1983) found no link between hand posture and language dominance using the Wada test. It is also acknowledged (e.g. Bishop, 1990) that many left-handers can write using either the inverted posture or the non-inverted posture and if this is the case and it is susceptible to change in the individual then it does not seem to be a strong predictor of cerebral dominance for language. It has also been suggested that posture can simply be an adaptive behaviour for what is best for the individual. It is possible that posture may be altered by an individual's educational experience, for example, Annett (1985) suggests that pressure to conform to various postures may differ across societies, or it is possible that individuals adopt an inverted posture so to advantage themselves when writing (e.g. Meulenbroek & Van Galen, 1989; Teasdale & Owen, 2001). In the latter case a left-hander with an inverted pen posture will be able to write without smudging the ink and perhaps more importantly they will be able to see what they are writing rather than it being concealed by their hand Other problems exist with the inverted hand posture itself. One problem is the lack of a clear definition of what an inverted hand posture is. Annett (1985) proposes that it could be defined as a point where the hand is turned around 180°. However, Peters (1996) defined hand posture in three different ways rather than simply inverted and non-inverted. He stated that as there was an element of ambiguity over what an inverted hand posture was then a third category should be introduced which was somewhere in between an inverted and non-inverted posture (see figure 2.2). This third posture was defined as parallel to the line of writing. It could then be easily clarified that if the hand were below the line of writing then this would be a non-inverted posture and if the hand were above the line of writing then this would be an inverted posture.

Figures regarding percentages of left- (and in some cases right-) handers with an inverted posture also fluctuate over studies. Annett (1985) studied 460 right-handers and 68 left-handers and found that 0.65% of the right-handers and 8.82% of the left-handers adopted the inverted writing posture. Studies by Bradshaw and Taylor (1979), Coren and Porac (1979) and McKeever (1979) reported percentages of left-handers adopting the inverted writing posture to be between 30 – 60%. More recently Teasdale and Owen (2001) studied a sample of 232 males and found that 51% of them adopted the inverted writing posture, 21% adopted a non-inverted writing posture and 28% of the sample could not be categorised clearly in to one of the categories.

An additional problem with classification of hand posture is that it depends on the person who categorises it. If there are discrepancies between researcher's definitions of what an inverted hand posture is then it is probable that figures will vary according to the individual doing the observing of a particular group. Teasdale and Owen (2001) reported ambiguities between researchers, as did Annett (1985). Peters (1996) allowed his participants to categorise their own postures. Thus is can be seen that different definitions of what inverted and non-inverted hand postures are, fluctuating statistics of inverted hand postures and ambiguities between researcher's classifications of an inverted hand posture are all important things to consider when examining the proposals made about those with inverted writing postures.

One final criticism of this model is that Levy and Nagylaki hypothesised that there were two alleles of each of two genes and that one controlled cerebral lateralisation and the other controlled whether the relationship between the hemisphere dominant for language was ipsilateral or contralateral to the dominant hand, however, Klar (1996) stated that this model was over complex as it proposes that a full expression of the allele only occurs when a dominant allele is present in the homozygous and heterozygous condition at each of the two loci. However, it doesn't state how much of or even if the gene is expressed when the recessive allele is present.

Overall, it is clear that the model is too vague to test directly and appears to rely too much on a postural assumption that doesn't seem to be supported by subsequent studies and is lacking in some important details.

2.2.3. Annett's Right Shift Theory

Annett first introduced a possible genetic model of handedness entitled the inheritance of cerebral dominance and handedness in 1964. This model proposed that handedness was determined by two alleles, D (which coded for right-handedness) and R (which coded for left-handedness). The D allele was considered to be the dominant allele and R was the recessive allele. Annett (1964) proposed that someone with the genotype DD would be right-handed and left-brain dominant whereas a person with the RR genotype would be left-handed and right brain dominant. Annett reported that those with the DR genotype would use either hand for skilled activities and their speech could be developed in either hemisphere (although she stated that this was subject to the strength of the recessive R allele). Annett added that due to the dominance of the D allele that most of the heterozygotes (those with the DR genotypes) would be right-handed and develop speech in their left hemispheres and others would have ipsilateral hand preference and speech dominance (right-handed and right hemisphere speech dominance and left-hand preference and left hemisphere speech dominance).

However, this model was found to be problematic and Annett worked to develop the right shift theory of handedness and brain asymmetry (first published in 1972). This theory has been constantly developed over the past 30 years and a summary of the main points will be presented. The theory has remained broadly similar since the original model; however, subtle factors and additional explanations have been added. The Right Shift theory has 2 main features. The first concerns hand skill. Annett stated that the difference in hand skill between the hands in humans and non-humans is normally distributed. The second feature is that there is a human shift towards dextrality (or right-handedness). However, Annett (1985) points out that there can be no absolute assertions made using this theory in that it cannot be used to generalise about the left- or right-handed population (e.g. all right-handers are…).

Handedness in humans

One important factor within this theory is that it distinguishes mixed-handers from consistent right- and left-handers (see chapter 3, section 3.2.4. for more details on Annett's hand classification system). Annett (1995) states that in order to get an accurate measurement of hand preference then handedness must be measured on a continuous scale that separates consistent left-handers and consistent right-handers from mixed-handers (of varying strengths). The strength of hand preference is also important in this theory as it aids in predicting relationships between handedness and cerebral dominance for language. The strength of hand preference is best calculated by examining the difference in skill between the left hand and the right hand (Bishop, 1990). Other hand classification systems and models work on a purely binary system of left- and right-hand preference (such as Levy & Nagylaki, 1972) and thus Annett argues that these models and classification systems may overlook differences and effects between those with consistent and inconsistent hand preferences.

Humans vs. Non-Humans

The Right Shift theory was founded on a comparison between humans and non-human handedness. The distribution of the hand preference of animals is U shaped. That is, around 25% of them are consistently right-pawed and 25% of them are consistently left-pawed with the other 50% distributed somewhere between a consistent left and consistent right paw preference (Annett, 1972, but see Chapter 1, section 1.2.). Annett (1995) stated that the distribution of non-human hand/paw preference was centred on 0 (as in the U shaped distribution) but the human distribution is displaced to the right by around 1 standard deviation (see figure 2.3. below)

Some researchers (e.g. Collins, 1969) have argued that there is no evidence that genetics play a part in the handedness of non-humans. Bishop (1990) argued that the handedness of animals was determined either purely by chance or by environmental factors and this resulted in the dominance of one hand (or paw) (but see Chapter 1, section 1.2, for a discussion of handedness in chimpanzees and other animals). Annett (1985) argues that the main factor separating humans from non-humans concerning laterality is that humans display some form of shift to the right whereas there is no such bias in non-humans. This idea of a shift to the right led Annett to develop the Right Shift theory and she wanted to investigate what actually caused this shift in humans. She proposed that there had to be something that was present in humans but not in non-humans in order to make this shift occur. Annett said that the main difference between the two groups was that humans had the ability of speech and therefore the shift may be connected to this in some way. More specifically, Annett (1985) proposed that the shift to the right is linked with left cerebral dominance for language. Annett (1985) linked the dominance of the left hemisphere for language to right hand dominance and therefore an inferior right hemisphere was related to weaker left hand skill. However, Annett (1972) stated that cultural, accidental and genetic variation should all be taken in to account when considering what causes the right shift in humans.

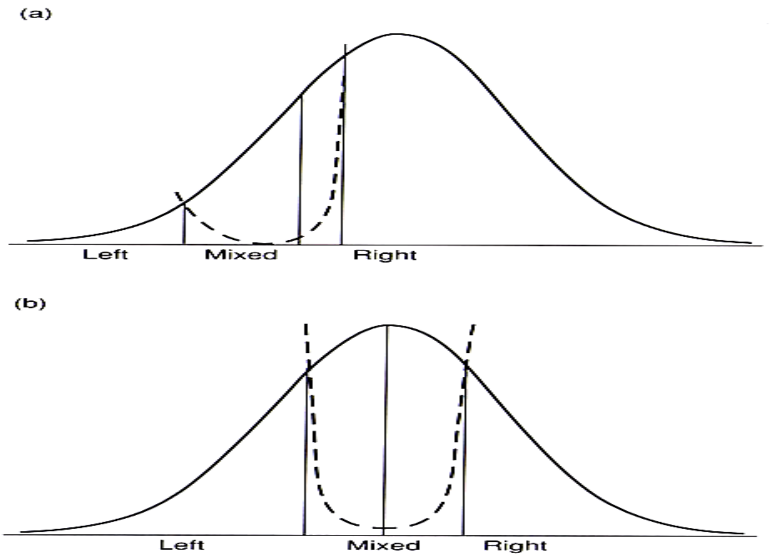


Figure 2.3: The relationship between hand preference and hand skill in humans (a) and in non-humans (b). (Annett, 2002, p.65)

Figure 2.3 shows the distribution of both hand preference and hand skill in humans (figure a) and non-humans (figure b). Figure a shows that the distribution of hand skill is slightly shifted to the right which indicates that in human society most people are more skilled with their right hand than their left hand. The ‘J’ shape within the normal distribution curve shows the distribution of hand preference in humans. This distribution indicates that a small proportion of the human population have a left hand preference and very few have a mixed hand preference and most people have a right hand preference. However, figure b shows that the hand skill distribution of non-humans is normally distributed around 0 which suggests that an equal number of non-humans have a more skilled left or right hand and that there is no dominantly skilled hand among non-humans. Additionally, the ‘U’ shaped distribution shows that an equal number of non-humans have a left or right hand preference with very few cases of mixed hand preferences, this is shown by the symmetrical nature of the distribution.

Right Shift Theory

Annett (1972) proposed her first version of the Right Shift in which she suggested that genetic variations in handedness could be due to the operation of a single gene, which could exist in either of two forms or alleles (RS+ which is the dominant allele and RS- which is the recessive allele). The dominant allele produces a ‘right shift’ in those who carry it, thus, the distribution of handedness heavily leans to the right.

This is labelled the RS+ allele but a small fraction of the population carrying this will be left handed due to environmental factors and influences.

One misconception about the Right Shift theory is that it involves a gene for handedness. The theory involves random biases to the left and right sides of the body and some individuals have chance factors plus the RS+ gene and some just have chance factors alone. Annett (1995) points out that no one has the right shift gene alone and that there is always the possibility for chance to be involved. The RS+ gene is the dominant gene and codes for left cerebral dominance for language rather than for right-handedness. This gene, however, is thought to increase the probability of right-handedness. One gene is passed on from each parent to the offspring and therefore three different combinations are possible. A person could be RS++, RS+- or RS - -. It would be expected that a person who is RS++ would be left hemisphere dominant for language and right-handed, as would the majority of people who were RS+-. When the RS+ gene is present it is thought that there is about a 95% chance of right-handedness (Annett, 1995). However, a person with the genotype RS - - would display a different pattern but not necessarily the reverse of those with the RS+ gene. Annett (1995) stated that the cerebral lateralisation of language and hand dominance (independent of cerebral dominance) were purely down to chance in those with the RS - - genotype. It is predicted in the Right Shift theory that those with the RS - - genotype would fall in to equal proportions of right and left brained speakers in that individuals with this genotype lack a factor which induces left hemisphere dominance for language and right hand dominance. The Right Shift theory also proposes that those with right hemisphere dominance for language (in normal samples) will almost all have the RS - - genotype. Although possession of the RS+ gene appears to increase the incidence of right-handedness, possession of the RS- gene does not increase the incidence of left-handedness. The incidence of left-handedness in this theory is down to chance in conjunction with having the RS - - genotype. Annett (1995) says that those with the double recessive gene would have an equal chance of becoming either left- or right-handed. Annett (1995) also points out that some left-handers carry the right shift gene (RS+) as strong random left-handedness would be reduced but not overruled by the right shift.

Annett (1995) stated that there is no gene for left-handedness or even a gene that induces left-handedness. Those with the right shift gene present (either the RS++ genotype or the RS+- genotype) will almost all have typical cerebral dominance (which is the left hemisphere being specialized for language). Those with the RS - -

genotype will have randomised cerebral specialization for language. Annett (1995) suggested that the brains of those with the RS++ genotype differ slightly from the brains of those with RS+- genotypes. Li, Zhu and Nuttall (2003) report that around 1/3 of the population is made up of people with the RS++ genotype. Bishop (1990) stated that if the RS+ gene were completely dominant then those with the RS++ genotype would not differ in phenotype from those with the RS+- genotype. However, Bishop argues that the RS+- genotype may be an intermediate genotype which falls somewhere in the middle of the RS++ and RS - - genotypes. Annett (1995) suggested that those with the RS+- genotype would have a moderate dose of the right shift factor while those with the RS++ factor would have a large dose of the right shift factor and therefore they would be expected to show a stronger right hand preference and be further shifted to the right.

Annett suggested that the RS+ allele is expressed more strongly in women than in men and from this she proposed that women therefore have a greater level of right-handedness (Annett, 1967). Annett also stated that this might account for the fact that most surveys reveal a higher proportion of left-handers among males. This is also supported by evidence from Oldfield (1971) who stated that there were more left-handers among males than females. However, Annett (1972) stated that if females are more asymmetrical to the right (in that their right shift is further than the right shift of males in the distribution of handedness) and the factor that determines handedness in males and females is the same, then left-handed females would be expected to possess a stronger version of left-handedness than males. Thus, if a female were atypically right-handed then in order to express left-handedness then the gene to express left-handedness would have to be strong in order to deviate from the norm, which is right-handedness (and a strong form of right-handedness in many cases if there is an increased shift to the right). This does not contradict Oldfield's statement that there are more left-handed males but one difference is that Oldfield does not comment on the strength of handedness in these left-handers and measures them in terms of a laterality quotient over a 10-item handedness inventory. Annett (1972), however, claims that many of the female left-handers in her samples are strong left-handers (using her 8 classification of hand preference – see Chapter 3, section 3.2.4. for further information).

A summary of Annett's Right Shift theory is that it is present in humans but not in non-humans (specifically any other primates), the right shift is stronger in females than in males and the strength and skill of the right side of the body is increased by the shift to the right. This, therefore, led to the conclusion that the shift must be linked to something that is unique to humans which is the development of speech (and more specifically the development of speech in the left hemisphere).

Proposed causes of the Right Shift theory

There have been various explanations for what causes the shift to the right in humans. Annett (2003) stated that explanations of cerebral dominance fall in to two main categories: natural and pathological. Annett (1995) argued that the main findings of her Right Shift Theory are due to genetic factors and not pathological factors. Annett (1985) stated, "*The fact that some left-handedness is due to pathological causes does not imply that all left-handedness is due to pathology. The right shift theory concerns natural variation in the general population*" (p441). Annett goes on to say the right shift theory suggests that the presence or the absence of the RS+ gene is associated with individual differences in cerebral organization that arise from natural variation (Annett, 2003). Annett argued that the most important factors to explain the shift to the right were genetic factors and cultural factors. More specifically, Annett (1985) stated that the factor (or gene(s)) that induces speech in the left hemisphere is genetic and that there are no genes for inducing speech in the right hemisphere or for displaying left-hand dominance (those with RS - -). This, according the theory, is left to chance with slight influences from culture and the environment where hand dominance is concerned.

However, Annett (1995) stated that a gene that influences hemispheric dominance and more specifically hemispheric dominance for language may have some disadvantages. One main disadvantage may be that because there is a huge commitment to the left hemisphere in those who have left hemisphere language specialisation then the right hemisphere may suffer at its' expense as there may be over commitment to the left with very little emphasis on the right hemisphere and its functions. Annett says that this disadvantage would be highest in those with the RS++ genotype (around 32% of the population according to Annett & Manning, 1990), as they would have the strongest shift to the right and the strongest chance of left cerebral dominance and right-handedness. Annett added that those with the RS+- genotype (around 49% of the population) would have a very strong chance of left cerebral dominance for language and right-handedness but this group would "*enjoy the advantages of lateralisation of speech to the left hemisphere, with minimal* *risk to the right hemisphere*" (Annett & Manning, 1990, p61) [1]. The disadvantage of over use of the left hemisphere would be absent in those with the RS - - genotype as cerebral dominance and handedness is left entirely down to chance and therefore there are no specific demands on either hemisphere and there is a higher chance of the left hemisphere not being dominant for language lateralisation. However, Annett and Manning (1990) reported that although this group are not at risk of hemisphere impairment (either to the right or the left hemisphere) they are at risk of developmental delays of speech and language skills as "*there is an inherent difficulty of programming a large brain to serve speech, when the corpus callosum is immature (the evolutionary pressure presumed to maintain the RS+ gene in the population*" (p62). Annett suggested that there is a balanced polymorphism with heterozygote advantage in the right shift theory (e.g. Annett, 1995). By this she means that it might be advantageous to have the genotype RS+- as these individuals will have the benefits of the RS+ gene but also the influence of the RS- gene, which lowers the over-commitment to the left hemisphere, and lack of commitment to the right hemisphere (Annett, 1978). Annett stated that left hemisphere advantage is present in gene carriers but is absent on non-gene carriers.

Annett (1995) stated that those with the RS - - genotype can have the same pattern of cerebral dominance and handedness as those with the RS++ genotype (left hemisphere cerebral dominance for language and right-handedness) due to chance. She added that chance is a major factor in the right shift theory and plays a part in almost any type of asymmetry (Annett, 1995). However, right hemisphere dominance for language or bilateral distribution of language is almost never expressed in the normal population with the RS+ gene but is expressed in around 30% of left-handers most of whom would be expected to have the RS - - genotype according to the right shift theory. Annett (1995) stated that although the right shift theory is concerned with cerebral dominance and language lateralisation, it is difficult to directly measure cerebral dominance and thus handedness can be used as a predictor of cerebral dominance patterns as it is a weak by-product of cerebral asymmetry and is easily measured. Annett (1985) stated that the shift in the population to the right could not be purely down to chance factors and she states that that this is not a feasible explanation.

---

[1] Annett contends that the most advantaged individuals should not be the most left-handed individuals (1992a, 1993a) but rather those biased towards dextrality. This advantage is what Annett referred to as "human balanced polymorphism".

Annett (1972) has also postulated that culture may influence the shift to the right in the right shift theory. She proposed that cultural influences, however, would depend on the presence of other people and also the kind of influence they would have (whether the influence was conscious or not). She also stated that if there was an equal chance that a person could use the right hand and the left hand then it would be probable that there would still be a higher proportion of right-handers in the 'chance' group than left-handers. The main reason for this is that as we live in a right-handed society the use of the right hand is encouraged through cultural influences (particularly in skilled activities). In the case of those with a strong left-hand preference, they would continue to use their left hands but those with a weak left hand preference would be more likely to change hand preference under cultural pressure. Thus, cultural influence could aid in the shift to the right in some groups - particularly those with weak preferences who could be easily influenced. However, Annett (1972) has proposed that cultural factors cannot explain the right shift independent of any other factors. Annett argued that if culture were solely responsible for the shift to the right then there would be a left-handed society somewhere in the world if society was balanced at birth by left- and right-handers and cultural influences determined the hand dominance of the society. As there are no known left-handed societies in the world then it appears that other factors must also be responsible for influencing this shift to the right.

Right shift in families

Annett (1983) tested children of two left-handed parents on a peg-moving task and found that 50% of the children were faster with their right hands and 50% were faster with their left hands. There was a slight bias towards favouring the right hand as the trials progressed but this difference was not significant. More importantly, if some left-handers carry the RS+ gene then it would be expected that these individuals would be more skilled with the right hand. Also, some of the parents of the children in the sample had had early birth traumas or difficulties and therefore could possibly be pathological left-handers (and thus carry the RS+ gene) (see section 2.5.). Annett found that the children in these families (ones which consisted of potentially pathological left-handed parents), although raised by two left-handed parents were just as biased to right-hand preferences as the right-handed control subjects. Annett (1983) concluded that this is evidence that the bias to dextrality is genetic but if there is an absence of a genetic factor then chance is sufficient to account for right- and left-handedness.

Annett (1994) reported that right-handers with all right-handed family members are likely to have the RS++ genotype and be left hemisphere dominant for language whereas right-handers with close relatives who are not right-handed are more likely to have the RS+- genotype. The influence of families on handedness can be further explored through twin studies.

Twin studies

Annett (1995) proposed that the right shift is larger in single born children than it is in twins. Handedness in twins is often thought to rule out any genetic influence of handedness because proportions of RR, RL and LL pairs are consistent with random allocation (Annett, 1995). It was also pointed out that proportions of RR, RL and LL pairs were almost identical in monozygotic and dizygotic twins. Collins (1970) found that in monozygotic twins the proportions of RR, RL and LL pairs were 75%, 23% and 2% respectively and were 78%, 21% and 1% in dizygotic twins. Thus, this illustrated that there was a higher incidence of two right-handed twins in dizygotic pairs than monozygotic pairs but a higher incidence of left-handedness in monozygotic pairs for both discordant twins and two left-handed twins. However, Annett (1995) proposed that if handedness in twins was down to chance then the pairings of RR, RL and LL should appear in the proportions 25%, 50% and 25% respectively. However, it has been found that there are an excess number of right-handers among twins that challenges the view that their handedness is purely down to chance. Annett (1995) proposes that handedness in twins is due to chance plus, in many cases, a factor which increases the probability of right-handedness. Annett states that this pattern would fit in with the Right Shift theory, as almost all of the variability within it is random. The model also fits in with the view that there is a higher incidence of right-handedness in twins because many of them will have the RS+ gene in some form (depending on the genotype of their parents) and those with the RS - - gene will have an equal chance of being left-handed or right-handed. When this occurs right-hand preference is higher as people and the environment can influence it.

It is also important to note that monozygotic twins have the same genotype (thus if one twin is RS- - and is left-handed the other twin will also be RS- - (but not necessarily left-handed) but dizygotic twins do not necessarily have the same genotype as they share only 50% of their genes (Annett, 2003). Monozygotic twins often differ for handedness, as do dizygotic twins. Monozygotic twins share the same genotype (and have identical genes) yet they sometimes differ for hand preference this therefore rules out mirror imaging in twins. Annett (2003) stated that recent theories have introduced chance factors that would permit monozygotic twins to differ for laterality even when there was a genetic influence. Annett (2003) implied that the right shift that occurs in single born individuals is different to that of twins. She stated that a smaller shift occurred in twins (both mz and dz pairs) and this implied that the expression of the RS+ gene was reduced in some way by the twinning (although Klar, 1999, suggests that evidence for this idea is lacking). Annett (1978) proposed that the reduction in the shift could be up to as much as 50% in order to match the prediction for twin pairs. However, a later prediction proposed that a reduction in the shift of 33% was a more realistic prediction (Annett, 1985). This reduction implies that twins are more often left-handed than single born individuals and also helps explain why many twins have discordant hand preference. This reduction in the right shift in twins implies that the RS+ gene may be a function of size or maturity at birth. Annett (2003) states that this is consistent with the higher frequency of right-handed females than males and the higher frequency of right-handedness in full term infants than premature or low birth weight infants.

Hand Skill

Hand skill is often used to indicate hand preferences (see Chapter 3, sections 3.5. & 3.6.). Annett (1972) stated that the distribution of hand skill appears to be universal in all species in that it forms a normal distribution (see figure 2.4). She added that hand skill is normally distributed and is something that can be more accurately measured in humans than in non-humans. The Right Shift Theory also examines distribution of hand preference and hand skill within the normal population. Annett and Kilshaw (1983) looked at hand skill using a peg-moving task in children. They found that in right-handed participants rather than hand skill specifically concerning speed and skill of the right-hand it depended in many cases on slowness and lack of skill in the left hand. According to Annett (1995), hand skill studies suggest that there is some form of left hand weakness which leads to strong dextrality, which she says is possibly associated with impairment of right hemisphere function. This observation of hand skill offers a possible explanation to why the RS+ gene has been limited in the population.

The right shift theory hypothesizes that the total population distribution will consist of three underlying distributions (one that assumes superior skill with the left hand, one that assumes no difference between the hands in skill and one that assumes superior skill with the right hand). However, the type of hand skill distribution obtained will depend on the task used. Peters (1987) noted that practice was a crucial variable. He added that prolonged practice with one hand on a task would emphasise differences between the 2 sides (e.g. when demonstrating hand skill using a pen – skill will be bimodal – one mode well to the left of 0 and the other at the corresponding point on the right). If a relatively unpractised task were used then bimodality would not be as apparent.

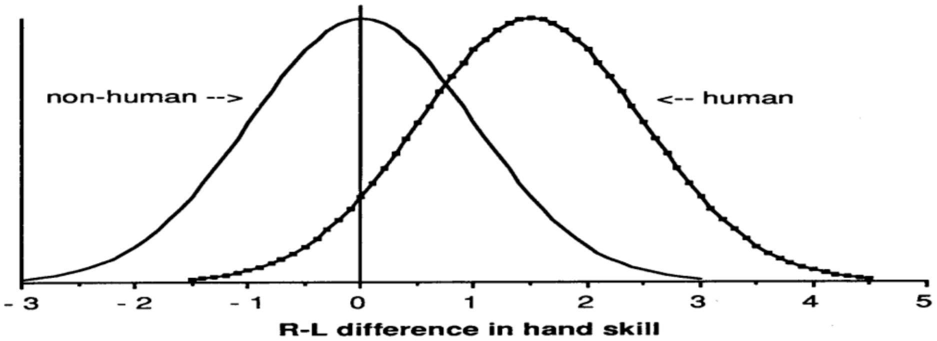


Figure 2.4: Right minus Left difference in hand skill for humans and non-humans. (Bishop, 1990, p43).

Problems and criticisms

Overall, Annett's right shift theory has been very influential in handedness research, but this doesn't mean that it is without its critics. For example, one criticism with this model is that it has so many components and levels that it may be possible to fit almost any data set to it (Bishop, 1990). This point is extended by Corballis (1991) who stated that the model could be interpreted in a few different ways to explain various findings. For example, it can be interpreted that because there are no left handed societies in this world then it cannot solely be culture acting on its own that influences handedness. However, the theory does not justify why culture could not be solely responsible for determining handedness. In assuming that culture cannot be solely responsible the theory assumes that genetics is a key part to determining handedness and that it is only those with weak hand preferences can be influenced by culture. However, the theory does not explain exactly how weak an individual's hand preference would have to be before there could be a cultural influence and also it does not take in to consideration the different types of cultural influence that could occur (and to what extent). These cultural influences could include, among many things, imitation of parents and/or teachers or perhaps even the general design of materials in the right-handed world. Corballis (1991) also argued that the absence of environmental and cultural pressure could not be guaranteed. He said that it would be almost impossible to do this. Also, Corballis stated that Annett does not define chance clearly and leaves it open for interpretation (again allowing different conclusions to be drawn depending on people's interpretations). He goes on to say that Annett's definition of chance is ambiguous and could probably be just as well defined and interpreted with respect to cultural and environmental influences and also parental influence.

Another criticism of the model, which leads on from the first criticism, is that the general right shift genetic model of handedness states that ¼ of the population are expected to have two RS+ alleles (due to classic genetic theory with one chromosome coming from each parent), ½ are expected to have RS + - and ¼ RS - - (this is because RS+ is the dominant gene). Therefore, according to this, ¼ of the population (RS - -) will have their cerebral asymmetry and handedness determined by chance (Corballis, 1991). This figure would result in about ½ of the 25% being left-handed and this figure of around 12.5% is consistent with the general estimate of the proportion of left-handers in society. However, the main criticism with this is that those 12.5% of left-handers are only determined, according to the theory, by having the RS - - genotype. This therefore does not take in to account any left-handers who carry the RS+ gene in any form (whether they are pathological left-handers or non-pathological but carry the RS+ gene). Corballis (1991) therefore argues that the figure of 12.5% of RS - - left-handers is too high and that a more realistic figure would be around 9% with the other 4% being made up of left-handers who carry the RS+ gene. Annett does not take these additional pathological left-handers in to account when estimating the proportion of left-handers and therefore the general figure for left-handedness in the population would be over estimated if the figures that Annett reports for left-handers with the RS- -genotype were combined with pathological left-handers (and also a few RS+ left-handers who are not pathological). However, although Annett predicts that 12.5% of those with the RS - - genotype will be left-handed, this is most likely not the case. If those with the genotype RS - - have their handedness determined mainly by chance then the influence of the right-handed world will have an effect and bias more of this population toward the right hand and thus this would reduce the proportion of left-handers with the RS - - genotype.

With respect to twin studies it could be argued that if handedness were purely genetic then all monozygotic twins would have the same handedness. Annett (1985) stated that there was room for environmental variation in some twins that would cause a difference in handedness and also in homozygous twins there appears to be no association in handedness between the twins.

2.2.4. McManus's Genetic Model

McManus (1985) proposed an alternative genetic model of handedness that, he says, differs from Annett's right shift theory. McManus's model is similar to that of Annett's as it is a single gene model that involves handedness being determined by two alleles at a single locus. The crux of McManus's (1985) theory is that the he states that the direction of hand preference is under genetic control and if an individual does not have the dextral gene (the gene that codes for right-handedness) then it is possible that the individual might become left-handed by chance. McManus states that handedness is controlled by a single gene locus, with a dominant 'D' allele specifying dextrality, and the recessive 'C' allele specifying chance. The D allele in this theory is similar to Annetts' right shift (RS+) gene, and C equates with the absence of the RS gene. McManus defines handedness using a binary system and states that a person is either left-handed or right-handed. In this model, those with the DD genotype will almost always, according to McManus, be right-handed, 75% of individuals with the DC genotype will be right-handed and 50% of those with the CC genotype will be right-handed (as determined by chance, see Table 2.1.).

Table 2.1: McManus's (1985) Genetic model and probability of handedness according to genotype.

Genotype	Chance of Being Right handed	Monozygotic Twins with this genotype
DD	100%	Right
DC	75%	75% Right (independently)
CC	50% (chance)	50% Right (independently)

McManus (2002) states that one of the most important points that genetic models of handedness need to outline is firstly how the hand preference of twins can differ and also how it is possible for two right-handed parents to have left-handed children (or explain why ¾ of children of 2 left-handed parents are right-handed[2]). McManus' genetic model attempts to explain how handedness in twins can differ and also how two right-handed parents can have left-handed offspring. With respect to handedness in identical twins, McManus proposed that twins with the DD genotype

---

[2] One feature of Annett's Theory is that the right shift negative allele (RS-) does not result in left-handedness but instead the absence of a bias toward right or left-handedness. This attempts to explain why children of two left-handed parents are divided almost equally into left and right-handers. McManus also attempts to explain this in his theory.

would always be right-handed. If the identical twins had the genotype CC then each twin would have a 50% chance of left-handedness but the 50% chance applies separately to each twin. In twins with the DC genotype the pattern is slightly more complicated as each twin would have a 1 in 4 chance of being left-handed. In dizygotic twins each twin would have their own genotype and thus their hand preference would be determined according to this model by its own individual genotype (determined by that of the parents). McManus explains the possibility of two right-handed parents having a left-handed child through the probability of both parents being heterozygous (DC) and thus passing on the C allele in both cases to the child and thus the child would have a 50% chance of becoming left-handed. With respect to the statistic that ¾ of children of two left-handed parents are right-handed McManus' model explains this by stating that if a child has the genotype CC then it would have a 50% chance of being right-handed but also 25% of people with the DC genotype are also left-handed so thus the more dominant D allele could be passed on to the offspring by the left-handed parent carrying this gene and thus the probability of the child being right-handed could be stronger.

McManus (1985) also considered the position between handedness and cerebral lateralisation for language. He stated that there was a link between parental handedness and lateralisation and proposed that an individual with at least one left-handed parent would be more likely to have right hemisphere language representation than those with two right-handed parents (however, this could be argued against depending firstly on the hand preference of the individual and secondly depending if one or both parents were left-handed and if so what type of left-hander they were).

One problem with this theory is that McManus does not clearly outline how bilateral representation of language can be explained. However, McManus attempts to explain this by stating that more than one language function can be lateralised and thus one function can be lateralised in one hemisphere while a different function can be lateralised in the other hemisphere.

This model has much in common with the right shift theory. One of the main similarities between the two models is that firstly there is a gene that biases toward dextrality but does not code directly for right-handedness. Secondly, the recessive gene in both McManus' and Annett's theories specify that those with the homozygous pairing of this gene (CC in McManus' case and RS - - in Annett's case) have their lateralisation determined by chance rather than it biasing toward left-handedness. McManus and Annett do not propose that any genotype biases towards left-handedness. However, one important difference between the models is that while Annett examines handedness in relation to hand skill, McManus looks at handedness in terms of preference rather than skill. Thus, Annett states that an individual inherits either a skill bias to the right or no bias while McManus argues that lack of bias to either side is characterised by those with the genotype CC. McManus also differs from Annett with respect to his views on hand skill as he states that rather than hand skill being normally distributed around zero for the population that there are two distributions, one that is shifted to the right of zero and the other shifted to the left of zero in order to illustrate that right-handers are more skilled with their right hands and left-handers are more skilled with their left hands. As McManus maintains that hand preference works on a binary system then he does not consider those that will be equally skilled with both hands or those that prefer to use one hand but are more skilled with the other. These differences in predictions for left-handers based on the two models may have important implications for the current study (see Section 2.7.).

2.2.5. Annett vs. McManus

McManus (1985) in his genetic theory of handedness proposed that some people inherit a gene for dextrality (D) (or right-handedness) and others inherit a gene for chance (C). There are many arguments that suggest that the right shift theory and McManus's genetic theory are very similar (see Corballis, 1991 for a review) with respect to the chance factor of the theories. Corballis (1998) stated that both Annett's and McManus' theories focus on a single gene locus with two separate alleles (and of these alleles in both theories one is associated to left cerebral dominance and right-handedness and the other is associated with chance factors) and also that both theories assume that the gene is uniquely human. Both Annett and McManus argue that there is a gene that allows lateralisation to be determined by chance in both theories, however, in Annett's theory the alternative gene to the chance gene is the right shift gene that determines cerebral dominance for language, which in effect influences hand preference, rather than determines it. In McManus's theory there is a chance gene and there is a dextrality gene that codes for right-handedness rather than specifically for a form of cerebral lateralisation. One main problem with this theory is that no gene has been discovered that actually codes for handedness and therefore the theory remains a little ambiguous compared to Annett's theory which does not specify a handedness gene but rather a gene which influences cerebral dominance for language. Corballis (1998) stated that the models of Annett and McManus are "essentially indistinguishable with respect to how well they can fit the data on the inheritance of handedness" (p153). Corballis concluded by proposing that having a chance gene may explain why handedness and cerebral asymmetry are not perfectly correlated in the population. Finally, Corballis (1997) states that although Annett and McManus propose different assumptions in fitting their models to data, there seems to be no reliable way at the present time to distinguish empirically between them. He concludes that whatever the nature of the gene, it is unlikely that it codes for handedness as such.

2.2.6. Klar's (1996) Random-Recessive Model

Klar (1996) took a different approach when he proposed in his single gene model that two alleles existed. The dominant allele in this model was RGHT (or R as it was also referred to) and this allele caused a person to become right-handed. The recessive, "non-functional" allele, as referred to by Klar, was known as r (this stood for random handed). Klar proposed that if a person had the genotype RR then they would almost certainly be right-handed, this was also the case if a person had the Rr genotype. However, if a person had the genotype rr then this would infer that handedness would be determined at random rather than that person automatically becoming left-handed. That is, there would be an equal chance of the individual having a left-hand or right-hand preference. Klar also inferred that there was some form of relationship between handedness and cerebral dominance for language. He speculated that the R allele was linked to the left cerebral hemisphere in some way and the influence of this allele caused the left hemisphere to become the dominant hemisphere and thus become responsible for the processing of language. Klar proposed that a function of the R allele was to link the dominant hemisphere to the development of right hand preference. This model, therefore, predicts that there will be a strong association between left cerebral dominance (particularly for language) and the development of right-hand preference (in those with the RR or Rr genotype). The model also predicts that in those with the rr genotype that there will be a random distribution of both hand preference and cerebral dominance. Klar stated that there was a correlation between cerebral dominance and handedness in right-handers with the RR and Rr genotypes but stated that there was no correlation between the two in left-handers with the rr genotype. He went on to say that even though there was no correlation between hand preference and cerebral lateralisation in those with the rr genotype, most of these individuals are still lateralised with around 70% having left cerebral dominance for language. However, Klar also proposed that in the absence of the R allele other genes controlling brain specialization could dictate lateralisation.

As previously mentioned, one of the main arguments against genetic theories was that up to half of children born to two left-handed parents are right-handed. Klar (1999) reported a study that examined couples that consisted of one right-hander who had two left-handed parents and another right-hander who had no left-handed parents. It was found that these pairings produced a higher percentage of left-handed children than pairings of right-handers where neither individual had a left-handed parent. Klar (1999) went on to say that the percentage of left-handed children produced by a right-handed couple where one individual's parents were left-handed was similar to the figures of a left-hander mating with a right-hander in general. Therefore, the right-handers in this example must have the same genotypes as left-handers in the population in order for them to be able to produce a higher number of left-handed children. Thus, this answers the argument that it is possible that up to half of the children of two left-handed parents can be right-handed but it is their genotype and their parent's genotypes that are important with respect to what their hand preference is most likely to be (in that each parent in Klar's model is passing on the r allele thus resulting in the child having the rr genotype which results in their hand preference being determined by chance and therefore it is highly possible (given that we live in a right-handed world) that this individual will become right-handed). Another argument against genetic theories is that despite sharing the same genes, around 18% of identical twins have discordant hand preference. It would be expected that if handedness were genetic then all identical (monozygotic twins) would have the same hand preference. However, Klar addressed this issue simply by stating that in his model those with the rr genotype would have their hand preference determined at random and therefore there would be high possibility of discordant hand preference in twins due to chance alone (providing they had the rr genotype).

2.2.7. McKeever's (2004) genetic model of handedness for writing and hand posture

The most recent genetic model of handedness that has been proposed is that of McKeever (2004). In his X-linked three-allele model, McKeever proposes that, unlike the theory of Levy and Nagylaki (1972), inverted hand posture is not highly correlated with cerebral lateralisation of language. For an extended summary of this model see

McKeever (2004). As this model has appeared late in the development of this thesis, then the focus will be on the more established and tested models outlined in the previous sections.

2.2.8. Summary of single gene models of cerebral dominance and handedness

Klar's model is similar in many ways to the models of Annett (1972; 1985; 1995) and McManus (1985). Firstly, all three models are single gene models that identify a dominant and recessive gene that is situated at one loci. Secondly, all three single gene theories discuss that there is a dominant genotype that codes for right-sidedness and that those with this gene will almost certainly be right-handed. More specifically, each theory looks at the relationship between cerebral dominance and handedness and proposes that left cerebral dominance for language is an important predictor of handedness and lateralisation. Klar (1999) stated that all three models' main functions where handedness was concerned was that the dominant allele in each model was responsible for the cerebral dominance of speech to the left hemisphere and more specifically, the development of this dominant hemisphere was linked to the dominant hand on the contralateral side (in most cases). However, Klar (1996) stated that having the RGHT gene (or R gene) causes a person to almost always be right-handed (but he does not define what figure 'almost always right-handed' refers to) whereas Annett (1985) stated that an individual with the right shift gene (RS+) would be likely to be right-handed (but not in all cases - e.g. pathological left-handers) and that the gene itself does not code for right-handedness but for cerebral dominance for language. Klar's (1996) model proposes that the R allele is fully dominant and that the r allele is recessive. However, this differs from the models of Annett and McManus as they both propose that there is an additive effect in their models, this means that there is an element of variation within their dominant alleles and that these alleles may be incompletely dominant – this would mean that there would be a chance that a percentage of heterozygotes would develop as non right-handers in these two models (8% in Annett's theory and 25% in McManus' theory, Klar, 1999) due to the incomplete dominance of the right shift gene (RS+) in Annett's case and the dextral (D) allele in McManus' case. Also, as Annett's RS+ gene is a continuously varying gene then it is possible that even a small percentage of those with the RS++ genotype could develop as left-handers.

Although many studies have concluded that environmental influences are favoured when explaining discordant hand preferences in monozygotic twins (e.g. James &

Orlebeke, 2002) there are still proposed genetic explanations as to why this might be the case. The issue of twins in the three single gene theories all provide slightly different explanations as to why there is discordant hand preference in monozygotic (identical) twins. As previously mentioned, Klar (1996) proposed that there are discordant hand preferences in monozygotic twins due to chance factors determining hand preference in those with the rr genotype. Similarly, McManus (1985) proposed that hand preference in twins with the CC genotype (the recessive genotype) would be decided by chance and it would be highly possible that twins could therefore have differing hand preferences. McManus goes on to say that it is possible that a number of those with the DC genotype (in which handedness occurs independently of each twin) may also have discordant hand preferences. Annett (1985) explained the discordance of hand preference in monozygotic twins by indicating that the RS+ gene was reduced in some way in twins (although it is not known how) and this allowed in some cases a higher chance of left-handedness in twins and weaker right-hand preferences in others.

In summary, all three genetic theories broadly account for the observed pattern of handedness, but may have some slightly different implications for the present study (see Section 2.7).

After consideration of genetic models of handedness the evidence for cultural and environmental influences also have to be considered. The next section will outline these arguments.

2.3. Handedness, Culture and the Environment

It has often been argued that right-handedness was due entirely to cultural pressure and that the natural condition was actually ambidexterity. However, Collins (cited in Springer & Deutsch, 1993) takes an extreme environmental position and argued that "*handedness is transmitted from one generation to the next through cultural and environmental biases*" p125. This suggests that the incidence of right-handedness is so large because it has been a learned response to a right-handed world and left-handedness exists when there is some sort of physical defect or some kind of emotional problem occurs and consequentially, the right-handed world response is not learned. In many societies, there have been strong sanctions against the use of the left hand, especially for activities such as eating or writing (Provins, 1997).

However, left-handedness has become better accepted over the last 30 years in North America and Western Europe but use of the right hand has been reported relatively recently in countries such as Spain, Italy and former Iron Curtain countries (Corballis, 1991). Studies have shown that in Taipei in China, only 3.5% of school children were exclusively left handed and in a study of school children in Japan, 7.2% were non right handed, this rose to 11% if those who changed from left to right were included (Corballis, 1991). Littlejohn (1973), Wieschopp (1973) and Lauterbach (1933) have reported that many children who use their left hands have been subjected to severe physical restraint or punishment (cited in Provins, 1997). Littlejohn, (cited in Provins, 1997), reported that the knuckles of the offending hand were rapped or bound tightly with rags when used in Sierra Leone. Elsewhere in Africa, a child's left hand was scalded to force them to use their right. In strict or conforming cultures, the incidence of left-handedness was shown to be low. In conforming societies such as Tanzania and Japan, a large population sample showed that less than 1% used their left hands for writing (Provins, 1997). Social conformity in handedness is often subtle and left-handedness still occurs despite a general population bias to the right. The most likely sources of environmental influences when learning to write comes from parents and teachers because the main phase of handedness development occurs from six months to six years. Harkins and Uzgiris, (1991), (cited in Provins, 1997), suggested that imitation of the mother may be one of the most salient features that could account for infant hand preference. This view is confirmed by Porac, Coren and Searleman (1986), they say that there is a decrease in the incidence of right handedness among the offspring of one left handed parent and this is greatest when the mother is left handed. This therefore leads to a conclusion that the role of maternal influence is an important factor in the determination of handedness.

Annett, (1967), said the discovery of pure left-handers who are as consistently left as most right-handers are consistently right, showed that there were some individuals on whom the supposed environmental pressures have had no observable effect. Blau, (1946), introduced a non-genetic theory of left-handedness (cited in Annett, 1967) and maintained it to be "*an expression of infantile negativism*". Blau set out to establish right-handedness as the normal well ordered human response to the environment. From his work, Blau concluded that handedness was not genetic and was only determined by the environment. He argued the right hand became dominant because society influenced it. Left-handedness arises therefore as a direct deviation from this norm, brought about by '*an inherent deficiency, faulty education,* *or emotional negativism'*. He says emotional negativism is the most common type of left-handedness; it develops from a child's active resistance to environmental and social pressures to become right-handed. In other words, the development of left-handedness is a deliberate challenge to the otherwise natural and normal strain of right-handedness (Langford, 1995). However, Corballis (1991) argues that "*left handers as a whole are no worse than right handers, intellectually, physically and emotionally*" p22. He also goes on to say that left-handers tend to show special maths and artistic talent and that the majority of left-handers are simply part of the normal population. He also says that left-handers may arise, in part, from genetic variation, that has no sinister connotations. Corballis concludes that it is likely that if cultural pressures were totally eliminated, right-handers would still make up the majority, with the proportion of left-handers around 12-13%.

Studies have suggested that left-handedness seems to run in families, although very rarely to the extent that it will run through the whole family. Corballis (1991) cited that 92.4% of those born to two right-handed parents were themselves right handed. If one or other parent was left handed, the incidence of the child being right handed dropped to 80.5% and if both parents were left handed, the chance of the child being right handed went down to 45.5% (Corballis, 1991). Springer and Deutsch (1993) expressed these figures in terms of the probability of having a left-handed child. They said that the probability of two right-handed parents having a left-handed child was 0.02. If one parent was left handed, then it would rise to 0.17 and if both parents were left handed, the child's probability of being left handed would be 0.46. These figures not only coincide with the genetic argument, but can also be accounted for by environmental arguments because whatever the handedness of the parents, it will have some form of influence on the offspring. So, if both parents are right handed, then the amount of left handed influences from the parents will be minimal and therefore the probability of a left-handed child will be low. If one parent is left handed then a certain amount of left-handed activities will be presented to the offspring and therefore it raises the chances of it becoming left-handed. Finally, if both parents are left handers, then a great deal of stimuli and activities will be done with the left hand and will increase the chances even more of left-handed offspring. However, this can be considered in more simple terms, such as the cultural or role models that are available to the child. In some cases, mixed role models may be present but in other cases, a child may relate and identify mostly with its mother who happens to be right handed and thus, the child if cultural and environmental influences are to be accepted, will probably be right handed. The same goes if a child related most to its left handed father or the person with whom they spend the most time.

Genetic models of handedness and cultural and environmental arguments of handedness have been considered in the previous two sections. However, after considering the evidence of these models and arguments and arriving at the conclusion that both the genetic argument and the cultural/environmental argument both have valuable contributions to make to what causes human handedness, a new focus was introduced by Laland, Van Horn and Feldman (1995) who developed what was known as the gene-culture model of human handedness which encompassed both genetic and environmental arguments.

2.4. Gene-culture models

2.4.1. Laland, Kumm, Van Horn and Feldman's (1995) Gene-Culture Model of Human Handedness

Many researchers have dismissed purely cultural and/or environmental handedness models as they are seen to have many flaws (such as why no left-handed societies exist and why right-handedness is common to all societies). The gene-culture model combined the genetic arguments and the cultural arguments to help explain the development of handedness. Laland et al. (1995) reported that standard genetic models assumed that variation in handedness was caused solely by genetics. They added that variation in human handedness is caused by accidents in early development that gives advantage of skill and/or strength to one side over the other. However, Laland et al. (1995) and Provins (1997) proposed that variation in handedness was entirely due to cultural and environmental factors (see environmental section (2.3.) for a summary of Provins' arguments). Laland et al. were not satisfied that only genetics could be responsible for handedness but took in to account that they did have an important role to play thus this led to the development of the gene-culture model. Laland et al stated that our genes are responsible for pushing handedness to favour the right but were not entirely sure how this occurred. They added that culture also has an important role to play and illustrated this with the example of if a child has two right-handed parents then the influence of right-handedness on an individual will increase, if a child has two left-handed parents then the influence of right-handedness will decrease but if a child has one right-handed parent and one left-handed parent then the influence will be cancelled out. In the gene-culture model it is proposed that natural selection (which in this case favours right-handedness or whatever originally underlay it) affected the probability of individuals becoming right-handed from chance levels. Laland et al. (1995) stated that everyone has the same genotype for handedness, that is, one with an increased chance of being right-handed and that left-handedness is produced by cultural and/or environmental influence. They added that the main cultural influence that affects an individual’s handedness is their upbringing and more specifically the influence of those closest to them (i.e. parental handedness). Laland et al. stated that parental influence could occur in one of two ways. Firstly, it could be indirect, subtle imitation where the individual merely copies their parent(s) (e.g. see Masur, 1988). Alternatively, the influence may involve direct instruction where use of the ‘wrong hand’ may result in some form of punishment (see Barsley, 1970 for examples of punishment). Laland et al. in their model do not state that cultural influence solely shapes hand preference and do not dismiss the suggestion that hand preference may exist before cultural influence or even pre-natally but they do propose that these preferences are sufficiently weak in the early stages so that cultural influence could have a major effect. This model differs from the previous genetic models (e.g. Levy & Nagylaki, 1972 and the single gene models of Annett, 1985; McManus, 1985 and Klar, 1996) as it solely examines hand preference and does not examine the role of cerebral dominance in great detail (although Laland et al. do acknowledge that there is a link between handedness and cerebral dominance they state that it is difficult to get enough reliable data to illustrate the pattern of cerebral dominance in left- and right-handers). Laland et al. accepted that there is significant variation in patterns of cerebral dominance but the cause of this variation is relatively unknown and could be due to genetic influence or environmental influence. Laland et al. stated that in order for their model to remain relatively similar to the previous handedness models (examining the relationship between hand and brain data) their model should show an interaction between processes that influence handedness and cerebral asymmetry.

With respect to the three problems outlined by Klar (1996) concerning genetic models of handedness and/or cerebral dominance (cultural biases influence hand preference; twins have an identical genotype but 18% are discordant for handedness and not all children of two left-handed parents are left-handed) the gene-culture model addressed these issues by adding the factor of cultural influence to the theory in order to help explain these issues. Rather than explaining these discrepancies through chance factors as the single gene models do the gene-culture theory explains cultural influence purely by indicating that handedness is not solely attributed to genetics but is also influenced by culture and the environment (particularly parental influence). The problem of discordant hand preferences in monozygotic twins is dealt with in this model as Laland et al. predict that monozygotic twins and dizygotic twins will have the same concordance rates and that cultural biases would be most likely to account for any differences. One problem with this theory may occur when addressing the point that not all children of two left-handed parents are themselves left-handed. If parental influence and genetics are both thought to influence handedness then it would appear very likely that a child of two left-handed parents who had their handedness determined both by culture and their parents would be left-handed but this is not the case in almost half of these incidences and thus this model does not clearly explain why this might happen. It could be, as Laland et al. indicate, that everyone has a genotype that predisposes them to right-handedness originally and this influence along with the general ‘right-handed world’ influence may override parental influence in some cases.

Therefore, the model proposed by Laland et al. (1995) incorporated both cultural and genetic factors and suggested that perhaps the strongest influence determining the hand preference of a child is parental handedness. Laland et al. proposed that this cultural influence might be stronger than any genetic influence proposed. This therefore complicates arguments that propose that handedness is purely genetic but adds additional scope to theories that state that there has to be some form of cultural or environmental influence. However, it is also a little bit vague in some details and it may be hard to measure the relative influence of these cultural factors in any meaningful way.

2.4.2. James and Orlebeke (2002)

A recent study by James and Orlebeke (2002) has challenged the view that handedness in twins can be explained through chance factors when debating the issue of discordant handedness in monozygotic pairs. James and Orlebeke indicated that there must be some form of environmental influence on handedness rather than a purely genetic explanation. They stated that twin’s probabilities of left-handedness differ and that they differ due to some factor(s) that correlate with their hand preference. Two factors that have been linked with left-handedness are birth weight and order of birth (in single born children and in twins). Left-handedness has often been associated with low birth weight in babies (e.g. Ross, Lipper & Auld, 1992) but this is proposed to be more common in single born babies rather than within twin pairs. A factor that has been suggested to influence hand preference in twins is birth order (e.g. Christian, Hunter, Evans & Standeford, 1979). James and Orlebeke (2002) examined the order of birth in six categories of (discordant) twins (MZ males; MZ females; MZ male-female; DZ males; DZ females and DZ male-female) and found that in each category the first-born was most likely to be the left-handed one. Out of 303 pairs of twins examined the left-handed twin was first born in 183 cases. James and Orlebeke also examined the birth weight of these twins but this data was not conclusive as the lighter twin was left-handed in 159 cases and the heavier twin was left-handed in 144 cases. James and Orlebeke concluded that left-handedness in twins did seem to be associated with birth order and thus this could account for discordant hand preference within twins with the first born being more likely to have a left-hand preference. However, with regards to birth weight, although there appeared to be no relationship in this study between the birth weight of the first born and second born twin and handedness it has been argued in previous studies (e.g. Orlebeke, van Baal, Boomsma & Neeleman, 1993) that the first born twin is more likely to be the heavier twin but in discordant twins this appears to be obscured (James & Orlebeke, 2002). James and Orlebeke state that the association of low birth weight and left-handedness is lower in discordant twins because the factor of birth order is stronger in determining handedness. It is concluded that these factors may give some indication as to what causes firstly left-handedness and more specifically, what causes discordant hand preference in monozygotic twins. James and Orlebeke (2002) report that each twin has to endure some form of hazard during their birth but that these individual hazards are very different depending on the birth order. It has been reported that the second born twin is more susceptible to hypoxia (a state of oxygen deficiency in the body which may cause impairment of function and in many cases death) whereas the first twin (who is thought to have a greater chance of left-handedness) is at more risk of physical trauma and this trauma is thought perhaps to be a determinant of left-handedness. James and Orlebeke concluded that genetics alone could not account for a complete explanation of handedness and that some environmental factor (such as birth order) would also have to play a part.

Thus, the gene-culture models of human handedness appear to fuse together the environmental and genetic ideas proposed by the previous models and arguments and indicate that genes and the environment both have a part to play in determining human handedness. There is some support for these models, but they have not been tested to the same extent as the purely genetic models (e.g. Annett, 1995)

The final argument to be considered when determining what causes human handedness is the pathological argument (which was briefly touched upon in the previous section).

2.5. Pathological Argument

Genetic views and environmental/cultural views of handedness have so far been considered. However, genetic handedness and environmentally determined handedness are often labelled under the title of natural handedness when comparing them to pathological handedness. Pathological handedness (and in most cases pathological left-handedness) is assumed to account for the excess of left-handers in groups such as epileptics, mental retardants or schizophrenics compared with those that are natural left-handers. Pathological left-handedness was defined by Coren (1992) as some form of "*injury or impairment that prevented a person from being right-handed*" p135. More specifically, pathological left-handedness is said to occur when an individual is left-hemisphere dominant (normally for speech) and has a natural right-hand preference. However, if some form of complication occurs in utero and damages the left-hemisphere in some way then dominance would be swapped over to the right hemisphere and the individual would become left-handed because of this dominance. Therefore a pathological left-hander is someone who, due to some form of brain damage, has had to switch to his or her other hemisphere and thus his or her hand preference has changed because of this. It is not only pathological left-handers that exist, pathological right-handers also exist but these individuals are much less common (see section on pathological right-handedness for a description of this).

Initial ideas of pathological left-handedness were far more extreme. In the early part of the 20th Century a quote describing pathological left-handedness was published in McClure's magazine (1913):

"*An adult brain, wrecked on the educated side by accident or disease, commonly never learns to do its work in the other, the victim remains crippled for the rest of his* *days. But a child, in whom the thinking area on the other side is still uncultivated, hurt on one side, can usually start over again with the other. A shift of this sort carries the body with it, and the child, instead of being permanently disabled, becomes left-handed*" (cited in Coren, 1992, p135).

More recently pathological left-handedness has been further researched and additional evidence, some of which supports and others that contradicts existing findings, has been found. Proposed causes of pathological handedness will be addressed and an examination of the reliability of these will be carried out.

2.5.1. Twins

It has been suggested that pathological left-handedness is often unusually high in twins (Bishop, 1990). One reason proposed for this is that twins undergo increased perinatal risks and therefore there is a higher chance of some form of damage in utero or during birth to either or both babies (e.g. lack of oxygen, difficult birth due to there being two babies). Bishop (1990) also added that a left-handed twin might be clumsier with their non-dominant hand and underachieve intellectually in some cases. It has also been found that in twins an estimated 22.5% of monozygotic twins have discordant hand preference and 19.3% of dizygotic twins were discordant for hand preference (Carter-Saltzman, Scarr, Barker & Katz, 1976). Adding to this, Christian et al. (1979) found that in pairs of discordant monozygotic twins, the left-handed twin was significantly more likely to be the first-born twin than the second born twin. However, Boklage (1981) found that there was a higher rate of left-handedness in the second born twin and argued that this was because the second twin has a more difficult birth than the first twin. This means the relationship between handedness and twins is unclear and yet to be fully determined.

2.5.2. Bakan

Bakan (1971) suggested that **all** left-handedness is pathological. That is, left-handedness arises due to an occurrence of underlying brain damage or some form of complication sustained around the time of birth. Bakan found that left-handers, on average, reported a higher rate of perinatal hazards than right-handers (these included caesarean section, breech birth and preterm birth). These perinatal hazards would presumably cause some form of damage (usually minor damage) to the left hemisphere in most cases and this would result in the switching of dominance from the now ‘damaged’ left hemisphere to the right hemisphere that would take on the role of the dominant hemisphere. In most people the left hemisphere is the dominant hemisphere (in both left- and right-handers) and the resulting damage to this hemisphere and the resulting dominance of the right hemisphere would mean that the individual would be left hand dominant. Bakan (1971) argues that damage to the left hemisphere is caused by hypoxia, where during birth there is a reduced oxygen supply to the brain and this can cause left hemisphere motor dysfunction. Bakan dismissed genetic theories of handedness arguing instead that it was a tendency to inherit difficult births or stressful pregnancies rather than inheriting a specific hand preference.

Bakan’s (1971) model is based around the following figures; approximately 15% of left-handers have right hemisphere dominance and 15% have bilateral dominance whereas less than 1% of the population have right hemisphere dominance and are right-handed. If there were no left hemisphere damage during birth then the child would be right-handed whereas any damage caused to the left hemisphere would result in pathological left-handedness. He also suggested that the incidence of left-handedness was significantly higher in first-born children or in children who were fourth born or later. Bakan termed this a high-risk parity factor and termed those who were either second or third born as a low-risk parity factors. Bakan suggested that first-born children would be subjected to the highest amount of birth trauma and/or complications that could increase the chance of some form of brain insult and thus increase the chance of the infant becoming a pathological left-hander. Bakan (1977) stated that the pathology that he refers to which is a possible cause of left-handedness is, in many cases, very minor and subtle. Another brief area that Bakan linked to left-handedness was the age of the mother when the child was born (maternal age).

Bakan, Dibb and Reed (1973) stated that children born to older mothers were more likely to be left-handed as first-born children to older mothers have a higher risk of birth stress. They found in their study that 17% of the left-handed sample consisted of first-born infants who were born to mothers aged 30 or more while only 8% of the right-handed sample were first-born infants to mothers of age 30 or more. McKeever, Suter and Rich (1995) found that more left-handed infants were born to older mothers (but this effect was only found in females). However, Bailey and McKeever (2004) used McKeever et al’s (1995) original sample and added more participants to it and this effect was only minimal. Bailey and McKeever proposed that when examining pathological left-handedness it might be easier to examine individuals with two right-handed parents as this will omit the possible confound that the offspring's left-handedness may be due to a genetic link with the parent(s) rather than due to pathological factors. Bailey and McKeever found that by restricting their sample to a group with two right-handed parents that the effects of maternal age and birth stress on handedness were not significant. Bailey and McKeever also found that Bakan's parity hypothesis was not supported in their study.

In addition, Bakan's theory has been criticised for being too extreme and suggesting that all cases of left-handedness are the result of brain damage. It has been argued that if all left-handedness were attributable to brain damage or birth complications at the time of birth that around 10% of the whole population would have been subjected to this damage – this would seem highly unlikely and would seem a very high number to be affected by brain damage (see Satz's argument below, section 2.5.3.). Also, another problem with Bakan's hypothesis is that in many studies concerning birth stress or trauma, the offspring themselves are asked to report how much and what kind of trauma they experienced, however, this could result in inaccurate reports in many cases and it is proposed that the mother would give a more accurate report. However, Coren (1992) made contact directly with mothers rather than the offspring and reported that there was an association between birth stress and handedness. Additionally, it is often not taken in to account when examining pathological left-handers what the hand preference of the parents is. In many cases the focus is on whether or not the infant suffered any trauma and if they did, and are left-handed, then the link is made that it is a case of pathological left-handedness in many cases. Indeed, Bailey and McKeever (2004) stated that very few studies collect handedness data from both parents and this could be a major flaw. The handedness of both parents should be examined before concluding that a child is a pathological left-hander, firstly because not all children that suffer some form of birth trauma are left-handed and secondly, not all left-handed children that experience birth trauma are necessarily pathological left-handers. If a child has two right-handed parents and suffers birth trauma and is left-handed then it is possible that this child is a pathological left-hander (although some children of two right-handed parents who do not suffer birth trauma are still left-handed). However, if a child has at least one left-handed parent and does suffer some form of birth complication then it is more difficult to determine if the left-handedness is due to the pathological influence or the genetic influence of one (or both) parent(s). If both parents are left-handed then there is an even stronger case that the left-handedness of the child would be influenced by genetic factors. A final factor to be considered is that Bakan does not take in to consideration any sex differences in pathological left-handedness caused by birth trauma. He attributes all left-handedness to birth trauma but does not state if one group (either males or females) is more likely to experience this over the other group. For example, McKeever et al. (1995) found that the high-risk parity factor (increased chance of left-handedness in first born child or fourth or later born child) was linked to females but not males while Searleman, Coren and Porac (1989) and Leviton and Kilty (1976) only found the effect in male children and the latter also found that the frequency of left-handedness increases as the birth order (of fourth offspring and above) increases. However, Hicks, Pellegrini and Evans (1978) failed to find the effect at all. Hubbard (1971) found the opposite effect that left-handedness increased in births with reduced stress or trauma and Schwartz (1977) found no relationship between handedness and birth stress. Thus there seems to be much controversy if firstly, the effect is there at all and secondly, if it is, is it more common in one sex or are there no sex differences?

Hopkins, Dahl and Pilcher (2000) suggest another problem related to these findings. They argue that although it was found in many cases that parity might be a factor in determining left-handedness, issues that are somehow connected with society and with the economy might confound it. Firstly, it is suggested that those with low incomes could have a poorer diet, higher rates of pregnancy and a lower level of prenatal care that could potentially contribute to pathologies connected with birth stresses and traumas (Bakan, 1977; Searleman et al. 1989) and thus this has to be taken into account when examining the participant group in each study as it may be a contributing factor. It could be argued that Bakan (1977) responds to these criticisms by stating that socio-economic status does play a role in the findings. He argued that one main reason why Hubbard (1971) did not find any differences was because he sampled students from a high paying, private university whereas he sampled his participants from state universities. Bakan stated that there is a clear relationship between birth trauma and socio-economic factors including health of the mother and medical care and therefore the results can differ according to the sample that they were taken from.

Bakan (1977) added that the sampling method used could also be responsible for Schwartz's non-supportive results. The participants used in Schwartz's study were sampled in Canada where it was alleged the mortality rate was 40 per 1000 in the 1950s (when most of the participants were born) this is contrasted with a mortality rate of 27 per 1000 in the USA at the same time (where Bakan conducted his research). Bakan therefore proposed that infant mortality occurred most when there was some form of birth risk or stress. Therefore the number of left-handers represented in Schwartz's study may be lower as a high number of pathological left-handers may have died during birth. Alternatively if there was some form of damage during birth that resulted in, for example, mental retardation then it would be unlikely that these individuals would be represented among the university sample that Schwartz took his sample from.

Finally, Bakan proposed that Schwartz took a very extreme definition of what is meant by 'pathological'. He states that Schwartz "argues that since left-handers are found in the university, this decreases the probability that their left-handedness is based on a pathological event" (Bakan, 1977, p838). Bakan stated that his own definition of pathological left-handedness, however, stated that it could be a very mild or subtle effect and would not effect the individual in such a way that they could not attend university unlike the strong definition given by Schwartz. With respect to the association between maternal age and left-handedness in children varying results have been found. Support for Bakan et al's. (1973) argument came from Coren and Searleman (1990) who found that there was a link between maternal age and handedness in that older mothers had more left-handed children. Other researchers only partially supported this finding. Smart, Jeffrey and Richards (1980) only found the link between maternal age and handedness in first-born children (which may link to the parity factors rather than that of maternal age) while McKeever et al. (1995) found this effect only in females (this was also the case for their research on parity). Peters and Perry (1991) did not find any relationship between maternal age and handedness while McManus (1981) did not find any relationship between either birth stress and handedness or maternal age and handedness and concluded that the development of left-handedness in the population is due to genetics and not pathology of any kind. Hopkins et al. (2000) concluded that although parity and maternal age may be connected in some way to pathology it is not always clear what that role actually is. A final problem with Bakan's work is that he states that all left-handers are pathological; he does not allow any scope at all for natural left-handedness either influenced by genetic factors or environmental/cultural factors (see sections 2.2. and 2.3. for these arguments).

In summary, it is clear that there are no convincing reasons to accept Bakan's contention that **all** left-handers are pathological, although it is clear that a strong link between left-handedness and pathology does exist. This will be explored in the next section.

2.5.3. Satz

Satz, Baymur and Van der Vlugt (1979) and Soper and Satz (1984), unlike Bakan, proposed that only part of the left-handed population was pathological. They hypothesised that at least two groups of left-handers exist in the population. The first of these groups defined by Satz (1972; 1973) is pathological left-handers. Satz (1972) predicts that around 20% of natural right-handers develop as pathological left-handers because of hemispheric damage. Satz stated that pathological left-handers consisted of those who had experienced some form of brain damage (often during birth) to the left hemisphere of the brain and had until then developed as right-handers but this damage forced the dominant hemisphere to switch to the right hemisphere and thus resulted in a left hand preference and right hemisphere language dominance in most cases. This is similar to what Bakan (e.g. 1971) proposed. Soper and Satz (1984) said that not all cases of pathological left-handedness involved a shift in the dominant hemisphere for language. They stated that the important factor in this is the actual timing of the damage to the brain and stated that the earlier the damage then the higher the likelihood of a shift in cerebral speech dominance. Satz et al. (1979) add that any damage in the period of time from pre-natal growth until around the first year of life is the most vulnerable time where the transfer of speech from one hemisphere to the other is most likely. Damage outside this time period would be less likely to result in a switch of the dominant hemisphere for speech control. Satz et al. (1979) also stated that if this damage can occur to the left hemisphere then it must also occur to the right hemisphere in some cases and thus pathological right-handers must also exist (see section 2.5.7.). This factor is often overlooked in studies that only use right-handed participants. Satz (1972) proposed that much less of the right-handed population would be pathological and that the remainder of the population had their hand preference determined by either genetics or the environment. However, Satz (1973) stated that minor damage to one hemisphere of the brain could, in many cases, lead to an increase in left-handedness and birth trauma is only one way that the damage could have occurred. Satz (1972) stated that birth stress is only one of a few suggested factors that the concept of pathological left-handedness comes from (other concepts include increased incidence of left-handedness in twins, increased left-handedness in epileptics and the increased incidence of left-handedness in the mentally ill). Satz, Orsini, Saslow and Henry (1985) stated that a high number of the left-handed population could be accounted for through the pathological representation of left-handers in clinical populations. Soper and Satz (1984) found that the extent of the brain injury could alter the level of left-handedness in many clinical populations.

The second group of left-handers proposed by Satz (e.g. 1973) was ‘natural left-handers’. This group comprised of those whose hand preference was determined by either genetic and/or environmental factors and who had suffered no form of brain insult or injury. Satz (1973) proposed that the incidence of natural left-handers in the population was about 8%. Thus comprising the majority of left-handed individuals. In relation to cerebral speech dominance the majority of this group would be left hemisphere dominant (around 70%) and the remainder of the group would be split between bilateral dominance and right hemisphere dominance. Satz et al. (1979) stated that very few ‘normal’ left-handers have speech that is controlled by the right hemisphere whereas most pathological left-handers have speech that is controlled by the right hemisphere. He predicted that left-handers who had experienced some form of early brain damage would be three times more likely to have speech controlled by the right hemisphere than left-handers who had not experienced any form of brain damage. Soper and Satz (1984) reviewed the model of pathological handedness and proposed an additional category. They added the third group ‘ambiguous handedness’ which resulted in the existence of pathological left-handedness, pathological right-handedness and ambiguous handedness (they did state that this group would be very low and would be comprised of those without a strong left or right hand preference). Soper and Satz (1984) proposed that ambiguous handedness occurred through some form of bilateral damage and thus there would be no clear dominance of either hand.

Satz (1973) therefore concluded that left-handedness could overall be classified in to two main groups; the first is linked to genetic factors while the second is linked to pathological factors. He states that the pathological group is the result of either some form of damage related to birth or development or to some form of childhood problem and adds that within this group physical and psychological problems are often observed. Thus, the view of Satz is similar in some ways to Bakan in that he attributes pathological left-handedness is down to brain damage of some form. However, Satz’s viewpoint also differs greatly in a number of ways. Firstly, Bakan assumes that all left-handers are pathological left-handers whereas Satz states that only a select group are pathological left-handers and the remaining left-handers have been influenced by genetic or environmental factors. Secondly, Bakan assumes that all damage to the hemispheres occurs during birth or is related to birth in some form (for example, maternal age, birth trauma and birth order). Whereas, Satz states that although the highest chance of damage resulting in pathological handedness is at or around the time of birth, damage can occur afterwards but have different consequences such as cerebral control does not always switch if the individual suffers damage later than the first year of life. Satz (1973) states that Bakan is unclear in much of his reasoning as to why the incidence of left-handedness is altered if an individual experiences early brain injury. Satz also considers a link between pathological left-handedness and various clinical populations, as there is a high proportion of left-handedness within certain groups. Bakan does not consider independent groups and concluded that all left-handers are pathological left-handers due to some form of birth related incident. Overall, the work of Satz supports the contention of the present study that assumes some adaptive component to handedness, at least for a larger proportion of left-handed individuals.

2.5.4. Crow

Crow’s work relates to pathology but does not focus completely on handedness; rather, the focus is on language and cerebral lateralisation (see chapter 1 for a review of this). However, the main finding of Crow’s research that involves handedness is connected to schizophrenia. Crow states that schizophrenic patients show a significant excess of mixed-handedness or left-handedness and a shift away from right hand dominance. Crow (e.g. 1997) explains the symptoms of schizophrenia through dysfunction of lateralisation and states that therefore those with a non-right hand preference may be more susceptible to this. One reason for this could be related to pathology. (For a more detailed review see Crow, 1997). This work does not directly inform the investigation of the mechanism for determining hand preference in the present study, but does relate to cerebral lateralisation discussed earlier (see Chapter 1, section 1.6.).

2.5.5. Bishop

Bishop (1984) estimated that one on every twenty left-handers is a pathological left-hander. This means that out of the whole left-handed population (pathological and natural) Bishop proposes that 5% are pathological left-handers. Again this has

important implications for the present study, as it supports the notion that the vast majority of left-handers are probably not brain damaged and can give us an insight into why left-handedness has evolved. Bishop (1990) proposed a number of reasons for the incidence of pathological left-handedness. Firstly she stated that one possible indicator was familial sinistrality. Familial sinistrality is one of the most widely used indexes as categorising people as pathological or non-pathological left-handers. Briggs and Nebes (1976) stated that if a person was left-handed but had no close left-handed relatives then it was unlikely that their left-handedness could be attributed to genetic influences and should be attributed to pathological factors. However, Bishop (1990) stated that this was not a strong argument and proposed that the genetic argument of handedness in itself is a weak argument. Bishop added that if a left-handed person did not have any close relatives that this did not mean that their hand preference could not still be influenced in some way by either genetic factors or by cultural or environmental influences. Bishop cites Annett's (1985) figures that there is only a 24% chance of having a left-handed child if one parent is left-handed and only a 45% chance of having a left-handed child if both parents are left-handed. This highlights that genetic factors cannot be completely dismissed when considering hand preference but could also be linked to chance factors within genetic theories.
Bishop (1984) stated that around 30% of left-handers with poor right hand skill are pathological left-handers. She added that all left-handers are not pathological but that hand preference can be affected in a number of ways. She concluded that in the incidence of hand preference being altered due to brain damage the effects of this could often be subtle and unnoticeable.

However, Bishop (1990) adds that one problem with left-handers could be that they are susceptible to a variety of conditions rather than these conditions causing them to be left-handed. These conditions include epilepsy, mental impairment, autism and developmental dyslexia, developmental disorders of speech and language (such as stuttering). This adds to the pathological argument that there are a higher number of left-handers in various clinical groups, but doesn't argue against the position of most left-handers being non-pathological (or natural).

2.5.6. Pathological right-handedness

A Pathological right-hander is defined as a natural left-hander who becomes right-handed due to some form of damage to the right hemisphere (Satz et al., 1979). The proportion of pathological right-handers is much lower than the number of pathological left-handers and there are a number of proposed reasons for this. Firstly, the left hemisphere, according to Coren (1992), appears to be more vulnerable than the right hemisphere to injury or damage. Therefore, if this is the case then the left hemisphere will be more easily damaged and will result in right hemisphere dominance and a higher incidence of pathological left-handers. Harris and Carlson (1988) stated that paralysis of the right side of the body due to injury to the left side of the brain may be up to four times more likely than paralysis to the left side of the body due to right hemisphere injury. They conclude that if this is the case then pathological left-handers are four times more likely to be found in the population than pathological right-handers. Harris and Carlson (1988) also back this up by stating that the blood supply to the left hemisphere is lower in volume than the right and thus the left hemisphere would be deprived of oxygen more quickly than the right, this is particularly the case as they add that the left hemisphere needs more energy to function than the right hemisphere does. Bishop (1990) also supports the view that the left hemisphere is more vulnerable than the right to starvation of oxygen and thus she states that there is a higher chance of damage and thus a higher chance of pathological left-handedness. Satz (1972) states that as it is assumed that there are many more right-handers to begin with than left-handers and when damage occurs, both hemispheres are equally as likely to be affected, then the pathological left-handers in the population will outnumber the pathological right handers (because most people don’t have their right hemisphere as the dominant hemisphere and thus any form of minor damage to this will go unnoticed in many cases as it will not affect speech or handedness). It may be the case that this helps to explain why there are excess left-handers in certain groups that may have been subjected to brain trauma (such as in metal retardants and epileptics where left-handedness is thought to be twice as high as in that of the ‘normal’ population). Corballis and Morgan (1978) introduced a similar theme to the work of Geschwind and Galaburda (1985a) (see section 2.5.9.) and proposed that there is a difference between the growth rates of the cerebral hemispheres of the brain during pregnancy. They state that the right hemisphere develops quicker and earlier than the left hemisphere but whereas Geschwind and Galaburda state that excess levels of testosterone stunt the growth of the left hemisphere and thus the right hemisphere becomes dominant, Corballis and Morgan propose that the left hemisphere catches up in its growth and continues to develop after the right hemisphere has stopped developing. However, Corballis and Morgan focus on the fact that because the left hemisphere develops over a longer period of time than the right hemisphere it is more vulnerable to damage over the entire period of development. This means that there is a greater chance that the left hemisphere will be damaged than the right hemisphere and thus this could cause an increase in the number of pathological left-handers over the number of pathological right-handers.

However, one problem with pathological right-handedness is that it not widely considered within literature and there is no clear way of measuring it. Most pathological studies (e.g. Bakan, 1971) focus upon left-handers and question them about various kinds of birth complications and stress but there is very little emphasis on birth complications relating to right-handers and thus the pathological right-handed group may be a neglected population in many studies.

2.5.7. Coren

Coren (1992) defined pathological left-handedness as an impairment that prevents a person from becoming right-handed. Coren (1992) proposed that the number of pathological left-handers was very high (around 50% of the entire left-handed population according to Coren & Searleman, 1990) but did not believe that all left-handedness was pathological. Coren believed that left-handedness might be the result, in many cases; of either some form of birth stress or by damage to the brain resulting in some form of psychological illness. Coren (1992) conducted a series of experimental studies within groups with psychological illnesses (such as epilepsy and schizophrenia). He examined the proportion of left-handers within these groups and found that, in general, the incidence of left-handers was higher. Coren concluded that these findings might lead to left-handedness being regarded as abnormal but in many cases there is no visible sign of this. Another experiment by Coren, Searleman and Porac (1982) examined the link between handedness and birth history. They interviewed a number of mothers and asked them if their children had experienced any form of birth trauma. Coren et al*'s* definition of birth trauma included premature birth, prolonged labour, breathing difficulties and breech birth. They found that when the mothers reported at least one of the birth traumas that there was an increase in probability that the child would be left-handed. Coren et al. also found that this effect was greater in males than in females. They explained this by stating that males are more vulnerable to brain damage than females. Also, Coren et al. found that there was a difference between the sexes for the likelihood of left-handedness and different birth traumas. For example, they found that males were more likely to be left-handed if they had been subjected to breech delivery, low birth weight, prolonged labour, caesarean births or multiple births while females were more likely to be left-handed if they had experienced premature birth, breathing difficulties, prolonged labour or multiple births. Ross et al. (1992) supported the link between left-handedness and low birth weight. They found that in their sample of 4-year-old children who had been divided in to two groups (a full term group and a group that consisted of premature children) that 80% of the full term group were right-handed while only 63% of the premature group had a right hand preference. O'Callaghan, Tudehope, Dugdale, Mohey, Burns and Cook (1987) studied low birth weight babies (defined as those who weighed less than 1000 grams) and found that aged 4 that 21 out the 39 infants sampled had a left-hand preference.

However, Harris and Carlson (1988) state that birth complications cannot be the only reason for the occurrence of left-handedness. They stated that if some cases of left-handedness are linked to incidences of brain damage then there must be some symptoms that can be readily identified in order to spot the injury. With regards to the proposition that left-handedness is associated with neurological injuries during birth or various forms of pregnancy complications, Coren (1990) anticipated that older mothers would be more likely than younger mothers to have left-handed children. Coren added the number of left-handed offspring would increase as the mothers' age increased. Coren (1990) tested this hypothesis by conducting a study that involved testing a group of college students' hand preferences and asking how old their mothers were at the time of the students' births. Coren found that as the age of the mother increased the chance of her having a left-handed child also increased. Coren firstly examined a group of 17 to 24 year old mothers and examined the hand preferences of their offspring (this was used as a comparison group as this age group is thought of as the 'safest' in which to give birth) in order to get a base line rate of handedness. From this Coren found that the children of mothers in the 35 to 39 years age category were 69% more likely to be left-handed than the comparison group and the children of mothers aged 40 and above were 128% more likely to be left-handed than the comparison group. This supports the view that firstly maternal age does have an influence on the hand preference of offspring and more specifically that birth complications are linked to pathology and may cause left-handedness in some cases. Finally, Coren does not conclude that all left-handedness is pathological in the way that Bakan does. Coren proposes that pathology can be something that in many cases goes unnoticed but in other cases is a major issue and states that pathological conditions such as birth trauma or certain abnormalities such as epilepsy can be associated with left-handedness.

Although most of the literature suggests that pathological left-handedness can be explained through damage to the left hemisphere often at birth, a number of additional reasons for pathological left-handedness have been proposed. The first is familial sinistrality. Briggs and Nebes (1976) stated that a left-handed person who has no close left-handed relatives could be considered to be a pathological left-hander, as it there would appear to be a lack of genetic influence. However, Bishop (1990) states that although this is one of the most often used indicators of pathology that it is unreliable. She states that there is an 8% chance of two right-handed parents having a left-handed child along with there only being a 24% chance of one left-handed parent having a left-handed child and thus genetics cannot be completely ruled out (Annett, 1985). Also, if the genetic models of Annett and McManus are supported then an element of hand preference is due to chance and thus, in Annett's case, if the offspring of two right-handed parents was left-handed then this could be because the parents' genotype was heterozygous (rs+-) and thus both parents passed on the recessive gene (rs -) to the offspring thus resulting in the genotype rs-- and therefore the individual's hand preference and cerebral dominance would be determined by chance. Thus the familial sinistrality argument appears to be weak. Another indicator of possible pathological left-handedness is clumsiness of the non-preferred hand. Bishop (1990) stated that individuals (either left-handers or right-handers) who have experienced some form of brain damage would often display poor use of the non-dominant hand. Thus she attributes that poor use of the non-dominant hand is a potential indicator of pathological handedness. However, this idea would again seem weak in its argument. Having poor use of the non-preferred hand does not necessarily mean that the individual has experienced brain damage especially with respect to those with right-hand preferences who are clumsy with or have poor skill in the left hand. Individuals that have strong right-hand preferences often display very little skill with their left hands mainly because they have very little need to use the left hand as most activities are performed with the right. However, in the case of left-handers, there is often much more call for them to use their right hands as they live in a world where most things are designed in this way.

2.5.8. Geschwind and Galaburda

Geschwind and Galaburda's theory is linked to pathological left-handedness but more accurately is a biological explanation of left-handedness. The theory proposes that an imbalance of testosterone in the foetus affects left hemisphere growth and causes a shift to non-right-handedness due to the more developed right hemisphere (and thus the more dominant hemisphere). Geschwind and Galaburda developed their theory around six main points. These were; left-handedness is more common in males than females; developmental disorders are more common in males than females and also in left-handers than right-handers; spatial skills of males exceed the spatial skills of females (but the verbal skills of females exceed those of males). They also examined the finding that left-handers have superior right hemisphere functions and lastly that immune disorders are more common in left-handedness. Geschwind and Galaburda (1985a, b, c) stated that the left hemisphere is the dominant hemisphere that controls handedness and language and similarly to Bakan, they state that left-handedness is, in effect, pathological. Geschwind and Galaburda propose that an imbalance of testosterone in the womb can cause both left-handedness and birth complications. The simplest explanation of the model is that the growth of the left hemisphere is slowed down or retarded in some way by an excess flooding of testosterone in the womb. Thus, when this slowing of the left hemisphere is occurring the corresponding parts of the right hemisphere increase in their development and growth. This increased growth and dominance of the right hemisphere would suppress the left hemisphere functions and promote right hemisphere functions. Because the role of pre-natal testosterone is central to the theory, Geschwind and Galaburda therefore propose that the incidence of left-handedness is often seen to be higher in males as males generally experience higher levels of testosterone and thus will show a greater shift to the right hemisphere and will have superior right hemisphere skills and lean towards left-handedness. However, females also experience this effect. All females are exposed to some level of testosterone but those who are exposed to excess levels will experience, according to Geschwind and Galaburda, slow growth of the left hemisphere and therefore an increased likelihood of left-handedness.

Some researchers have reported a lack of support for Geschwind and Galaburda's (1985) findings. For example, Grimshaw, Bryden and Finegan (1995) examined the level of pre-natal testosterone in the amniotic fluid of babies during the second trimester and related this to the lateralisation of speech and handedness when the child was 10 years old. They found that girls who had higher levels of pre-natal testosterone were more strongly right-handed and had strong left hemisphere dominance for speech. Boys with higher levels of testosterone were found to have stronger right hemisphere specialization for the recognition of emotion (they also controlled for birth stress and genetic factors during this study). Witelson (1991) found that pre-natal testosterone relates to stronger lateralisation of function. A few problems exist within this theory. Noorozian, Lotfi, Gassemzadeh, Emami and Mehrabi (2002) pointed out that there is a concern with the theory that Geschwind and Galaburda predict that if there is a shift due to the slow growth of the left hemisphere that language and handedness are both predicted to shift. Noorozian et al. argue that this disregards evidence that women are less lateralised than men for language functions. Also, Rosen, Sherman and Galaburda (1991) argue that a brain that is symmetrical has a larger right hemisphere than a brain that is asymmetrical and thus this suggests that in many cases there is rapid growth of the right hemisphere rather than a slowing of the growth of the left hemisphere in symmetrical brains. Grimshaw et al. (1995) propose that little evidence on the relationship between pre-natal testosterone and cerebral lateralisation exists. Bryden, McManus and Bulman-Fleming (1994) stated that the Geschwind and Galaburda model was not well supported by recent data. They stated that there are inconsistencies between handedness and some of the immune disorders that are predicted by the model. They state that some of the disorders such as allergies and asthma are linked to a higher increase in left-handers while other disorders show that right-handers are more at risk (such as arthritis).

There are three main theories that have been linked with the role of pre-natal testosterone and a link towards individual differences in lateralisation. These will be briefly outlined.

1) The first theory is the sexual differentiation theory: this states that there is a link between pre-natal testosterone and cerebral lateralisation. Annett (1985) has found that there are higher rates of left-handedness in males than females (although in some cases females have a stronger left-hand preference than males) and Bryden (1988) found that women are less lateralized than men. Researchers (such as Levy & Gur, 1980) proposed that it was possible that there is an association between a high level of pre-natal testosterone and a higher masculine cohort of left-handers.

2) Geschwind and Galaburda’s (1985) theory of left-handedness. This theory states that left-handedness is partly genetic but that other predictors of left-handedness are associated with pre-natal testosterone (see section above for an extended explanation of this). From this Geschwind and Galaburda (1985) proposed that pre-natal testosterone slowed down the growth of specific areas of the left hemisphere during critical periods of brain development. Geschwind and Galaburda predict that this pre-natal testosterone also influences the immune system and thus link this

effect to the higher level of immune disorders among left-handers. At the centre of Geschwind and Galaburda's theory is the relationship between pre-natal testosterone and cerebral lateralisation and more specifically, the relationship between handedness, lateralisation and a number of disorders that include developmental disorders and immune disorders.

3) The Callosal hypothesis - The main focus of this hypothesis is that cerebral lateralisation does not result from any specific developmental effects in either hemisphere but instead results from the pruning of Callosal axons during foetal development. (See Witelson (1991) for additional details of this hypothesis).
Overall, it appears that testosterone does probably have an important influence in the pre-natal organisation of lateralised differences, although the direct role it plays in handedness is unclear. However, it may help our to understanding of sex differences and lateralised behaviours other than handedness (see Chapter 1).

2.5.9. Harris and Carlson

Harris and Carlson (1988) state that most left-handedness is unlikely to be pathological but state that the definition of pathological handedness differs across researchers and that the findings can be summarised into two main models of pathological left-handedness. The first is what they refer to as the 'Two Type Model' – in this model they suggest that only some left-handedness is pathological. The view is that surplus left-handers are found in clinical populations (particularly epileptics and mental retardants) but it is considered that these people are actually genotypic right-handers who are left-handed due to injury to the left hemisphere. These people are said to have pathological left-handedness. This is '*an abnormal condition initiated by injury or disease processes leading to certain structural and functional changes in the left hemisphere*' (Harris & Carlson, 1988, p293). They suggest, however, that left-handers in the general population are presumed to be neurologically normal. Satz (1972) previously proposed this basic model. He stated that brain injury is just as likely to happen to the right hemisphere as it is to the left-hemisphere. He also held the view that left-hemisphere lesions lead to more switched handedness as there are many more right-handed people in the population and thus, when early brain injury occurs and causes a change in hand dominance, the results will more often be pathological left-handedness rather than pathological right-handedness. Satz et al. (1985) therefore suggested that pathological factors can account for some of the elevated incidences of left-handedness among clinical populations as well as some left-handedness among the population in general, but he states that the remaining left-handers in the population are ‘natural’ and their left-handedness is genetic in origin. The other model proposed by Harris and Carlson (1988) is the ‘One-Type Model’; in this model it is assumed that all left-handedness is pathological. This view considers the suggestion that all left-handers are actually genotypic right-handers. Thus, even left-handers who do not show any form of psychological dysfunction are thought to have some form of very mild left cerebral dysfunction and left-handedness is the only symptom. The originator of this type of model was Bakan (1971) who, as previously stated, suggested that left-handedness was a condition that resulted form some form of birth stress. The ‘brain damage’ theory of left-handedness assumes that right-handedness and left cerebral dominance are characteristics of humans. If this were the case then left-handedness would be an abnormality due to cerebral impairment (Annett, 2002).

2.5.10. Pathological Conclusion

This section argues that there is sufficient evidence to suggest that some left-handedness appears to be pathological. Very few researchers would support the view that all left-handedness is pathological but many would support that a proportion of left-handedness has pathological origins. Schwartz (1977) concluded that one main problem with defining and testing for pathological handedness is that in many studies the methods of measuring and categorising handedness have been unreliable. Some studies have used the writing hand as a valid measurement (e.g. Bakan, 1971) while others have asked participants to report their own hand preference (e.g. Hubbard, 1971). Schwartz, however, used a handedness questionnaire (that of Crovitz and Zener) to determine hand preference.

One major problem with Bakan’s work is that, as previously stated, he proposed that all left-handers were pathological. If this were the case then firstly, there would not be a cause for genetic arguments of left-handedness or of cultural or environmental influence. The theory has been criticised for being too extreme and it does not account for the fact that in general, left-handers do not show any deficits in cognitive performances or inferior motor proficiency. However, Satz (1973) proposed that there are both pathological and natural left-handers in the population and this view seems to be better supported. One final problem with examining handedness and birth stress is that the samples often need to be very large and in many cases consist of samples that have been combined in order to have a large enough sample to find an effect but in most cases the findings are very weak.

Some researchers do not support the existence of pathological left-handedness. McManus (1983) suggests that there is no such thing as pathological left-handedness and that no piece of literature exists that shows any proof of this. He suggests that damage to one hemisphere may involve switching to the other hemisphere in very extreme cases but that this is not always essential especially if the damage is subtle.

2.6. Pathology v Genetics

Differences may exist between left and right-handers for certain tasks but these do not always consist of an inferior performance by the left-hander, often a superior performance is achieved on tasks by left-handers (e.g. Halpern, Haviland & Killian, 1998). This points to the suggestion that not all left-handers are pathological left-handers because if they were it would be expected that they would constantly perform poorer than their right-handed counterparts. Left-handedness may sometimes be due to pathology but overall, the majority of left-handers are part of the ‘normal’ population and left-handedness may just arise from a genetic variation. Bishop (1990) states that it is not reasonable to regard all left-handers as pathological. She does; however, state that hand preference can be affected by underlying neurological impairment that can raise the proportion of left-handers in the population. Pathological left-handedness is not solely attributed to those with obvious signs of brain damage, according to Bishop (1990) it can occur when there is no hard neurological evidence of this. Bishop estimates that around one in every twenty left-handers is a pathological left-hander but better ways of distinguishing this need to be developed. Among the indicators cited by Bishop to determine pathological left-handedness are, familial sinistrality (but she states that this is often misclassified), strength of handedness and poor motor skill on one side. Annett (2002) states a number of reasons why the hypothesis that atypical asymmetries are due to brain pathology is highly unlikely. These include the fact that left-handedness occurs among non-human primates. The pathology view proposes that the natural primate variation for handedness was lost in the transition from ape-like to human-like ancestors and then was introduced in humans as an ‘abnormal’ variation. Annett states that it is much simpler to assume continuity. Annett (1985) and McManus

(1981) in their models state that chance factors are important in determining left-handedness in many cases but state that birth risk does not have an important role to play in determining handedness. Annett (2002) also proposes that left-handers are often found among those who have high achievements in, amongst other things, the arts, music and sport and it seems problematic to link these individuals to having some form of early brain damage. Bakan et al. (1973) proposed that pregnancy and birth risk factors have a high influence in determining handedness (particularly left-handedness) and this is supported by McKeever et al. (1995) who propose that up to 30% of left-handed females may be left-handed because if pregnancy and birth risk factors. However, it seems to be that many researchers have found specific sex effects linking to differences between left-handedness and birth risk factors (e.g. Leviton & Kilty, 1976; McKeever et al., 1995). Thus, Bailey and McKeever (2004) stated that in order to take sex differences in to account current genetic models would have to examine and acknowledge the possible role of birth stress and it’s link to left-handed females and the possible genetic effect(s) within this. Bailey and McKeever (2004) conclude by stating that pathological theories of left-handedness do not compromise genetic theories of handedness and report that their findings are consistent with genetic arguments rather than the pathological ones.

Therefore, it seems that according to these views, genetics play a major part in determining our handedness, but if it was only genetics that determined our handedness then no left-handed parents would have right-handed children and no right handed parents would have left handed children. This, however, is known not to be the case. Therefore, evidence seems to suggest that to determine handedness firstly there is some form of genetic basis to this but it is subject to change by the environment in which the individual is raised and handedness will be determined by the external stimuli an individual receives. Also, in some cases the occurrence of pathological left-handedness does seem to occur but not in the proportions that Bakan proposes (i.e. that all left-handedness is pathological). In some cases when some form of damage does occur to the left hemisphere then it is possible that there might be some form of switching between the hemispheres resulting in, in some cases, a switch to the hand preference. This would also apply to a switch in the opposite direction. However, in almost all cases this effect will not be noticed and also the hand preference would not have been known in many cases as to ascertain whether there had been any form of switching in the hand preference. However, a link could be made to Hepper et al’s. (1991; 1998) studies as to consider whether the thumb sucking observed in utero remained constant after some form of birth stress or if it switched due to pathological factors. It therefore seems probable that genetics and the environment can influence handedness but in other cases, a certain percentage of the population are pathological left-handers.

2.7. Implications for current research

Implications for the current program of research can be derived from many of the theories covered within this chapter. The initial research idea involved devising an appropriate way to measure handedness (see chapter 3 for details) and this could only be done in the context of these theories (e.g. is hand skill or hand preference the major consideration).

Annett's right shift theory perhaps is the most salient theory relating to the behaviour of left- and right-handers. Annett (2002) states that there are no clear cognitive or performance differences between left- and right-handers as a population. She states that the performances of left-handers are no more inferior on a series of tasks than the performance of right-handers. Thus the implications of Annett's findings with relation to the current research are that there should be no difference in the behaviour of left- and right-handers on the solving of the novel problem (either in the way that they think or tackle it or in the end result (such as timing and number of moves). As the problem-solving task is not a task of hand skill then Annett's findings of hand skill cannot be directly applied to this. However, if differences are found between left- and right-handers on the problem solving task then Annett does not clearly state why this might be the case. The right shift theory states the group that should be most advantaged are heterozygotes (those with the genotype RS+-) as they do not have the pressure that RS++ homozygotes do on the left hemisphere and can use the right hemisphere more to an extent. However, one problem with this is that it is difficult to tell in many cases whether a right-hander would have the RS++ genotype or the RS+- genotype and thus predictions could not be made on this basis. Also, some left-handers would also have the RS+- genotype and thus may potentially be differently lateralised from those left-handers with the RS- - genotype but again there is no clear way of determining these genotypes. Also, in relation to this, Annett (1985) predicts that there would be deficits on the extreme ends of the left- and right-handedness continuum. Annett links this to her finding that those who tend to perform better on tests such as IQ tests tend to be either weakly left-handed or left-handed in skill. Thus, in order to explore this finding, sub-groups of left- and right-handers, ranging from strong to weak, can be examined on the current problem-solving task. A series of researchers (such as Bishop, 1990) state that the performances of left-handers will be worse than those of right-handers (often due to some form of pathology). If this were the case then it would be expected that right-handers would perform better on the novel problem-solving task than left-handers (Chapter 4).

Annett does not support the pathological view that left-handers are inferior to right-handers on performance due to them being 'brain damaged' in some form. Annett does acknowledge that some left-handedness must be pathological in origin but links most pathological left-handedness to groups who have perhaps experienced a shift in handedness due to trauma of some form and thus are part of a clinical group. Although Annett states that there are no differences between left- and right-handers, other researchers have found differences between these groups. McManus and Mascie-Taylor (1983) found that there was an advantage of right-handedness in IQ scores but this difference was very small. Annett concludes by stating that there would be no expected difference between a group of 'normal' left-handers and a group of 'normal' right-handers. However, one major barrier to testing this, is that there is no reliable way of determining normal vs. pathological left-handers.

Bakan (e.g. 1971) stated that all left-handers are pathological and proposed that pathological left-handers would be inferior to right-handers. However, Satz (e.g. 1973) stated that not all left-handers were pathological left-handers and that a proportion of 'natural' left-handers existed that were determined by either genetics or the environment. Satz's findings propose that 'natural' left-handers would be expected to perform no differently than 'natural' right-handers. However, the group of pathological left-handers would be expected to be inferior to both the group of 'natural' left-handers and right-handers in general. Again, this pathological approach poses problems to relate to the current research. Pathological handedness is most commonly defined as a switch from one hemisphere to the other causing a switch in hand preference and is most often attributed to some form of damage to the brain that results from birth stress or trauma. If there are existing differences between pathological and natural left-handers and a difference between them and right-handers then this cannot be clearly examined during the course of the current experiments as there is no clear way of establishing whether a person is a pathological left-hander or a 'natural' left-hander. Also, the existence of pathological right-handedness is not clearly accounted for and no assumption is made as to whether there would be an expected difference between pathological right-handers and ‘natural’ right-handers and whether pathological right-handers would be expected to be superior or inferior in performance compared to ‘natural’ left-handers. Again the identification of pathological right-handers would be impossible to establish and this would be even more difficult than identifying pathological left-handers as there is very little literature that recognises the existence of pathological right-handers and thus almost all right-handers are assumed to be natural right-handers. It would thus be very difficult to draw any conclusions with regards to pathological handedness relating to the current experiments given the difficulty of identifying and defining these individuals. One last factor relating to the existence of pathological right-handedness that has to be considered. If all right-handers are considered to be natural right-handers but there are a proportion of pathological right-handers within this group then it may cause different results or effects within this group due to the possible difference in performance between pathological and natural right-handers. Thus, the existences of pathological right-handers have to be considered within a group and are as important as the existence of pathological left-handers but are much smaller in number.

If Annett’s work is supported or left-handers show a superior performance on a series of tasks then this fails to back up the pathological argument. However, it is also possible that this supports the gene-culture model.

Chapter 3: Review of measurement and categorisation of handedness

3.0 Aims of the Chapter

This chapter will examine different methods of measuring handedness and will describe and review the handedness inventories that are most commonly used and the different hand skill tests that are used to assess handedness. A summary of the debate between hand preference (which assesses the hand favoured for a number of items, Bishop, 1990) and hand skill (which measures the proficiency of each hand while carrying out a skilled activity and examines which hand is more skilled, Bishop, 1999) will also be addressed. The development of the questionnaire that was used to determine hand preference throughout the thesis will also be described. The validity and reliability of self-report scales will be discussed and the reliability of the questionnaire used for the thesis will be examined.

3.1. Self-report scales of handedness

The optimum way of measuring hand preference is often a fiercely contested area. There appears to be a distinct lack of agreement across handedness research and researchers as how to ascertain the best measurement or even how to define hand preference in many cases. However, Corballis (1997) stated that nearly all people can define whether they consider themselves to be left- or right-handed and around 90% of the human population define themselves as right-handed. Corballis (1997) added that the issue of measurement of handedness depends on many different factors but one fundamental issue is whether handedness refers to hand preference, hand skill or both.

"*The most notorious problem is that there is no agreement as to the definition of handedness and hence no agreement on how to classify people in order to discover how many fall into different handedness groups*." (Annett, 1998a, p63)

It is difficult to define how handedness can be assessed and thus, the most obvious way to find out which hand a person uses to do various things is to ask. However, asking a person what their hand preference is can cause problems as the use of a single hand to perform a variety of different manual actions is very rare and in many individuals, very unlikely. It appears that the best way to find out the hand preference of an individual is to ask them to perform specific activities or ask them with which hand they perform specific activities (using some form of self-report inventory). The consistency of a person's handedness can be determined through this type of self-report questionnaire (Provins & Cunliffe, 1972). In many cases the researcher gets the individual to carry out these activities using relevant props or equipment and notes the hand they use to do this. (See section 3.2. for a review of handedness inventories). Disagreement not only exists over what is the best way to measure handedness but also over definitions of handedness, i.e. when can someone be defined as left-handed? Or is there more than one type of left-handedness and right-handedness and if so what are the different types and how are they defined? The simplest classification of handedness only distinguishes left-handedness and right-handedness; however, more complex definitions and categorisations of hand preference exist (see section 3.2. for a review of different categories of hand preference). There are many advantages in using hand preference inventories. Firstly, they normally require very little (or in some cases no) apparatus and are quick and easy to administer and score (Bishop, 1990). Also data can be collected from large groups at the same time and questionnaires can be distributed long distance or on-line for completion. The validity and reliability of these types of questionnaire have been questioned and these issues will be covered in section 3.5.

The distribution of hand preference is normally 'J' shaped (see figure 2.3. in Chapter 2) with the highest incidence occurring at the extreme, strong right-hand side and a smaller number at the extreme, strong left-hand side. Those who are not strongly left- or right-handed exist at all points along the continuum between the two extreme points.

3.2. Commonly used handedness inventories and resulting definitions of hand preference

Many different handedness inventories exist and these vary quite broadly. Some of the inventories are very short and only ask up to 10 questions (e.g. The Edinburgh Handedness Inventory – Oldfield, 1971) whereas others cover up to 40 items (e.g.

The Waterloo handedness questionnaire – Bryden, 1977). The response choices and the scoring of these inventories also differ; some of them require responses on a three-point scale (Left, either and right hand) while others are (more commonly) answered on a five-point scale (from 'always right', through 'usually right', 'either', 'usually left' to 'always left'). Inventories that are scored across a three-point scale are usually (but not always) given a score of 1 for a right hand response, 0 for an either response and –1 for a left hand response and the total scores are grouped as a positive score resulting in a right-hand preference, a score of zero resulting in what many of the researchers term as ‘ambidexterity’ and a negative score indicating a left hand preference. On a five-point scale the scores range from 2 for a right hand always answer, 1 for a right hand most of the time, 0 for either, -1 for left hand most of the time and –2 for left hand always. The total scores for the five-point questionnaire result in different groupings of hand preference. Where the three-point scale only distinguishes left-handedness, right-handedness and ambidexterity, the five-point scale also distinguishes between strength of preference within the handedness categories. Many of the researchers who use five-point scales have their own ‘cut-off’ points for what score distinguishes, for example, a strong left-hand preference compared to a weak left-hand preference but these are all reasonably consistent within the categories. Additionally, Annett (2002) has a different scoring system for her inventory and a wide variety of handedness categories (see section 3.2.4. for details of this). One additional scoring and response factor that will be covered is that of a laterality quotient (see section 3.2.7. for details of this). The different designs, response choices and scoring systems of the most frequently used handedness inventories will be outlined in more detail below.

3.2.1. McManus (1985)

McManus (1985) proposed the simplest categorisation of handedness when he argued handedness is best measured by taking the hand preferred for writing. McManus argued that the most skilled action a person does is write and thus the hand preferred for this would indicate the individual’s hand preference. He proposed that a single dichotomy between left- and right-handers was the most meaningful way of sub-dividing individuals, so long as there were no strong cultural pressures against left-handedness. In doing this he implied that there were no essential behavioural differences within the categories ‘left-handers’ and ‘right-handers’. Also, by stating that individuals could be placed in to these two groups McManus implied that strength of hand preference is not important and that the importance lay in the direction of hand preference. Even though McManus states that the classification of left- and right-handers based on writing hand is the most meaningful way of dividing individuals unless there is some form of cultural pressure he does not explain what the alternative would be if there was any form of cultural pressure to shift the writing hand. If any from of cultural or educational pressure occurred then part of this model would be seen as invalid as the individual would not always be expressing their natural hand preference when writing if they had been pressurised to shift from left-handedness to right-handedness. Also, particularly among the older generation it was not uncommon for children to be forced in some way to switch hand preference from left to right but these individuals do not always remember that they were switched and therefore would not always be able to even report this shift. However, McManus (2002) argued that measuring handedness by means of multiple item handedness inventories does not always give an accurate measurement and the best way to get an accurate measurement is to keep the questionnaire brief. McManus (2002) maintains that when the direction of handedness is assessed there is still no superior indicator of handedness than the writing hand and that most of the items on handedness inventories result in the majority of same responses as the writing hand and therefore there is no need to add these surplus statements. McManus (2002) concludes that the only item that can satisfactorily be distinguished for preference from writing is throwing. McManus supports Peters and Servos's (1989) suggestion that hand preference for throwing and for writing are often inconsistent and cites that this has been extensively validated (see section 3.2.6. for further details).

3.2.2. Waterloo Handedness Inventory: Bryden (1977); Steenhuis & Bryden, (1989)

The Waterloo handedness inventory is a thirty-six-item questionnaire that asks specifically about uni-manual tasks (i.e. tasks that only require the use of one hand) and is one of the most frequently used inventories to assess hand preference. Bryden (1977) suggested that there are two factors underlying hand preference, one representing skilled performance and the other unskilled. The questions included in the Waterloo handedness inventory cover examples of skilled and unskilled actions. Examples of some of the skilled questions include 'with which hand would you use a paintbrush to paint a wall', 'with which hand would you use an iron to iron a shirt', 'with which hand would you use a spoon to eat soup' and 'with which hand would use to throw a dart' while some examples of unskilled actions include 'with which hand would you use to drink a mug of coffee' and 'with which hand would you use to point to something in the distance' (a more detailed description of the questionnaire can be found in Steenhuis & Bryden, 1989) . The questionnaire gives a choice of five responses that range from 'always use the left hand'; 'usually use the left hand'; 'use both hands equally often' to 'usually use the right hand' and 'always use the right hand'. Calculating each individual statement's score and summing up all of the items on the questionnaire determine a total score. A scoring system of –2 for 'always use the left hand' to 2 for 'always use the right hand' is assigned. It is therefore expected that those with a right-hand preference will have a positive score and those with a left-hand preference will have a negative score on the questionnaire.

One problem with the Waterloo handedness inventory is that many of the questions are ambiguous. Statements regarding which hand someone holds a walking stick with or which hand they use to hold a mug of coffee would not always reflect an individual's hand preference. It may depend on the position of the mug for drinking coffee or with regards to a walking stick the hand used to hold it may be determined by the side that it is being used to support and not necessarily which hand is more comfortable. Also, because there are a large number of statements many of the actions asked about are very similar, an example of this within the questionnaire is one statement asks what hand the individual writes with, another asks what hand is used to paint with a paintbrush while another asks which hand uses a rubber on the top of a pencil. These items all require fine dexterity and are not strongly distinguished from each other. Thus it seems that having too many items on a handedness inventory such as this may lose the effect of determining a reliable measurement of hand preference. However, having a longer questionnaire does have advantages as it allows a number of responses to be made and therefore it is easier to determine the strength of hand preference through a higher number of responses. However, Annett (1998b) states that strength of hand preference can be measured as effectively with a much shorter handedness inventory. A brief discussion of the optimum number of questionnaire items to measure handedness is outlined in section 3.2.6.

3.2.3. The Crovitz-Zener Scale (1962)

The Crovitz-Zener scale is one of the earliest handedness inventories still in use. The questionnaire consists of fourteen-items which include 'holding a glass while drinking', ' holding a bottle to take the lid off', 'holding a potato to peel', 'drawing, ‘using scissors’ and ‘using a toothbrush’. Unlike most other handedness inventories that either use a three-point scale or a five-point scale, the Crovitz-Zener scale uses a six-point scale which is the same as the five point scale but has the additional choice of ‘don’t know’ if the individual in uncertain which hand they would use for a particular action. The scoring of the Crovitz-Zener scale is also different to the usual scoring system for the five-point scales. Rather than ranging from a score or 2 to –2 this scale goes from a scale of 1 to 5 where a strong right hand response would score 1 and a strong left hand response would score 5. If the ‘don’t know’ response is chosen then no score is given for that particular statement. In order to avoid any form of response set when completing this questionnaire five of the activities included within it refer to activities that a right-handed person would normally do with the left hand. These items include’ what hand do you use to hold a potato to peel’ because a right-handed person would peel the potato using the right hand they should respond that they hold the potato in their left hand and are thus avoiding answering ‘right hand always’ to each statement and have to think more carefully about each statement. The statements that refer to the left hand of a person who is right hand dominant are scored in a reverse fashion. A score of fourteen would therefore mean extremely right-handed and a score of seventy would mean extremely left-handed.

One problem with the Crovitz-Zener scale is that it makes assumptions that people can not only report their hand preference for a number of activities but that they can also judge the strength of performance on whether they always use that particular hand or whether they only sometimes use it. The types of activities individuals are asked about on handedness inventories are often performed automatically in everyday life and when it comes to reporting their preference on these questionnaires some people are often surprised by the outcome when they are encouraged to mime as they are not sure when solely asked about a particular activity and find that they do not use the hand that they thought they did. Bishop, Ross, Daniels and Bright (1996) state that if a person who is prohibited in some way from miming an action cannot tell which hand they use to perform some of the actions (especially activities such as holding a toothbrush) then they cannot accurately respond to whether they do particular activities some of the time or most of the time if they are unaware of the actual hand in some cases that they use to do this. This criticism is not specific to the Crovitz-Zener scale, this applies to all of the inventories which use a five-point scale where individuals are asked not only to indicate their hand preference but also the strength of preference.

3.2.4. Annett handedness questionnaire (1970) and subsequent revisions

Annett (1985) states that there is so much controversy in handedness assessment that the variance for percentage of left-handers in the population is vast. She cites that it ranges somewhere from 1% to 30%. Annett therefore states that if agreement cannot be reached, as how to classify handedness and this variance exists between researchers then it would be difficult to generalise findings to the left- and right-handed populations in general. The most common figure cited for the percentage of left-handers is somewhere around 9 to 15%. Annett (1985) herself predicts that only around 3-4% of left-handers are consistent left-handers and the remaining left-handers in the population are mixed-handers of some description. Annett (2002) stated that mixed-handers could be referred to as those who write with one hand and do a number of skilled activities with the other or those with some form of inconsistent preference between different actions (although one hand is still often more strongly preferred for particular actions).

Annett (1985) proposes potential explanations for why this variance amongst researchers exists. Firstly, she states that there could be differences between the groups studied (except from their handedness). For example, one group might contain more males than females and thus it is reported that there is a higher incidence of left-handedness amongst males therefore the level of left-handedness would be higher amongst this group. Another example could be age. As left-handedness is not discouraged in most societies any more then it would be expected that there would be higher incidences of left-handedness amongst younger people than older people (as many older people will have experienced some attempt to switch their hand preference from left to right). Therefore if a participant group in one study consisted of mainly older people then it would be expected that the incidence of left-handedness would be relatively lower than a group that was comprised of mainly younger people. Secondly, Annett said that some measurements might be observed while others may be self-reported. This could make a difference in classification as a group who are using the self-report method may think that they know which hand they use to perform an activity but this may not always be accurate whereas a group that are observed are acting out the activities and are more likely to give a true reflection of their preference. Annett (1985) adds that in some cases observational studies have to be carried out if the participant group is one that is unable to respond to a questionnaire (e.g. young children). Therefore, the way that measurements are taken can have an effect on the final hand preference classification. Annett (1985) suggests that a final reason for variance among left-handers may be because of the way that researchers classify handedness. For example, some researchers may only look at consistent or strong preferences while others may be interested in only skilled activities. It is dependent on the individual researcher's criterion how handedness is classified in many cases and thus this causes a large amount of variance due to the different questionnaires and measuring strategies used.

Annett (2002) therefore stated that clear predetermined rules for classifying handedness needed to be outlined. She stated that handedness is not a dichotomous variable but is measured along a continuum (Annett, 2002). Annett (1998b) stated that handedness classification is dependent on many factors and not only does it depend upon culture, sex and individual researcher criteria, it can also depend on the method used to recruit participants. Annett found that things such as volunteer biases can affect individual classifications; along with the way in which participants are recruited (which can also be linked to volunteer biases) and the way in which handedness is analysed. Annett (1998) states that unless these things are controlled for then it is difficult to make direct comparisons of different handedness groups (and also within handedness groups).

Annett's (1970) questionnaire consisted of 12 items (see appendix 1). These were write; throw; hold a tennis racket; hold a match; scissors; thread a needle; sweep with a broom; shovel with a shovel; deal cards; hammer; use a toothbrush and unscrew a jar lid. Participants were asked to answer each question and respond using left, right or either responses. Annett (1985) states that the first step in her analysis of hand preference analysis was to distinguish mixed-handers from consistent left- and right-handers. Annett (1970) developed a decision tree in which she illustrated how her classification system was developed (see figure 3.1). The first and most simple thing she considers is the writing hand and splits this in to right-handed and left-handed. Within each group she split left-handers in to pure left-handers and mixed left-handers and split right-handers in to pure right-handers and mixed right-handers. It is these four groups that are often used to broadly categorise participants on Annett's questionnaire. A person is classified as a pure right-hander if they indicated that they use their right hand for all of the activities on the questionnaire or if they used their right hand or either hand for all of the activities. A pure left-hander is someone who uses their left hand exclusively or their left hand

and either hand to perform all items on the questionnaire. A classification of ‘mixed right-hander’ is given to people who write with their right hand but indicate that they perform another activity on the questionnaire with their left hand and finally, a ‘mixed left-hander’ is someone who writes with their left hand but does at least one of the other activities with their right hand.

However, Annett (1970) further divided these four handedness groups in to eight more specific groups. See Figure 3.1 below. Row 3: Preference Classification shows the 1970 version and Row 4: Revision shows the 1998 revised version.

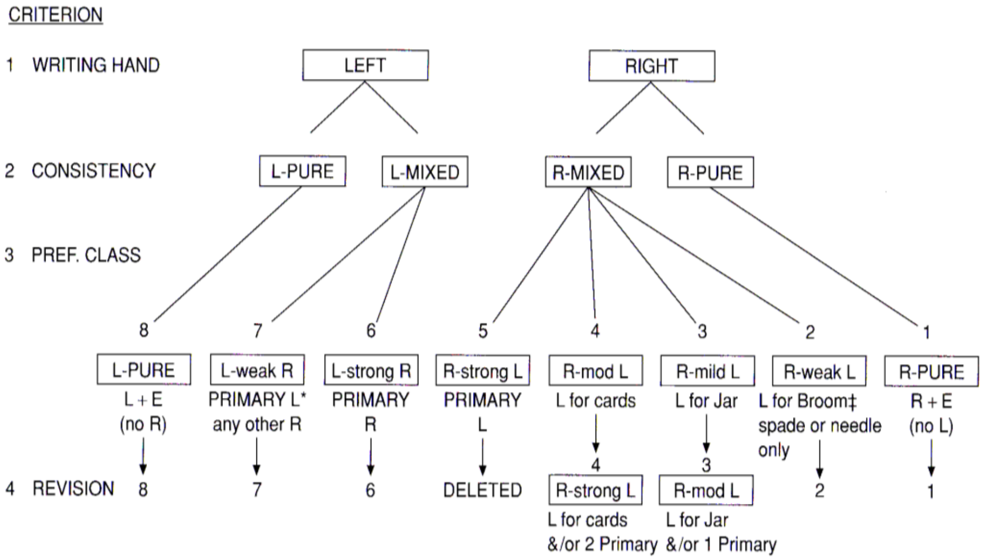


Figure 3.1: Annett’s (1998b) revised hand classification system with breakdowns of all handedness groups (from Annett (2002), p44)

(Primary actions are writing, throwing, racket, match, hammer and toothbrush. Non-primary actions are scissors, needle, broom, spade, dealing cards and unscrewing the lid of a jar).

Firstly, Annett divided her 12 item questionnaire in to two different categories where writing; throwing; using a tennis racket; striking a match; hammering a nail and using a toothbrush were considered to be primary actions and using scissors; threading a needle; sweeping with a broom; using a shovel; dealing cards and unscrewing a jar lid were considered to be non-primary actions. Annett (1970) devised these 8 new handedness groups based on these primary and non-primary actions. These groups were based on empirical evidence of differences between the hands on a hand skill task. Classification group 1 consisted of pure right-handers and individuals were classed as this if they indicated that they did not use the left hand for any actions at all on the questionnaire. Group 2 were classed as right-weak left and were those who used their right or either hand for all actions but used the left hand for either sweeping with a broom; using a shovel or threading a needle (all of these are non-primary actions). Group 3 were classed as right-mild left and these individuals were right-handed writers but they unscrewed the lid off a jar with the left hand. Group 4 were classed as right-moderate left and were right-handed writers who used the right hand or either hand for all actions but used the left hand for dealing cards. Group 5 were classed as right-strong left and used the right hand for writing but used the left hand for any one of the primary actions. Group 6 were classed as left-strong right and were left-handed writers with strong right-hand preferences for any of the primary actions. Group 7 were left-handed for any primary actions and right-handed for any other actions. Finally, group 8 were pure left-handers and exclusively used the left or either hand to perform all 12 actions on the handedness questionnaire and did not use the right hand at all. Annett (1985) revised these classifications and deleted category 5 and redefined categories 3 and 4 to incorporate the original class 5 (this is the version that can be seen in figure 3.1 above). All of the left-handed classifications (groups 6, 7 and 8) stayed the same, as did classifications 1 and 2 for right-handers.

Annett (1998b) added that if an individual could be classified in more than one group then the left most case would take precedence. For example, if an individual was classed as falling in to group 2 and group 4 then their final allocation would be to group 4 as this is more favoured to the left. In the revised classification system group 3 was amended from right-mild left to right-moderate left, which was defined by right-handed writers who perform any one primary action using the left hand or unscrew the lid off a jar using the left hand. Category 4 was redefined as right-strong left (the original class 5) and this was revised to include right-handed writers who perform at least two primary actions with the left hand and/or deal playing cards with the left hand. These classes took in to account degrees of hand skill but in some cases one category may have more strongly dextral people in it even though the category does not suggest this. For example, those in class 2 could be more dextral than those in class 1 as many people in class 1 could perform many of the actions with either hand.

Annett (1995) concluded that dividing participants in to sub-groups of left- and right-handers offer a reliable method of analysing the different degrees of left- and right-handedness. This approach contrasts with those who examine degrees of hand preference using a laterality quotient or a 5-point likert scale.

However, there are problems with Annett's classification system. Peters (1998) says that there are too many classifications and it is not only confusing and sometimes complex to follow which category each individual fits in to, but also in order to examine differences between the sub-groups there would have to be an adequate number of participants in each category so that comparisons could be made and this would require many participants and certain sub-groups will be much more common than others. Nevertheless, Annett's handedness questionnaire has been found to be one of the most valid handedness questionnaires and also one of the most used, as it is quick and simple to administer and score when the classifications are kept to a minimum.

3.2.5. Peters (1990)

Peters (1990) distinguished between three hand preference classification groups. He examined the throwing performances of left- and right-handers using a procedure used by Ponton (1987) who reported that left-handers who showed a tendency to prefer the left hand for a number of preference activities showed motor performance that was inferior to the performance shown by left-handers with more inconsistent preferences. Peters and Servos (1989) failed to replicate these findings but did find that classifying left-handers in to sub-groups in this way not only showed that these sub-groups differed in degree of preference but also in performance asymmetries. Peters (1990) found that 'strong' left-handers showed a strong relationship between hand preference and hand performance and thus referred to them as consistent left-handers, whereas weaker left-handers tended to show very little relationship between the their hand preference and their hand strength, Peters referred to this group as inconsistent left-handers. He then simplified the groups into: Consistent right-handers who write and throw with the right hand; consistent left-handers who write and throw with the left hand and inconsistent left-handers, those who write with the left and throw with the right hand. He does not include a category for inconsistent right-handers as he indicated that it was a very rare occurrence that someone would write with the right but throw with the left and therefore there would not be enough people in a category of this type. Peters went on to say that the exclusion of the inconsistent right hand category was because it is possible to explain right-handed writing and left-handed throwing in terms of environmental pressures against the left hand as the writing hand and a neutral attitude towards the throwing hand but no equivalent environmental explanation can be given for individuals who throw with the right and write with the left (Peters, 1996). Peters justifies the use of the inconsistent left-handed group in the study as he states that almost a third of all left-handers are inconsistent left-handers (Murphy & Peters, 1994).

This classification system is advantageous as it is quick to assess and uses two items (writing and throwing) that have been shown to be strong predictors of hand preference. However, one criticism is that Peters states that there is no need for an inconsistent right-handed group as it is rare to find a right-handed writer who throws with the left hand but there may be a group of these people who do throw with the left and write with the right thus there is need to include an inconsistent right hand category.

3.2.6. Peters (1998)

After Peter's (1990) consideration of consistent and inconsistent hand preferences he examined questionnaire measurement of hand preference and studied what made an effective, valid and reliable questionnaire.

Peters (1998) stated that the most effective questionnaires should contain three things. Firstly, items that cover both skilled and unskilled activities, secondly, a sufficient number of questions to allow for an element of variability over different items and thirdly, they should allow for responses to be made on a ranked scale rather than on a forced choice left/right scale. Peters stated that one major advantage of using a questionnaire that encompassed all of the above factors was that it would be flexible enough to accommodate a variety of classification schemes of handedness. Peters also stated that within this questionnaire there should be face validity; construct validity and external validity (see section 3.5. for more details on validity).

Peters (1998) also researched what the optimal length of a questionnaire measuring hand preference should be. Peters (1998) said that there was an assumption by many researchers that the longer a questionnaire was the more activities it would cover and it would therefore give a realistic but variable measurement of hand preference. Annett (1985) added though that the more items participants are asked about on handedness inventories the more complicated it becomes. However, the number of items in these questionnaires varied considerably across researchers – Singh and Kundu (1994) cited in Peters (1998) used an 87-item questionnaire, Messinger and Messinger (1995) used a 55-item questionnaire while Steenhuis and Bryden (1989) started out with a 60-item questionnaire that was finally reduced to a 32-item questionnaire. Peters added that short questionnaires (ones that have 10 items or less) have also been found to be effective as they can still discriminate between groups of left- and right-handers and they are quick to complete (e.g. Peters & Servos, 1989). However, criticisms against short questionnaires have included that there is little data in order to make comparisons of handedness groups or be able to split the groups effectively from only 10 (and sometimes fewer) items. Peters (1998) stated that the optimum length for a questionnaire was around 30 items so that it was long enough to get enough discrimination between items and allow multiple handedness groups to be distinguished but also short enough to complete quickly and effectively without containing additional questions that were perhaps ambiguous and not useful for determining handedness. One last advantage of using longer questionnaires is that the shorter questionnaires can be incorporated within the questionnaires and thus checks can be made on more than one handedness scale to measure hand preference.

Peter’s (1998) questionnaire contained 25 items these items were: drawing; knife; comb hair; pick up a very small object; pick up a book; screw in a light bulb; dial a pushbutton phone; wave goodbye; pet dog or cat; wash face with cloth; pick up a heavy object; pick up a heavy suitcase; bat baseball; write; brush teeth; throw ball; hold tennis racket; hammer in a nail (which holds the hammer); scissors; strike match; thread needle; sweep with broom; shovel with large shovel; deal cards and unscrew the lid off a jar (see appendix 2). This questionnaire contains all 12 of Annett’s (1970) handedness inventory statements and 8 out 10 of Oldfield’s (1971) (and therefore Bishop et al.’s., 1996) statements. Although Peters only included 8 out of the 10 EHI items he substituted unscrewing the lid of a jar for opening a box lid and hammering in a nail for eating with a spoon (although for the questionnaire used in my thesis these have been changed back to the original EHI items in order to be able to make direct comparisons – see section 3.7). Peters (1998) administered his questionnaire twice and used a different scoring system each time. The first time he used a 5-point likert scale that ranged from always left, mostly left, hand, mostly right and always right and was scored 1, 2, 3, 4 and 5 respectively. Peters then gave his participants 6 motor tasks to complete (these included various peg moving, button pushing and tapping tasks) before administering the questionnaire for a second time.

The second version of the questionnaire contained forced choice responses so that the participant could only respond using left hand, right hand or either hand. Peters found that three of the items included in his 25-item inventory did not aid in the discrimination of handedness and were therefore removed from his analysis, these were: sweep with a broom; shovel with a large shovel and bat a baseball.

In conclusion, Peters (1998) examined what made a good hand preference questionnaire and used this to design a questionnaire that acknowledged these results. He concluded that a hand preference questionnaire should not have too many items but should have enough so that variance could be accounted for (somewhere in the region of 25 to 30 statements according to Peters). He also argued that the most effective questionnaires are ones that are flexible enough to allow a range of classification schemes to be measured within the questionnaire (e.g. Annett's classifications and the EHI). Peters concluded that the use of a 5-point scale was more effective on a handedness questionnaire than a forced-choice 3 – point scale because the use of a 3-point scale lost much of the variance in the data whereas a 5-point scale examined strength as well as preference of individuals and allowed distinct sub-handedness groups to be formed within each left-handed and right-handed group.

3.2.7. Edinburgh Handedness Inventory Oldfield (1971)

The Edinburgh handedness inventory (EHI) originally consisted of twenty items. However, Oldfield (1971) revised this and 10 of the 20 items were used as the final shortened version of the EHI (see appendix 1). The aim of this revised questionnaire was to act as a simple and brief method of quantitatively measuring handedness. Individuals were asked to indicate their hand preference for each item by placing a cross (+) in the appropriate column (left or right). If the individual wanted to indicate a strong hand preference for a particular action the placed two crosses (++) in the appropriate column and if they wanted to respond with an 'either' response they placed a cross in both columns. Where an action required two hands (e.g. striking a match) individuals were given direct instructions as to what hand was being asked about (so for example when striking a match they would be asked which hand held the match rather than the box). The 10 items in this questionnaire were writing, drawing, throwing, scissors, toothbrush, knife (without fork), spoon, broom (upper hand), match (hand holding match), and box lid (hand lifting lid). An example of responses to the EHI is given below.

	L	R
1. Writing	++	
2. Drawing	++	
3. Throwing	+	+

The above example shows someone who is strongly left-handed for writing and drawing but chooses either hand for throwing.

In order to score the questionnaire the number of crosses placed in the left column are added up and the number of crosses in the right column are added up. A laterality quotient is then calculated using the following formula: **100(R-L)/(R+L).**

The total number of left crosses are subtracted from the total number of right crosses and are divided by the total number of left and right crosses added together. This score is then multiplied by 100 to give a laterality quotient between **100** and **–100**. Thus someone who responds with two crosses for each action in the left column on the questionnaire would have 20 crosses in the left and 0 crosses in the right thus their formula would be 100(0-20)/(0+20) which would give a total of –100 for the laterality quotient which would reveal a strong, consistent left-hander. This scoring system is very similar to the 5-point scale used by questionnaires such as Crovitz and Zener (1962) where two crosses in the right column equate to ‘always use the right hand’ and one cross in the left column would equate to ‘left hand most of the time’. Oldfield suggests that the higher the laterality quotient is the stronger the hand preference is so scores close to 100 depict a strongly right-handed person and scores close to –100 depict a strongly left-handed person. Oldfield (1971) does not, however, split the laterality quotients down in to different strengths of handedness and speculates that a low negative score is a weak left-hander and such like. He does add that someone with a laterality quotient of about +31 to +40 would have quite a moderate tendency towards left-handedness although they would be right-hand dominant. However, only about half of the people who scored within this range responded that they had any tendency towards left-handedness. Oldfield himself admitted that the EHI was not ideal but was adequate for quantitatively measuring handedness particularly among large groups of people, as it is very quick and very simple to administer and complete.

However, criticisms have been made against the EHI and the use of laterality quotients to classify handedness. One of the biggest critics of this system is Annett (e.g. Annett, 1985; 1995; 1998). Annett (1985) stated that a major criticism of this type of inventory and scoring system was that actions that differ considerably in skill and in frequency of left hand use are assigned the same scores no matter what the action is. For example, writing which is considered to be a skilled activity, and one that is proposed to strongly predict hand preference, is treated in the same fashion and is scored in the same way as unscrewing the lid off a jar, which is considered to be a non-skilled action and one that many right-handers perform with the left hand. Annett (1995) also states that using a 5-point scale to depict how often someone does an action (i.e. always or most of the time) is unreliable as many actions are automatic and thus individuals will probably not be able to predict how often and with which hand they perform them and will therefore not always give an entirely accurate response. Another problem with this is, as previously mentioned, males are more likely to choose 'most of the time' responses than females and thus males will appear to have weaker hand preferences than females even though this is not necessarily a true indication of their hand preference (e.g. Annett, 2002). One final criticism of the EHI is that the format of the questionnaire is set in such a way that it allows for a response bias to occur. Thus if the participant wanted to respond with the right hand for each question then they would respond 'right hand' for each individual action. In many questionnaires there is some form of reverse scoring or counterbalancing of the actions in order to avoid this response set being made. Some questionnaires may ask which hand is at the bottom of the broom so that a right handed person will normally respond 'left hand' and thus this avoids responding with the right hand for each question and is totalled by a reverse scoring system for these particular questions.

3.2.8. Bishop, Ross, Daniels & Bright (1996)

Bishop et al. (1996) examined the measurement of hand preference across three groups of right-handers. In order to distinguish the different groups they used the questions of the Edinburgh handedness inventory (Oldfield, 1971) but used a five point likert scale (right hand always to left hand always) rather than the crosses used in the original EHI. From this Bishop et al., devised their own categories of right-handers. They defined exclusive strong right-handers (Rs) as individuals who always used their right hands for at least 8 out of the 10 items on the EHI and who used their right hands most of the time for the remaining items. Bishop et al. defined exclusive weak right-handers (Rw) as those who used the right hand most of the time for at three or more activities on the questionnaire and always used the right hand for the remaining items. The third categories of right-handers were described as predominant right-handers (Rp). Predominant right-hander were described as those that preferred to use their right hands for most of the activities on the questionnaire but used their left hand for at least one of the activities. As Bishop et al*.* only examined the different categories of right-handers in their study they did not outline the division of left-handed groups.

Therefore in the course of the thesis when groups are examined and categorised in relation to how they would be using other studies and questionnaires the left-handed group when being divided according to Bishop et al.'s categories will be done so using the same rules as those applied to the right-handed group but substituting left hand where the original used right hand. For example, a strong left-hander (Sl) would be someone who always used the left hand for at least 8 out of the 10 items on the EHI and used their left hand most of the time for the remaining items. Thus, even though Bishop et al*.* use a 5-point likert scale for the questionnaire they do not impose a numerical score but instead apply a similar technique as someone like Annett who states that applying a numerical score often does not reflect the true hand preference of the individual especially if they use a mixture of the left and right hands and also depending on whether they state they use a particular hand all of the time or only most of the time as this can change the scores considerably. The handedness questionnaire used by Bishop et al*.* (the EHI – Oldfield, 1971) is one of the most widely used handedness inventories and thus has been extensively examined for reliability and validity. However, one major criticism against the EHI is the use of the laterality quotient and the somewhat often-inaccurate measurement of hand preference from this score.

Bishop et al*.,* though avoid this criticism by applying a different scoring system to the EHI by using a 5-point scale in order to examine strength of preference but not quantifying the score in any way. Thus, there is no numerical score attached to this measurement and categories are defined by the number of times the dominant hand is used. One criticism against the way that Bishop et al*.* have divided the categories of right-handedness is that there is room for much variance within the categories weak right-handers and predominant right-handers. A weak right-hander is defined as using the right hand most of the time for 3 or more activities and always using the right hand for the remaining activities. However, a weak right-hander could range from someone who used their right hand most of the time for only 3 activities and always used their right hand for the other 7 activities to someone who used their right hand most of the time for 9 items out of 10 and only used their right hand always for the other 1 remaining item. Thus, there is much variance within the weak right-handedness category. Similarly in the predominant right-hander category the basic definition is that the individual prefers to use the right hand for most items but uses the left hand for at least one item. Again, there may be a lot of variance within this category. For example, one individual in this category may be someone who uses the right hand for 9 items out of 10 and uses the left hand for the other items while another may use the right hand for only 6 of the items and use the left hand for the other 4 items. This latter individual would appear to be much more left-handed (or much less right-handed) that the first individual outlined but they would be classified in the same handedness group. Also, it would depend on which items the individuals were 'performing' left-handed and which ones were right-handed as some of the items on the questionnaire are better predictors of handedness than others (e.g. writing and drawing are better predictors than sweeping with a broom, Peters, 1998).

One final criticism is that in the predominantly right-handed category, Bishop et al. do not clearly state whether using the right hand for most items counts equally whether the individual states that they always use the right hand or if they use the right hand most of the time. In the other two categories they specify how many actions have to be performed with the right hand always and the right hand most of the time. A summary of the handedness inventories and classifications outlined in this section can be found in Table 3.1. below.

3.2.9. Summary

Therefore, in summary different forms of handedness inventories have been described in the section above. It can be seen that these differ not only on the items that they consist of but also in the number of questions/statements they have and the way in which they participants are asked to respond. For example, McManus only asks about the writing hand; Annett asks 12 questions and asks participants to respond if they use the left, right or either hand; Oldfield (1971) asks 10 questions but participants have to respond using crosses and a laterality quotient is calculated; the Crovitz-Zener scale (1962) consists of 14 statements and asks participants to respond on a 5-point scale to examine strength of handedness; Peters (1990) examines consistent and inconsistent handed preferences by means of throwing and writing and Peter’s (1998) questionnaire consists of 25 items and contains most of the statements from the previously mentioned inventories and can be responded to either on a 5-point scale or on a 3-point forced choice scale (left, right or either). It has been said that longer handedness questionnaires have the advantage of attaining a distribution of scores that is more normal shaped (but bimodally so) than J-shaped (e.g. McManus, 2002) and thus may be one reason why there is a link between hand preference and hand skill as hand skill is also normally distributed (see section 3.6. for more details on hand skill).

McManus (1984) stated that he was not convinced that questionnaires properly differentiated different 'types' of handedness, and certainly not the large numbers of sub-types that have been proposed by Annett (1970). He added that even the differentiation of 'skilled' and 'unskilled’ activities would often be difficult to separate and define and this would probably change across researchers. Therefore, in conclusion, there are a variety of handedness inventories available and some are more widely used than others. However, as many inventories measure different aspects of handedness (for example, some only look at skilled actions while others look at a broad range of skilled and unskilled actions) and categorise handedness groups in many different ways then it is the prerogative of each individual researcher to consider what they want to measure and what the most effective way of achieving this would be.

In summary, I think that perhaps although accurate measurements of handedness can be achieved through tests of hand skill it is quicker, easier and valid to use measurements of hand preference in order to categorise handedness. Tests of hand skill can be time consuming, particularly if they are part of a test battery while hand preference questionnaires are quick and easy to both administer and quantify. Therefore, it was decided to use a hand preference questionnaire to measure handedness in my thesis. It was decided that the best questionnaire to use was that of Peters (1998) (see sections 3.7. & 3.8. for further details). The reason for this was that the questionnaire was made up of all of the items in Annett’s (1970) questionnaire and almost all of the items in Oldfield’s (1971) EHI questionnaire (and the missing two questions were added in in order to cover all questions) alongside a number of additional items that could be used to determine hand preference. This way a number of handedness measurements could be taken within this questionnaire and responses could be categorised according to Peters; Oldfield and Bishop. It was decided to use the 5-point likert scale in order to collect data on the strength of handedness; however, due to lack of numbers in some of the categories the data were eventually merged to make simple left and right categories.

3.3. Problems with handedness inventories

Annett (1998a) stated that '*a source of reliability is that researchers assume that they know what handedness is and proceed to classify people on the basis of their own particular tests or questionnaires, without recognising the small variations in the questions asked and the criteria of classification can yield very different estimates*.' (p. 65).

The most common approach to measure handedness is to produce a number of different manual activities to which an individual indicates a preferred hand and these are summed to produce a score of handedness. These are usually quick to administer and can therefore be used to measure many people at one time. However, Bishop, et al*.* (1996) stated that it is important to note that the hand preference of an individual can vary hugely across the handedness inventories. They cited the Crovitz-Zener scale (1962), Annett's (1970) handedness questionnaire and the Edinburgh Handedness Inventory (Oldfield, 1971) as examples of how handedness fluctuates according to the scale used. They also stated that many people are unaware which hand they use to perform some activities until they are actually presented with a handedness questionnaire and are often surprised by the outcome of the questionnaire. Bishop et al. stated that because it is the case that people don't know which hand they use to perform certain activities, then it is difficult for them to respond on a questionnaire such as Crovitz-Zener (1962) as to the strength as well as the direction of hand preference. That is, if people are unsure which hand they use to perform certain activities then it might be difficult for them to accurately state whether they use a particular hand 'always' or 'most of the time'.

Bishop et al*.* (1996) also stated that not much attention has been devoted to the assessment of handedness. Bishop (1990) stated that there is an urgent need for a standard method of quantifying laterality.

Table 3.1: Summary of the main handedness inventories and the advantages and disadvantages of each of them

Measure	**Type of scale/response**	**Number of questions**	**Advantages**	**Disadvantages**
Crovitz-Zener (1962)	**6-point scale** *(gives a 'don't know' option)*	**14**	Many items are reversed to avoid a response set and make participants think about their answers.	Responses could be deemed unreliable due to being asked how often they performed certain actions.
Annett (1970) + updated versions	**Left, right or either**	**12**	Widely used and tested for reliability & validity. Quick & simple to administer & score. Can be simplified & altered depending on number of participants and degrees of handedness being measured	Often thought to have too many different classifications. Can be complex and confusing. Need a large number of participants in order to have a sufficient number in each group.
EHI Oldfield (1971)	**Indicates strength of preference by placing crosses in columns**	**10**	Quick & easy to administer. Reliable & widely used.	Laterality quotient can be ambiguous & is not widely used. Questionnaire could be susceptible to a response bias.
Waterloo Bryden et al. (1977)	**5-point likert scale** *(uni-manual questions)*	**36**	Includes many questions in order to determine strength of hand preference	Many of these questions are ambiguous & very similar to each other.
McManus (1985)	**Writing hand only**	**N/A**	Very simple.	Does not discriminate within categories. Does not consider people who may have 'switched' handedness

Peters (1990)	**Writing and throwing hand only**	**N/A**	Quick to assess. The 2 measures are strong predictors of handedness.	May not cover all preferences as there are only 3 categories and inconsistent right-handers are not included.
Bishop et al. (1996)	**5-point scale but uses the EHI**	**10**	Quick & easy to administer. Reliable & widely used. Does not use the Laterality quotient & adopts a wider classification system	There are a number of different categories for left- and right-handers and this there is room for much variance within groups
Peters (1998)	**5-point scale and also a forced choice scale**	**25** (but reduced to 22 after analysis)	Flexible enough to accommodate additional handedness inventory scales within it. Has a wide variety of uni-manual & bi-manual actions. Carried out twice when administered & is regarded as reliable.	Contains a few ambiguous items.

The above table summarises the main points of each of the main handedness inventories and measurements described in this chapter. The measurements range from a single action (writing – McManus (1985) to the 36 items of the Waterloo handedness inventory (Bryden et al. (1977). Each inventory has a number of advantages and disadvantages however, the inventories of Annett (1970) and Oldfield (1971) remain those which are most commonly used.

However, questionnaires designed to test handedness are not without their problems. Marchant, McGrew and Eibl-Eibesfeldt (1995) stated that many of these questionnaires might be of dubious validity (see section 3.5.). Raczkowski, Kalat and Nebes (1974) said that it is unsafe to assume that a subject who says he uses one hand for a particular task actually does so. Participant's memories may be inaccurate or they may answer uncertain items in the same way that they answer most others. Questionnaire items should therefore be tested for reliability and validity before they are included in the questionnaire. However, in terms of measurement of handedness, questionnaires are still the most widely used because they are quick and convenient and straightforward to use.

Bourassa, McManus and Bryden (1996) reported that one problem that occurs through using handedness inventories to measure hand preference is that the participant often gets caught up in some form of response set, that is if they answer right-hand always for a few statements then they will often continue this response style without fully considering the individual statement for the remainder of the questionnaire. Steps are often taken to address this and statements within a questionnaire are often balanced or asked in such a way so that they have to think about a particular hand if the action being asked about requires the use of both hands – i.e. when using a needle and thread the individual can be asked which hand holds the needle or which hand holds the thread, alternatively the individual may be asked to respond to which hand moves depending on whether they move the thread through the needle or whether they place the needle on top of the thread. In asking about particular actions in such a way this helps avoid drawing the individual into responding that (s)he uses the same hand for each individual action. Bradshaw (1989) added that another problem with handedness inventories is that not only do people respond using solely their dominant hand but also others respond with deliberate use of their non-preferred hand (even when they wouldn't normally use this hand).

Another problem with handedness inventories is that according to Bryden (1977) men are more likely to answer that they do something 'most of the time' rather than 'always' when given the choice in the five-point scales. This could cause potential problems as if they are right-handed but choose the 'right hand most of the time' option then this reduces their overall handedness score and their total score may be lower in some cases than a left-hander who does some things with their left hand but also uses their right hand 'always' to do other actions and therefore would have a higher overall total score. Alternatively, it could lead to men claiming that they are left-handed when they only perform a few activities with their left hand but they are not identifying the strong right-handedness categories for other actions. Bishop (1990) also states that questionnaires that claim to measure strength of preference (e.g. using 5-point scales) are actually not measuring strength but more consistency of hand preference.

Therefore, in summary there are many problems with using handedness inventories and most of the problems occur through the different measurements used. These include the number of questions used and could also relate to the type of question used (see section 3.2.6. for a review of the optimum number of questions to include); the numerous methods of scoring the questionnaires (see section 3.3. for a summary) and the different categories of handedness depending on the type of inventory used. This therefore causes confusion among those trying to define handedness as the specific inventory used could alter the classification of handedness due to the different questions and scoring systems within different handedness inventories. Finally, one pattern that tends to become apparent when reviewing handedness is that right-handers tend to show a more strong and consistent hand preference compared to left-handers who often show a more variable and weak hand preference and this may often be more exaggerated depending on the type of inventory used and show much further divisions between the handedness group just by the type of questions asked in the inventory.

3.4. Validity and reliability of self-report hand preference inventories

Peters (1998) suggested that handedness questionnaires should have face validity and construct validity. That is, these questionnaires should reflect both ‘common understanding’ of handedness in terms of preferences of everyday activities and stand in a meaningful relation to the self-classification of individuals (face validity) and that a questionnaire should relate to some underlying theoretical concept of handedness (construct validity). Peters (1998) added that a handedness questionnaire also needs external validity where there is a focus on the relationship between preference and performance of the hand(s). Annett (1985) stated that right-handers are usually found to be more consistent in their hand preferences than left-handers who are often found to have inconsistent hand preferences. Annett questioned whether most left-handers could be considered as mixed-handers due to this inconsistency of hand preference. Thus, in hand preference questionnaires it is more likely that the correlation between right-handers who complete the questionnaire twice will be stronger than the correlations between left-handers as they are more likely to either give inconsistent information as their preferences are mixed in many cases or give fluctuating information about the strength of preference and the hand of preference for certain actions if their preferences are inconsistent. Annett (1985) also states that using laterality quotients to define handedness is not reliable. She states that it is impossible to assign numerical values to all activities in the questionnaire when some items refer to skilled actions while others refer to unskilled actions. Thus she concludes that there is little internal validity within questionnaires that use this system. Annett adds that as the individual themselves decide on their degree of strength of hand preference then this in itself is probably not an accurate estimate and there is often an increased number of ‘either’ responses which are often taken to be much inflated than is really the case.

In handedness research, convenience often overrides validity, according to Marchant et al. (1995), “*It is easier to ask a subject to disclose her hand preference by ticking a box on a questionnaire than to ask them to perform a set of tasks in a controlled setting*” (p240). It is thus easier to induce these performances artificially than to observe a subject behaving spontaneously in everyday activities in the real world. But, each step removed from the real world introduces chances for error and “*makes more difficult a functional explanation of laterality as a product of natural and cultural selection*” (Marchant et al*,* 1995, p240).

Raczkowski et al. (1974) argue that it is unlikely that a person who says that they use a particular hand to perform an action actually does so when completing a paper and pencil questionnaire (without having the equipment to act out the items available). That is a person may say that they hammer with their left hand when asked but when presented with a hand preference questionnaire and a hammer to act out the actions they might discover that they actually hammer with their right hand. This is particularly the case when a person is unsure of which hand they use and they often either guess which hand they use (which is often inaccurate) or they respond that they use the same hand as the majority of their other answers on the questionnaire (again which can be inaccurate). Raczkowski et al. therefore state that questionnaires should always be checked for reliability and validity in order to avoid inaccurate responding as much as possible. They examined the reliability of questionnaire items by asking participants to complete a handedness questionnaire (questionnaire 1) and then one month later they asked the same participants to complete the same questionnaire again (questionnaire 2). The percentage of responses on questionnaire 1 that corresponded with responses on questionnaire 2 was examined. Cases were discarded if a participant responded that they used either hand on one questionnaire but not on the other as this indicated a lack of a definite preference for this action by the participant. They noted that a change of 5% or less was regarded as fairly consistent while a change of 14% or above was regarded as poor. Raczkowski et al. (1974) concluded therefore that in general test-retest reliability is reasonable amongst handedness questionnaires. It has been found that reliability and validity within questionnaires differ according to the actions that are entailed in the questionnaire. For example, some items within the questionnaire have high validity and reliability. Annett (1985) found that the most valid and reliable items in her questionnaire were writing, drawing, using a tennis racket and using a toothbrush. However, actions that require two hands are often considered to be weak on reliability and validity, for example, striking a match or sweeping with a broom. Annett (1998b) states that the way in which a handedness questionnaire is administered can also have an effect on whether it is deemed reliable or not. She noted that children were often tested individually when given tests of hand preference and hand skill but groups such as students are often given this kind of task to complete in a practical class where they time and observe each other in pairs and thus there are a number of different ‘researchers’ recording measurements compared with a consistent person recording the measurements of those taking part in an individual setting. Therefore there might be some form of discrepancy in the measurements taken in the groups or there might be more chance of inaccurate performance in a laboratory setting due to inconsistent instructions by different people and inconsistent timings and measurements being recorded.

3.5. Determining hand preference using proficiency measures

An alternative way to measure a person’s hand preference is to get them to perform a specific motor task or a series of tasks with each hand individually and note which hand the person performs more efficiently with (Provins & Cunliffe, 1972). These tasks are often referred to as tasks of hand skill and numerous arguments exist as to whether hand preference and hand skill are the same thing or whether they measure something different (see section 3.7. for a review). Annett’s (e.g. 2002) right shift theory was founded upon asymmetry of hand skill. She found that this asymmetry occurred because in most cases there is a difference in skill between the hands. Annett said that the distribution of hand skill is continuous and is normally distributed but there is a shift to the right in this distribution and in other cases (i.e. more skilled left-handers) there is a normal distribution with no shift that is symmetrical around 0 (see chapter 2 for more details of the right shift theory). Borod, Caron and Koff (1984) found that left- and right-hander's scores on a variety of hand skill measures were normally distributed and were similar in range and overall scores. Bishop (1989) argues that testing the proficiency of each hand allows fine distinctions between the hands to be identified. She adds that using tests of hand skill are often more reliable as they consist of tasks where the individual has not been specifically taught unlike some of the items on a handedness inventory where the individual may have been taught to use a specific hand to do something or may have been forced to use a specific hand (e.g. using the right hand for writing). Bishop adds that the distribution of hand skill (unlike that of hand preference) tends to be normally distributed with there being very discrete differences in skill between the hands in many cases. She adds that tests of hand skill can pick up very fine and subtle differences between the hands and thus even slightly more skill in one hand can bias that side and make it the dominant or preferred side for any unimanual task.

One of the simplest and most often cited motor tasks used to determine hand preference is the grooved pegboard used by Annett (e.g. 1985; 2002). This test comprises of a wooden block with a row of ten pegs in it and a row of ten corresponding holes for the pegs to fit in to (the two rows are parallel). The task requires the participant to transfer all of the pegs from one row to the other using only one hand and only moving one peg at a time. Five trials are carried out with each hand and the order that these are completed in is counterbalanced for handedness. The time taken to complete each trial is measured from the time that the first peg is moved until the last peg is placed in the final hole. The mean score for the right hand and the left hand trials is calculated and the difference between the two hands is noted.

Other tests of hand skill involve handwriting. Provins and Cunliffe (1972) tested hand skill by asking their participants to write the alphabet six times, as one continuous word, as quickly as possible. Participants did this with one hand and then with the other. The time taken to write the entire alphabet was recorded and upon the completion of the six trials with each hand the mean score for each hand was calculated. Provins and Cunliffe (1972) noted that there would be large practice effects involved with this type of hand skill test as the preferred hand would be trained for writing and should therefore be much quicker than the non-preferred hand. However, handwriting is seen to be one of the most reliable measures of hand skill. Borod et al. (1984) looked at a number of tests of hand skill involving strength; speed and accuracy. To measure strength participants had to squeeze a dynamometer that calculated the grip strength of each hand. Tasks of speed included placing dots in 40 circles and marking targets in very small squares. Finally, tests of accuracy included simultaneous writing in which the participant had to write the numbers 1 to 12 with both hands at the same time in vertical columns on paper with their eyes closed. Scores were given to correctly written, legible numbers. Bishop et al. (1996) introduced three tests of relative hand skill using groups of right-handers. She looked at peg moving, tapping speed and reaching (see Bishop et al. (1996) for a review of these).

Some researchers have found that tests of hand skill are reliable while others have questioned their reliability. Annett, Hudson and Turner (1974) found that test-retest measures for various tests of hand skill have been adequate. They found that significant test-retest reliability was found for each hand and for the differences between the hands. Annett (1976) argued that using a test of hand skill, such as her peg-moving task, lead to a more advanced measure of handedness. However, Provins and Cunliffe (1972) examined a hand skill task similar to Annett's peg-moving task and found that there was very little test-retest reliability. They found that out of seven hand skill tasks (dexterity; handwriting; darts; tapping; ratchet; hand grip strength and grip strength endurance) five were not significantly reliable. They concluded that the most reliable tasks of hand skill were handwriting and tapping. Peters (1990) added that tapping might vary in differences between the hands depending on the force of the tapping being done. Tapley and Bryden (1985) tested hand skill with the task of placing dots in circles as quickly as possible. They found that this test was a highly reliable measure of hand skill and that it correlated with measures of hand preference. With respect to the reliability of measures of hand skill Bishop (1989) stated that the strength of the reliability depended upon the specific task used to measure hand skill.

An advantage of using hand skill measurements to measure handedness is that it avoids many of the problems that occur while using handedness inventories such as which items to use in the questionnaire or how to quantify or collate the scores on it. However, selecting an appropriate hand skill task can also be difficult. Tasks of hand skill cover a variety of different measurements and thus it depends on what measurement is taken as to what conclusions can be drawn. Different measures that can be taken include speed, strength, dexterity and steadiness (Bishop, 1990). It has been found that some of these aspects of hand skill correlate higher with hand preference than others (e.g. hand preference does not correlate highly with strength, Bishop, 1990).

Tests of hand skill tend to reveal that the preferred hand tends to be faster and more accurate than the non-preferred hand. It has been proposed that the bigger the difference in skill between the hands (as measured by, for example, time), the stronger the preference is for the more skilled hand over the less skilled hand. Therefore, the smaller the difference in skill between the hands, the less difference there is for preference of one hand over the other. However, this pattern is not always accurate. It is often found that the right hand of left-handers is faster or stronger in tests of hand skill. One explanation for this could be, as previously mentioned, that the right hands of left-handers have a certain element of skill as they have had to adapt to the right-handed world and therefore needed to perform certain skilled actions with their right hands. Also, even if the right hand of left-handers is not more skilled in these tasks than the left hand, in general, it is more skilled than the non-preferred hand of right-handers again because of the need for left-handers to use their right hands to perform some actions. This, however, is not the case for the left hands of right-handers. Murphy and Peters (1994) examined hand strength and found that right-handers have a clear difference between the hands with the right hand being much stronger than the left whereas they found that left-handers did not show this clear hand strength asymmetry.

One disadvantage of hand skill measurements is where handedness inventories are quick and easy to administer, tests of hand skill are often time consuming and can only be used on one person at a time. Also, tests of hand skill often require equipment or apparatus, which can often result in it not being portable while handedness inventories rarely require any equipment and can be easily ported. However, Tapley and Bryden (1985) conducted a study in which they devised a test of hand skill that could be administered to groups at a time. This, therefore, addresses the problem that only individuals can be tested on measures of hand skill. Another disadvantage is that there could be practice effects when carrying out tests. Many researchers try to carry out hand skill tasks that have little familiarity to the participants in order to avoid practice effects but as hand skill tasks have to be carried out at least twice (and in some cases twice with each hand if something like side of task is being controlled for) then it is difficult to avoid these practice effects. However, Bryden and Allard (1998) found that extended practice of hand skill tasks benefited both hands (with slightly more bias to the preferred hand) thus practice effects did not overtly favour one hand and this was not a major reason to avoid hand skill tasks. Also, Annett et al. (1974) found that practice improved the speed of each hand but did not alter the difference in skill between the hands.

Therefore although tests of hand skill seem to measure handedness as effectively as hand preference questionnaires it can be seen from this section that tests of hand skill are not without problems. Measurements are not always accurate, as some results may have come about by chance. For example, a person may be more skilled with the right hand but complete a peg-moving task faster with the left hand on the trials that were being measured. Also, the additional factor that most left-handers have a certain amount of skill in their right hands can also affect the results in tests of hand skill. The following section will compare and contrast measurements of hand preference and hand skill.

3.6. Hand preference versus hand skill

Annett (1985) stated that handedness is firstly a matter of skill rather than preference. She proposed that evidence of a right shift in humans could be demonstrated using a peg-moving task of hand skill. Annett et al. (1974) stated that the degree of hand preference was determined by the distribution of hand skill.

Researchers investigating human handedness often make use of hand preference inventories, but many feel that responses to such questionnaires are highly subjective and have sought more direct and objective measures (Bryden, McManus & Bulman-Fleming, 1994). Annett (1985) stated that using a peg-moving task was valuable because it has been shown to be reliable and related to other measures of handedness (mainly hand skill). One problem is that some researchers (e.g. Porac & Coren, 1981) state that measures of hand skill do not correlate well with measures of preference as assessed by questionnaires. However, Corballis (1997) stated that there is a strong relationship between hand preference and hand skill. He added that people identified as left- or right-handed for hand preference are almost always classified with the same preference for hand skill and vice versa. Bryden et al. (1994) has shown that skill measures are reasonably related to preference measures that assess the same activity. However, differences between the hands for different skills may be relatively unrelated to one another because an individual who prefers a specific hand to carry out unimanual activities in a number of different situations will always use that hand even when it is uncomfortable or awkward to do so.

Performance, according to Borod et al*.* (1984) involves tests such as strength, speed and accuracy. But Provins and Magliaro (1993) stated that handedness characteristics of individuals consist of determining the preferred hand in carrying out a range of manual activities or by recording different achievements of both hands on one task. Hand skill tends to apply to activities that require a bit more concentration and 'skill' whereas hand preference often refers not only to skilled actions on a handedness questionnaire but also in some cases to a number of unskilled actions.
Annett cites that there is a relationship between hand preference and hand skill. Annett (1985) found that individuals who were placed in to groups according to their strength of hand preference had an almost perfect correlation between their handedness strength scores and their performance on a peg-moving task. Also, Peters (1998) suggests that hand preference and performance are closely linked.

Although some researchers accept that hand preference measurements (i.e. questionnaires) and hand skill measurements are essentially measuring the similar things, other researchers are strongly against this viewpoint and maintain that these measurements are completely separate entities. Two of the biggest advocates of this view are Porac and Coren (e.g. 1981). They stated that hand skill, hand strength and hand proficiency are all separate aspects of the behaviour of handedness. Porac and Coren found that although there was a positive relationship between hand preference and hand skill that the strength of the correlation was not as strong as was often claimed (with a correlation co-efficient of around 0.6 often cited). Porac and Coren (1981) also noted that there must be a difference between hand preference and hand skill because the distribution of the two concepts are so different (J shaped for hand preference and normally distributed for hand skill).

Bishop (1989) described the discrepancies between hand preference and hand skill measures. She stated that hand preference and hand skill measurements are imperfectly correlated (with a correlation co-efficient of around 0.7 for a 5 item questionnaire and 0.72 for a 9 item questionnaire). However, she states that although the distributions of hand preference and hand skill are very different it does not necessarily mean that hand preference and hand skill do not share similar origins. However, Bishop (1990) added that although these correlations were not strong, they were not weak enough to say that there was no form of relationship at all. But, Bishop et al*.* (1996) cited that the differences between the distributions of hand preference and hand skill were evidence that they did not measure the same thing. Bishop (1989) used a model to illustrate these discrepancies. In this model Bishop set out to argue that these correlations between hand preference and hand skill (although not perfectly correlated) are not inconsistent with the view that hand preference is related to hand skill in that hand preference indirectly depends on hand skill. Bishop also examined the notion that the differences in distribution between hand preference and hand skill supposed that they could not be related. However, the model studied whether the probability that one hand will be preferred for a given activity is proportional to the relative proficiency of the two sides (for details of the model see Bishop, 1989). Bishop concluded that the findings of the relationship between hand preference and hand proficiency do not go against the view that preference is determined by proficiency but she does state that they are not the same thing. Also, McManus (1985) stated that it is not clear if strength of hand preference is reflected in hand skill performance and thus proposes that in some cases preference and performance may not be closely linked. He adds that this may be because in early development hand preference precedes hand skill.

There are both advantages and disadvantages for why it is better to determine handedness by means of preference questionnaires or by tests of hand skill. One advantage of using questionnaires is that large groups can be assessed at the same time or can even be assessed from a distance (which would also be advantageous for examining cultural differences of hand preference). In contrast to this, tests of hand skill usually involve only being able to test people individually.

Gangestead and Yeo (1994) stated that tests of hand skill show much finer differences between the hands than questionnaires do. They added that questionnaires might not show up any differences between those who are weakly right-handed and those who are strongly right-handed but a test of hand skill will pick up this difference and determine the strength of an individual's hand preference. However, there are problems with this. Some tests of hand skill may pick up on differences between the hands and these may be in the 'correct' direction, that it if a person prefers the right-hand then they will be more skilled with this hand. However, in many cases when individuals take part in tests of hand skill it is often the case that the 'non-preferred hand' comes out as the one that is quicker and is therefore considered to be more skilful because it is faster in terms of fine manual dexterity. Being more skilled with one hand and preferring the other hand was a concept backed up by McManus, Murray, Doyle and Baron-Cohen (1992). They found that in a study with children with autism; children with mental retardation and a group of normal controls that only 50% of the children with autism were concordant for hand preference and hand skill (that is 50% of the children preferred the same hand that they were more skilled with while 50% preferred the opposite hand to the one that they were most skilled with), 92% of the children with mental retardation were concordant and 90% of the normal control group were concordant for hand preference and hand skill.

However, when considering differences between hand skill in left- and right-handers one confound has to be addressed. Those who are left-handed will often have a fairly skilled right hand but those who are right-handed will often have a highly unskilled left hand. One reason for this is that because the world is designed for right-handers most things are designed for right hand use and thus left-handers have to adapt in order to get by in this right-handed world. Left-handers therefore ultimately have some element of skill in their right hands but as right-handers very seldom have to use their left hands then they are not as skilled, in most cases, as either their own right hand or the right hand of a left-hander. Thus it seems to be that in order to get a fully comprehensive measurement of handedness both measures of hand preference and hand skill have to be taken in to consideration.

Bishop (1990) assessed whether measurements of hand preference or hand skill would give the most accurate measurement of handedness and proposed that the most important decision to make should be based on validity. However, Bishop states that the validity of the measure has to relate to what it is going to be used for, i.e. is it valid for the particular purpose that is being examined. Thus, she proposes that, as many researchers will have different purposes that they need to measure handedness for and there will be much variability between studies then different tests of hand preference and hand skill will be valid (or not) in accordance to the individual. Bishop (1990) concludes the debate on hand preference and hand skill by declaring that the two concepts do not measure the same thing. She states that handedness inventories can lack validity in many cases and are often difficult to quantify and assign categories to. Bishop adds that handedness inventories only reflect someone’s preference for a number of actions on a questionnaire and does not indicate how skilled a person’s left or right hand is. She states that measures of hand skill are probably more reliable than measures of hand preference but much work needs to be done to examine tests of hand skill for reliability and validity.

Therefore, it can be concluded from this that although there tends to be a difference in skill between the left and right hands that this is not always the case. In most cases a person’s preferred hand is the one with which they are most skilled with but in a small number of cases the opposite is found (and this could either be caused by the person being genuinely more skilled with this hand or it could have occurred by chance). This could particularly be the case for left-handers who could genuinely be just as skilled or more skilled with their right hands. Therefore in order to gain as accurate a measurement as possible of a person's hand preference it would perhaps be best to carry out a test of hand skill and a handedness questionnaire. However, as previously mentioned a test of hand skill would have been too time consuming for the purposes of my studies as there were several additional components to each experiment. Therefore a handedness questionnaire was given, as it was quick to administer and contained a sufficient amount of information in it in order to categorise participants in to handedness groups.

3.7. Current Questionnaire – adapted version of Peter's (1998)

The questionnaire used during this thesis was that of Peters (1998) (for details of this questionnaire see appendix 2), this originally only had 25 items in it but was changed in order to include all of the items from the main handedness inventories. These inventories were the Edinburgh handedness inventory (Oldfield, 1971); Annett's (1970) handedness questionnaire; Peter's (1990) essential two items (writing and throwing) used to distinguish between consistent and inconsistent handedness alongside and Peter's (1998) handedness questionnaire. Bishop et al. (1996) also suggested a different method of categorising hand preference (see section 3.2.7.) but used the Edinburgh handedness inventory to illustrate this rather than devising a questionnaire of her own (this categorisation method is also included in the analysis of the 'Fastest Finger First' study and the Computer Task outlined in Chapter 6, see appendices 15 and 22 for these additional analyses). The two items that Peter's (1998) inventory lacked which were included within the other main questionnaires (the EHI – Oldfield, 1971) were '*with which hand do you use to eat with a spoon'* and '*with which hand do you use to open a box lid'*. Peters (1998) chose to omit these items and substitute them with hammering in a nail and unscrewing the lid off a jar but in order to have the direct set of EHI items within this questionnaire, Oldfield's original items were added again. After these items were added the revised version of Peter's questionnaire became a 27-item inventory. The same five-point scale as the one used by Peter's (1998) was used which ranged from 'right hand always' through to 'left hand always'. A score of 2 was given for each 'right hand always' response and –2 was given for each 'left hand always response'. A total score was calculated and individuals were divided in to simple handedness groups of left-handers and right-handers where a positive score was regarded as showing a right-hand preference and a negative score indicated a left-hand preference. It was decided to use the 5-point scale that Peters used rather than using the forced choice scale that he used when he administered the questionnaire for a second time as this scoring system was more effective for examining degrees of preference. Also, Peters (1998) stated that distinctions for many of the handedness items would be lost with a simple forced choice scale of left, right or either. In addition in my for the study 1 and study 3 in Chapter 6 and the first state study in Chapter 7 each handedness group (left and right) was divided in to sub-groups. Strong left-handers were considered as those scoring –35+and strong right-handers were those scoring 35+. Those scoring between -34 and –1 were regarded as mixed left-handers and those scoring between 34 and 1 were regarded as mixed right-handers. Analyses were done to see if strength of hand preference had an effect on performance (see appendices 15, 22 and 28). However, it was found that when the handedness groups were split in to these sub-categories that there were often not high enough numbers in each category in order to compare the performances of each group and thus it was decided to still measure handedness on the 5-point scale but to keep the categories broad in order to have enough participants for analysis in each group. Participants who wrote with the left hand but upon completion of the questionnaire fell in to the right-handed category were excluded from the analysis as there were not enough people in this category in order to examine and analyse performances (there were no participants who wrote with the right hand but were categorised as left-handed after completion of the questionnaire). Therefore in most of the experiments carried out during the thesis the simple dichotomy of left-handedness and right-handedness was kept in order to get as many participants as possible to make a direct comparisons (although a third group of mixed-handers may be examined at a later date). There was an element of difficulty obtaining enough left-handed participants (who were also divided in to groups of males and females) to participate in the study especially as they were taking part voluntarily and more importantly as they are infrequent within the population (only 10% of the population are left-handed) and thus the sub-divisions of the groups would have required many more participants than was possible to obtain.

The results obtained in experiments 1 and 3 in my thesis were not only measured using the adapted Peter’s inventory (the original choice of method for measuring handedness) but also by a number of other inventories such as that of Annett (1970) and Oldfield (1971). Statistics were performed on this data and in general they remained consistent suggesting that we can interpret our results based on different handedness questionnaire measurements. For some of the results for experiment 3 some findings were only significant using certain handedness inventories and not others. When analysing the state/trait data (see appendix 28) only the groups who were classified in the strong handedness groups (e.g. EHI strong, Annett consistent, Waterloo strong) showed a significant difference in state anxiety between left and right-handers. Those who were in the weak/mixed classification groups failed to show a difference between groups. It therefore suggests that how handedness is measured could affect results. For a more detailed account of these results see appendix 28.

3.8. Reliability of the adapted Peter's (1998) handedness questionnaire

3.8.1. Method

3.8.2. Participants

40 participants took part in this reliability study, 31 were right-handed, 26 females and 5 males (as measured by the adapted version of Peter's 1998 questionnaire) and 9 were left-handed, 8 females and 1 male. Participants were selected via convenience sampling. There were originally 51 participants but 11 were excluded from the analysis as they only took part in 1 testing session.

3.8.3. Materials and apparatus

A copy of Peter's (1998) adapted handedness questionnaire was given to the participants in both testing sessions. A copy of this questionnaire can be found in appendix 2. On the second testing session participants were provided with the props mentioned on the questionnaire. These were a pen (to illustrate drawing and writing), a knife, a comb, a box of matches (which illustrated striking a match and picking up a small object), a book, a light bulb, a phone, a stuffed toy dog (to illustrate stroking a dog or cat), a face cloth, a bag (to illustrate picking up a suitcase), a baseball bat, a toothbrush, a ball, a tennis racket, a hammer and a nail, scissors, a spoon, a needle and thread, a brush, a shovel, a deck of cards, a shoebox (to illustrate opening a box lid) and a jar.

3.8.4. Procedure

Participants were given the first questionnaire during a Psychology laboratory class. Participants were asked to imagine that their hands were empty and to state which hand they would normally use to do each of the subsequent actions on the questionnaire (for example writing and combing hair). No props were given to act out these actions with. Participants were given an identification number to put on their questionnaire when they were finished and they handed the completed questionnaire in to the experimenter. One week later the same procedure was carried out again. However, when the participants were given the questionnaire they were also provided with a series of props with which to act out each action with. Participants were instructed to act out every action (even if they were certain that they used a particular hand) in order to fill in the questionnaire in a consistent manner. Again the identification number of each participant was entered on the questionnaire and once they had competed all of the hand preference actions the questionnaires were submitted. The experimenter scored each questionnaire and each participant was given two had preference scores and correlations were carried out in order to investigate the reliability of the questionnaire.

3.8.5. Results

A Spearman's rho correlation was carried out and it was found that there was a significant strong positive relationship between the total handedness scores from week 1 and the total handedness scores from week 2 Rs(40) = 0.82, $p<0.001$.

This finding suggests that the questionnaire scores did not differ too much across the individuals from week 1 to week 2. However, there were some fluctuations in the scores and this tended to be caused by the choice of the 'always' and 'most of the time' responses. Although the choice of hand preference for each item did not change choosing the 'most of the time' response would reduce the score by 1 for each item or similarly choosing the 'always' response in place of the 'most of the time' response would increase scores by for each item. Therefore using a likert scale in order to measure the strength of hand preference is perhaps not always the most effective method. Perhaps using a forced choice of left hand, right hand or either hand, along with a test of hand skill, may be a more effective measurement of hand preference.

Chapter 4: Impulsivity and planning

4.0. Summary of the main aims of the thesis

One key concept central to my thesis is the reported differences in response styles between left- and right-handed monkeys and apes (e.g. Cameron & Rogers, 1999; Hopkins & Bennett, 1994). These findings suggested that fundamental differences exist in the way(s) that these primates interact with the world which are related to handedness. It has been noted that very few human studies have reported differences between left- and right-handers' behaviour and their interaction with the world and therefore the main aim of my thesis is to investigate the response styles of human left- and right-handers towards a variety of different novel tasks. The investigation of these potential response style differences will be carried out over a series of experiments, which will be designed according to the findings of each preceding experiment in order to investigate the potential response style differences in humans.

4.1. Aims of Chapter

Recent primate laterality research has indicated that right-handed primates take less time to respond to novel objects than left-handed primates (e.g. Hopkins & Bennett, 1994 and Cameron & Rogers, 1999). It was postulated that this response style difference might also be evident in humans (Rogers, 1999). Therefore a study was devised in order to test this (the 3-disk Tower of Hanoi) and this will be outlined in this chapter. Thus as it has been reported that right-handed primates approach novel objects quicker than left-handers it could be interpreted that right-handed primates are more impulsive in their behaviours than left-handers. This chapter will therefore briefly review some of the current impulsivity literature and will examine different definitions of impulsivity and details of how it can be measured as a prelude to the study. This chapter will also examine possible reasons for why it might be expected that there could be a difference in the approach to novel problem-solving behaviour between left- and right-handed humans and will cover existing planning literature, emotional processing, stress and anxiety and the issue of novelty as possible reasons or explanations for this. The Tower of Hanoi experiment will then be introduced and covered. The chapter will conclude by discussing the findings of the Tower of Hanoi and impulsivity experiments.

4.2. General introduction

Recent primate laterality research has indicated that right-handed marmoset monkeys take less time to respond to novel objects (within a novel environment) than their left-handed counterparts (Cameron & Rogers, 1999). Thus, it appears that the introduction of a novel object initiates some form of delay in the response of left-handers compared to right-handers. This finding was also supported by Rogers (1999) who found a difference in approach behaviour to a novel object between left-handed and right-handed marmosets and by Hopkins and Bennett (1994) who found that left-handed chimpanzees were slower to respond to novel objects than right-handed chimpanzees. Rogers (1999) suggested that these findings could be accounted for due to the differences in hemispheric specialisation for processing novel stimuli and controlling emotional responses. She proposed that the left hemisphere controls exploratory behaviour while the right hemisphere is associated with inhibitory or avoidance behaviour and thus this would suggest that right-handers would be influenced by the dominant left hemisphere and would be more likely to demonstrate exploratory behaviour while left-handers would be more likely to be controlled by the right hemisphere and demonstrate avoidance behaviour. Davidson (1992) also states that approach or exploration behaviour is related to the left hemisphere while avoidance behaviour is linked with activation of the right hemisphere. Although Rogers' (1999) findings were on marmoset monkeys she hypothesises that the same may be true for non-human primates.

Existing evidence that supports Roger's (1999) and Davidson's (1992) views is the Valence-Specific Hypothesis of emotional processing. This hypothesis suggests that the left hemisphere is specialised for processing positive emotions while the right hemisphere is specialised for processing negative emotions. This could therefore be linked to Rogers and Davidson's suggestion that the right hemisphere is associated with avoidance behaviour (or negative emotions) and the left hemisphere is associated with approach behaviour (or positive emotions). An additional link to the right hemisphere being associated with negative emotions or avoidance behaviour is that one of the emotions that may be evident in a novel situation is an increased level of anxiety. Several studies have reported that left-handers are more anxious than right-handers (e.g. Orme, 1970; Hicks & Pellegrini, 1978; Davidson & Schaffer, 1983; Dillon, 1989). Thus, it was decided to test Roger's suggestion that the findings of a difference in the behaviour of left- and right-handed marmosets towards novel objects or problem solving may also exist in humans. To do this a novel problem-solving task had to be used and the Tower of Hanoi was used as this is a widely used problem-solving task and is relatively easy to measure participants' responses to it. As the Tower of Hanoi is not only a problem-solving task but is more explicitly a task of planning (although there are conflicting arguments whether this is really the case, see section 4.3.1. for details of this) then an additional possibility if there is a delay in responding between left- and right-handers is that one group may be planning the solution to the problem more than the other and therefore the issue of planning has to be considered. Also, as the findings of Hopkins and Bennett (1994) and Cameron and Rogers (1999) suggested that left-handers took longer to respond to a novel problem it was decided to examine whether right-handers may be more impulsive in general than left-handers and therefore two measurements of impulsivity were included. The first measurement was the Barratt Impulsivity Scale (version 11, e.g. Patton, Stanford and Barratt, 1995), a self-report questionnaire and the second impulsivity measurement was a matching figures reaction time computerised task.

4.3. Introduction to the Tower of Hanoi study – Experiment 1

In human psychology few studies have examined the role of hemispheric dominance in relation to approach behaviour. However, Cameron and Rogers (1999) recently found in a study of primates that hemispheric dominance, as demonstrated by hand preference, might play a major role in demonstrating differences in how individuals interact with their surroundings. Rogers (1999) suggested that these findings could be the same for humans. Thus, a study was devised to test if this was the case for humans and potential reasons for why this might be the case are examined. The Tower of Hanoi problem-solving experiment is outlined here and the findings are discussed.

4.3.1. The Tower of Hanoi and planning

The Tower of Hanoi (TOH) disk transfer task is often used to look at peoples' planning or thought strategies (Welsh, 1991). It is a tool which is used widely to examine problem solving behaviour (Goel & Grafman, 1995). The versions of the Tower of Hanoi task used in different studies have varied considerably (Spitz, Minksy & Bessellieu, 1984) but typically the task consists of three pegs of equal length and disks of different sizes and different colours stacked on one or more peg(s). The task can be performed with various numbers of disks. The easiest version consists of three disks but as additional disks are added the task becomes very difficult to complete. The peg (or pegs) on which the disks are stacked to begin with is known as the start state and the order in which the disks have to be when the task is complete is the goal state. The task is completed when the participant places the same tower from the initial ring stack on the empty goal peg by following a series of rules. There are three rules that must be followed when completing this task; only one disk can be moved at a time; all disks that are not being used must remain on a peg and a larger disk must never be placed upon a smaller disk. According to Bishop, Aamodt-Leeper, Cresswell, McGurk and Skuse (2001) The Tower of Hanoi gives a quantitative index of planning ability as the numbers of steps used to solve the task are easily measured.

A similar tool to the Tower of Hanoi that is often used to examine planning is the Tower of London. The Tower of London (TOL) was introduced by Shallice (1982) in order to identify planning impairments in patients with frontal lobe lesions. It has also been frequently used to identify problems with planning aspects of executive function (Anderson, Anderson & Lajoie, 1996). It has also been suggested that the planning component of this task is created due to thinking ahead to ensure that the task is solved as efficiently as possible (Morris, Miotto, Feigenbaum, Bullock & Polkey, 1997). Owen (1997) states that the TOL requires planning because if an early incorrect move is made then it can make the task virtually unsolvable unless the participant can undo all of the moves that they have performed up until the wrong move. The Tower of London consists of a number of different coloured balls (ranging from 2 to 6) that are placed on three pegs of differing sizes. Once again, an initial state and a goal state are set and the participant has to rearrange the balls on the pegs to match the goal-state. In order to solve the Tower of London correctly, only a certain number of balls can be placed on each peg (Welsh, Satterlee-Cartmell & Stine, 1999). According to Owen (1997) the TOL is thought to depend more heavily on planning than spatial abilities. Ward & Allport (1997) developed a five-disk Tower of London for normal participants. It is similar to that of the Tower of Hanoi in that the disks are graduated in size however, it is different from the Tower of London as disks are used rather than balls. The disks are stacked on one peg of three (all pegs are of equal length). The aim of the revised Tower of London is similar to the Tower of Hanoi in that participants have to transfer the disks from the initial peg to the same order on the goal peg. Participants must obey the rules of moving only one disk at a time and must never place a larger disk on top of a smaller disk.

According to Scholnick & Friedman (1993) the Tower of Hanoi is an ideal piece of apparatus to measure planning as people can control the outcomes of their plans. The Tower of Hanoi and the Tower of London have been taken to be tests of planning ability and poor performance on them is often interpreted as inefficient planning ability (Gilhooly, Phillips, Wynn, Logie & Della Sala, 1999; Phillips, Wynn, Gilhooly, Della Sala & Logie, 1999). Goel, Pullara & Grafman (2001) state that in order to solve the task efficiently it appears that participants have to look several moves ahead and plan the solution in their heads ***before*** physically moving any disks. Thus, both the Tower of London and Hanoi tasks are viewed as measures of planning ability, with successful and efficient performance on the tasks depending on the subject's ability to plan ahead, by making a correct series of moves instead of making individual moves that are independent of other moves (Welsh, 1991). An important factor when solving the TOH and TOL is working memory as participants are often required to mentally make the moves first before physically doing so and therefore need to hold these moves in memory while carrying them out. Phillips et al. (1999) state that the demands on working memory will be huge as planning an effective solution to the Tower of London requires the participant to come up with a plan then remember the plan while executing it. However, Goel & Grafman (1995) believe that the TOH does not necessarily measure planning or the ability to 'look ahead'. They say that the interpretation of what people mean by 'planning' is often confused and so the definition is so vague that every cognitive activity can be interpreted as involving planning. They believe that having the ability to look ahead or plan is not necessary or sufficient to solve the TOH. Goel and Grafman believe that the main issue in solving the Tower of Hanoi is the realisation on the participants' part that a 'backwards' move has to be made in order to solve the problem in the optimum number of moves. Given that performance on the TOH & TOL tasks has frequently been believed to be dependent on the ability to plan ahead (Goel et al. 2001), a number of studies have examined whether instructing subjects to plan ahead does actually improve performance on the TOH and TOL tasks (Ward & Allport, 1997; Gilhooly et al., 1999; Phillips, Wynn, McPherson & Gilhooly, 2001).

In some studies no instructions about pre-planning are given, but in others participants are asked to make a full mental pre-plan before beginning the task (Phillips et al., 2001). Work by Ward & Allport (1997) instructed participants to plan their whole sequence of moves mentally before they began physically solving the task. Kafer & Hunter (1997) follow this by stating that since the participant has to perform the task in a minimum number of moves they therefore have to try to solve the problem before attempting the solution. Participants are sometimes informed what the minimum number of moves is to solve the task and in other studies this information is not given (Phillips et al*.*, 2001). Gilhooly et al. (1999) adopted a “think aloud” method for their participants while solving the Tower of London. This was done to obtain data on participants’ planning processes before they moved any disks of the task. Gilhooly et al*.* found that there were often discrepancies between the plan that people make before the execution of moves and the actual moves that they make. They also found that when people were instructed to think out loud that it slowed down planning and moving but did not change the participant’s approach to the task. Gilhooly et al. concluded that some people do make mental plans but rather than solely using this plan throughout the task they seem to plan as they go along and add parts of their pre-plan. In other versions of the Tower of Hanoi and Tower of London there is no explicit emphasis on planning (Phillips et al., 2001). The idea is to instruct the participant how to go about solving the task by indicating that they will begin with the initial state and have to end up with the goal state and outline the rules that they must follow while carrying out the task. In the present study there is no kind of planning instruction given and the participant can solve it in any way as long as they obey the rules.

In Phillips et al.’s (2001) study participants were assigned to one of three conditions – a plan condition, where they had to construct a mental plan of the minimum number of moves needed to solve the task; an inform condition, where they were told the minimum number of moves needed to solve the task and then asked to construct a mental plan, and a control condition where no specific planning instructions were given. Phillips et al*.* were interested to see if those who were given no planning instructions would plan for a shorter period of time than the two groups that were given planning instructions. They were also interested to see if the participants in the two planning conditions would complete the task in fewer moves than the control condition if pre-planning was vital for efficient performance on the Tower of London. It was found that those in the planning conditions spent more time making plans than those in the control condition but there was no effect of instructions to plan on how efficiently participants completed the task. This is an unexpected finding as it suggests that, contrary to earlier suggestions (e.g. Goel et al*.,* 2001), completing the TOH efficiently does not appear to depend on making a plan prior to beginning the task. Moreover, that planning before beginning the TOH task may not improve task performance.

One possible explanation of this finding is that participants were unable to make accurate pre-plans prior to starting the task and that is why they showed no improvements in performance. In a follow up experiment, Phillips et al. (2001) investigated whether people were able to plan mentally by examining their ability to identify various intermediate states of an optimum mental plan. They found that participants could make accurate pre-plans for up to two sub-goals ahead but not for three. Phillips et al. therefore concluded that people could make effective mental plans but only for a limited number of moves. However, mental pre-planning is not necessarily more effective in terms of quicker performance or a more accurate solution. They concluded that accurate performance on the Tower of London depends largely upon on-line planning – planning carried out during the execution phase (Ward & Allport, 1997) – in that decisions made during planning can be subject to change during the process of the task. This supports Gilhooly et al.'s (1999) earlier findings that showed that efficient performance on the TOH depends primarily on planning during task completion and that pre-plans were often subject to revision.

4.4. Possible reasons for delays in responding to novel problem solving

4.4.1. Planning

How people think about a novel object or situation may be concerned with how they approach it. Some people may have a greater tendency to consider a situation and plan what they might do before approaching and responding whereas others may respond immediately (see 4.3.1. for more details on planning). Planning can be defined as the process that encompasses the mental generation, evaluation, and selection of action sequences so as to effectively meet some future goal (Scholnick & Friedman, 1993; Gilhooly et al. 1999). Baker, Rogers, Owen, Frith, Dolan, Frackowiak and Robbins (1996) suggest that the essence of planning is the attainment of a goal through intervening steps that do not necessarily lead directly to that goal. Thus, like most problem solving tasks, tasks that require planning typically consist of a starting state, a goal state, and a set of intermediate states, which people have to negotiate in order to complete the plan. Owen (1997) states that a basic requirement of many cognitive and motor tasks is having the ability to plan ahead. He goes on to say that in cognitive planning a goal is achieved through a series of intermediate steps that do not always directly lead to the goal but aid to solve the task. Thus, it is important in the current study to examine the approach of the participants towards the Tower of Hanoi task. The Tower of Hanoi is often used as a planning task but in this context it is used as a problem-solving task and participants will not be instructed to plan in any way. Therefore, if there is a difference in approach between left- and right-handers towards the Tower of Hanoi then planning may be one possible reason why this is the case. However, no current literature has examined or reported if there are any existing differences in planning strategies between left- and right-handers. This issue will be further examined in chapter 7.

4.4.2. Motor control

Motor control is predominantly located in the hemisphere contralateral to the dominant hand (Shallice, 1982). Thus, if an individual is right-handed, then final control of motor action is by the left hemisphere and the opposite is true for left-handers. The results of many studies have suggested that there are differences in cognitive processing between left and right-handers, with left-handers often cited as superior in skills normally associated with right hemisphere dominance, such as maths (Annett & Manning, 1990) and visuo-spatial tasks such as mental rotation (Annett, 1992; Bishop, 1990). Conversely right-handers are often cited to excel at tasks predominantly controlled by the left-hemisphere, such as verbal tasks (Corballis, 1991). If handedness and hemispheric dominance can influence performance on a range of purely cognitive measures it is also possible that it influences the motor behaviour of an individual when that individual interacts with the world. That is, handedness is possibly the most direct expression of hemispheric dominance and therefore any influence of hemispheric dominance on cognition may be most apparent in the control of motor behaviour.

There are strong reasons to believe that lateralisation differences in cognition may be most strongly expressed as differences in motor control between left and right-handers. Corballis (1998) argues that evidence for cerebral asymmetries is more likely to be found in motor systems rather than perceptual systems (but see Rogers & Andrew (2002) for an alternative viewpoint). Whereas perceptual asymmetries are revealed only under restricted conditions, such as brief displays, motor asymmetries are readily apparent in almost all motor behaviour, including reaching, grasping, speech production (but less so for speech comprehension), and facial expression. In fact most motor behaviour is asymmetrical, with approximately 90 percent of humans preferring their right hand and being more skilled at using that hand (e.g. Amunts, Jäncke, Mohlberg, Steinmetz & Zillies, 2000; Amunts, Schlaug, Schleicher, Steinmetz, Dabringhaus, Roland & Zillies, 1996). Such a consistent and obvious asymmetry does not exist for perceptual processing.

Corballis suggests that organisms may be at a disadvantage if their perceptual system is substantially asymmetrical, with any bias in processing on one side of the perceptual field potentially making the organism vulnerable to attack or unable to locate prey (but see Rogers, 2000, & Vallortigara, 2000). In contrast, a number of advantages might be conveyed by motor asymmetries as opposed to perceptual asymmetries. For example, motor lateralisation may be important in fast sequential actions where the transfer of information between the hemispheres could delay responding. In addition 'lateralisation would also eliminate the possibility of interhemispheric conflict, especially in internally generated actions' (Corballis, 1998, p153). Thus, motor asymmetries are readily apparent, highly consistent, and could potentially provide the most direct measure of processing differences between right- and left-handers.

Roger's (1999) findings extend earlier work by Hopkins and Bennett (1994) who found that both female chimpanzees, and chimpanzees with a left-hand preference, were slower to approach novel objects than male chimpanzees, or those with a right-hand preference.

It can be noted, however, that contradictory findings have been reported by Watson and Ward (1996) who investigated temperament and problem solving in the small-eared bush baby (*Otolemur garnettii*). They found that left-handed subjects were less inhibited in their approach to novel objects than right-handed subjects.

4.4.3. Emotional Processing

Evidence which supports Rogers (1999) and Davidson's (1992) view that approach and avoidance behaviour may be controlled by different hemispheres comes from studies that have examined how each hemisphere processes positive and negative emotions. Two conflicting theories have been proposed to explain the role of each hemisphere in emotional processing. One view, known as the Right-Hemisphere Hypothesis, suggests that all emotional information is processed by the right hemisphere (Borod, 1993). However, an alternative view is the Valence-Specific Hypothesis, which suggests that the left hemisphere is specialised for processing positive emotions whereas the right hemisphere is specialised for processing negative emotions (Silberman & Weingartner, 1986; Jansari, Tranel & Adolphs, 2000). If the valence hypothesis is correct then it could be the case that the right hemisphere is associated with avoidance behaviour (negative emotions) and the left hemisphere with approach behaviour (positive emotions) (Davidson, 1993). Hopkins and Bennett (1994) argue that approach behaviour is associated with positive emotions, controlled by the left hemisphere, and that avoidance behaviour is associated with negative emotions, controlled by the right hemisphere. Such a view is supported by evidence showing that monkeys with extreme right-frontal activity exhibit more fearful behaviour than those with extreme left-frontal activity (Kalin, Larson, Shelton & Davidson, 1998). This result lends support to the Valence-Specific Hypothesis and also suggests that, in novel situations, left-handers can display a form of avoidance behaviour and right-handers can display a form of approach behaviour.

4.4.4. Stress and Anxiety

If right-hemisphere activation is associated with avoidance behaviour and negative emotional states then it may be expected that left-handers show other negative emotions in novel situations, such as increased anxiety. Although no study has examined laterality and anxiety in novel situations several studies have found left-handers to be more anxious than right-handers (Orme, 1970; Hicks & Pellegrini., 1978; Davidson & Schaffer, 1983). However, other studies have produced a variety of results, including no relationship between hand preference and anxiety (Beaton & Moseley, 1984; Merckelbach, de Ruiter & Olff, 1989) or increased anxiety in strongly left and right-handed people compared to mixed-handers (Wienrich, Wells & McManus, 1982).

Stronger support for the view that right hemispheric motor control may be associated with anxiety and shyness, and consequently approach behaviour, comes from studies with primates and human infants. Westergaard, Champoux, and Suomi (2001a) found that left-handed preference in infant rhesus monkeys is associated with greater levels of the stress hormone cortisol. Moreover, high cortisol levels at 6 months were predictive of a left-hand bias at both 6 months and 12 months of age (Westergaard, Byrne & Suomi, 2000). Based on these findings they argue that greater stress during infancy can cause a left-handed preference in rhesus monkeys. However, an alternative explanation of this finding might be that left-handedness, and right hemisphere motor dominance, increases anxiety and stress rather than stress causing the hand preference. Also, Westergaard, Chavanne, Houser, Cleveland, Snoy, Suomi and Higley (2004) recently found that there was a positive relationship between handedness index scores in female rhesus macaques and concentration levels of the stress hormone cortisol. That is, the higher the handedness score (where a positive score indicates a right-hand preference and a negative score indicates a left-hand preference) the higher the level of cortisol is. This contradicts the previous findings of Westergaard et al. (2001a) who reported that left-hand preference in infant macaques is associated with higher levels of cortisol. The hand preference of each macaque was determined over 50 trials by independent researchers who examined the food reaching of the individuals.

This interpretation is supported by results from EEG studies with human infants. Temperamentally anxious human infants who exhibit shyness and behavioural inhibition to novel situations have been found to show greater right-hemisphere frontal activation compared to left frontal activation (Fox, Henderson, Rubin, Calkins & Schmidt, 2001; Schmidt, Fox, Schulkin & Gold, 1999; Schmidt & Fox, 1996; Calkins, Fox, & Marshal, 1996). Behaviourally inhibited infants show greater right frontal activation as early 4 months (Schmidt & Fox, 1996) and greater right frontal EEG activity has been found to be associated with shyness in 7 year olds (Schmidt, et al., 1999). In addition, differences in right and left frontal activity at 4 months of age are predictive of sociability in infants during the second year of life (Schmidt & Fox, 1996). These results provide strong converging evidence that indicates that right hemisphere activation, or dominance, is associated with behavioural inhibition in novel situations.

4.5. Aims of the current study

The Tower of Hanoi (TOH) task was employed in this study to measure and examine approach behaviour in left and right-handed participants to a novel problem. In order to complete the standard 3-disk TOH task participants have to make a number of movements that could be easily and readily recorded and measured. Thus, completion of the TOH task provides a measure of motor behaviour in a novel situation. In addition, as completion of the task is believed to require planning (e.g. Goel et al., 2001) it was expected that participants might delay initiating their first move during a pre-planning stage. It was expected that if left-handers take longer to initiate motor responses in novel situations then they might take longer to make the first move in comparison to the right-handers. Thus, it was predicted that the time to initiate the first move on the TOH might be follow a similar pattern to the time it takes primates to initiate responding to novel objects. That is, it is predicted that as left-handed primates take longer to respond to novel tasks and objects then left-handed humans might reflect this response style. Also, if left-handers take longer during the pre-planning stage of the TOH then it is possible that this will lead to performance benefits in comparison to right-handers. Goel et al. (2001) suggest that to be able to solve the TOH efficiently participants have to plan several moves ahead before physically moving any disks and state that poor performance on the task reflects a deficiency in planning ability. Therefore, a competent performance on the Tower of Hanoi may depend on the ability to delay initial responding and to plan a few moves ahead in this time. Also, a 3-disk version of the Tower of Hanoi was used in order for participants to be able to solve the problem effectively. The issue of complexity and the Tower of Hanoi is addressed in chapter 7.

Alternatively, any delay in initiating the first move could simply result in the left-handers taking longer to complete the task in comparison to the right-handers. Phillips et al. (2001) examined planning instructions and performance on the Tower of Hanoi. They found that participants who were instructed to make full mental plans, planned longer than those not instructed to plan, but this had no effect on how effective a person was at solving the task. ‘Planning/initiation’ time in the current study begins when the Tower of Hanoi is shown to the participant and ends when the first disk is moved. Solution time includes planning time and the time taken to solve the task.

4.5.1. Theoretical rationale for Tower of Hanoi study and hypotheses

Recent evidence from research with primates suggests that right hemisphere motor control is associated with a more cautious cognitive style in novel situations whereas left hemisphere motor control is associated with a bolder approach (Rogers, 1999). Similarly right hemisphere activation is associated with behavioural inhibition, shyness and avoidance behaviour in human infants (Schmidt et al., 1999) and increased levels of stress in macaques (Westergaard, Lussier, Suomi & Higley, 2001). As hand preference is potentially the most direct measure of hemispheric dominance it is hypothesised that handedness will influence the behavioural response of individuals towards the Tower of Hanoi. It is predicted that as left-handers seem to be more cautious at responding in novel situations (Hopkins & Bennett, 1994; Cameron & Rogers, 1999; Rogers, 1999) then they would be slower to initiate responding on the Tower of Hanoi in comparison to right-handers. In addition, based on Hopkins and Bennett’s (1994) finding that females may also be more cautious in novel situations it was also expected that the female participants would delay their first move. No predictions are made on the number of moves taken to solve the task or the time taken to complete it as there are no previous experimental findings on which to makes these.

The reason for using the Tower of Hanoi as the task was that Cameron and Rogers (1999) used a problem-solving task which involved marmosets working out how to get mealworms out of a large tank containing a number of tubes and therefore the time taken to start touching the apparatus to try and retrieve the mealworms was considered as the most important measurement. Therefore in order to have a relatively similar human parallel a problem solving task that could be potentially worked out first was needed to mirror the measurements of Cameron and Rogers. It was decided to use the 3-disk Tower of Hanoi as this is a relatively simple task and the complexity of the task was not of the utmost importance. In fact the task needed to be relatively simple so that it would be relatively simple for all participants. Hopkins and Bennett (1994) used a series of novel objects and let the chimpanzees in their sample approach them. This latency time was considered as their most important measurement. Therefore in order to fuse both the procedures of Cameron and Rogers and Hopkins and Bennett a problem-solving task was needed for this current experiment and it had to be novel. All participants in the current experiment will be asked if they have seen or done the Tower of Hanoi before in order to ensure that the task is novel to all participants.

The dependent variables in the current study are the time taken to make the first move on the Tower of Hanoi; the number of moves taken to solve the Tower of Hanoi and the total time taken to solve the Tower of Hanoi.

4.6. Method

4.6.1. Participants

90 participants took part in the study. However, 6 participants who stated that they were left-handed but revealed a right-hand preference when they had completed the handedness questionnaire were excluded from the analysis, leaving 84 participants, 37 of whom were male and 47 were female. All participants were university staff and students at the University of Abertay Dundee. 42 participants were left-handed (23 females and 19 males) and 42 participants were right-handed (24 females and 18 males). All participants had normal colour vision and normal or corrected-to-normal visual acuity.

4.6.2. Materials and Apparatus

The Tower of Hanoi consisted of three white pegs in a row, one of which had three coloured rings of differing sizes stacked on it (The largest ring was purple, the medium ring was green and the smallest ring was blue) (see figure 4.4). A digital stopwatch with a split-time function was used to measure participant's completion times and a screen was used to conceal the Tower of Hanoi apparatus prior to them starting the task. A Tower of Hanoi scoring sheet was used to record the time taken to move the first disk, the time taken to complete the task, the number of moves taken to complete the task and the number of errors made (see appendix 7 for a copy of this). A set of instructions detailing the rules of the Tower of Hanoi was also given to participants. The instructions stated that there would be three disks on one peg and the aim was to get the disks on to the peg at the other end in the same order using the following rules: only one disk can be moved at a time; a bigger disk could never be placed on top of a smaller disk and only the dominant hand could be used to move the disks (see appendix 6a and appendix 6b for a copy of the instructions). There were two instruction sheets as the side of the disks was counterbalanced across participants with half of the sample starting with the disks on the right and half of the sample starting with the disks on the left (the order was also balanced within sex and handedness groups). Hand Preference was assessed using Peter's (adapted) (1998) handedness questionnaire.

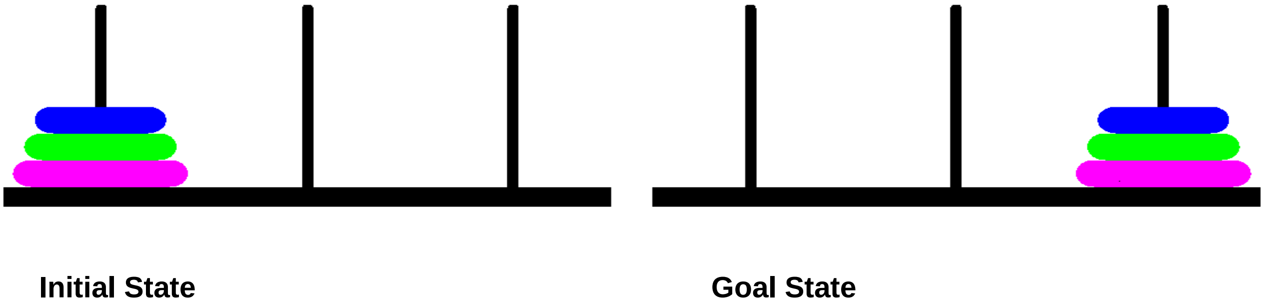


Figure 4.1: The Tower of Hanoi showing the initial and goal states

4.6.3. Procedure

Prior to beginning the Tower of Hanoi task participants were presented with a set of instructions depicting the initial state and the goal state and outlining the rules to be followed. The Tower of Hanoi apparatus was hidden behind a screen so that the participant could not begin planning the solution to the task until they were instructed to do so. The participant was given no planning instructions and no indication of how many moves the task could be solved in. All participants were tested individually. The direction was counterbalanced, 50% did left to right and 50% right to left and all participants were instructed to use their preferred hand to move the TOH disks. When the participant indicated that they understood what was expected, the screen was removed and the stopwatch was started. The time taken until the participant moved or touched the first disk was recorded, as was the number of moves they made and the time it took them to complete the task (along with the number of errors made). Participants then completed Peter's (1998) handedness inventory to get an accurate measure of their hand preference. Six participants, who used their left-hand to complete the TOH, but showed right hand dominance on the handedness inventory, were excluded from the analysis (leaving a final sample of 84 participants). Participants who had completed the Tower of Hanoi before were also omitted from analysis to ensure that the task remained novel.

4.7. Results

Table 4.1: Mean time (in seconds) taken for participants to move the first disk of the Tower of Hanoi (initiation time) (with standard deviations in parentheses).

	Left	**Right**	**Overall**
Male	6.8 *(10.6)*	1.5 *(1.1)*	4.1 *(5.9)*
Female	5.2 *(5.2)*	1.5 *(0.9)*	3.3 *(3.1)*
Overall	6.0 *(7.9)*	1.5 *(1.0)*	

The above table shows that left-handed males took the longest time on average to touch or move the first disk on the Tower of Hanoi; this was followed by left-handed females who took an average of 5.18 seconds to move the first disk. Right-handed males took an average of 1.5 seconds to move the first disk with right-handed females taking exactly the same time at 1.5 seconds. The left-handed males and the left-handed females had the most variable scores with standard deviations of 10.6 and 5.2 respectively. Males on average took longer than females to move the first disk (4.1 vs. 3.3 seconds) and left-handers took longer on average than right-handers to move the first disk (6.0 vs. 1.5 seconds).

A 2 x 2 (handedness (left Vs. right) by sex (male Vs. female)) between subjects ANOVA was carried out on the time taken by participants to move the first disk on the Tower of Hanoi task. There was a significant main effect of hand preference F(1,80) = 12.98, p<0.01 with left-handers taking significantly longer to move the first disk compared to right-handers (6.0 seconds Vs. 1.5 seconds). However, the effect of sex was not significant F(1,80) = 0.399, p>0.05 and the interaction between hand preference and sex also failed to reach significance F(1,80) = 0.370, p>0.05.

Because the variance was unequal across groups, it was possible that the observed effect was due to outliers. To check, outliers that were 2.5 standard deviations above or below the mean were removed and the data was re-analysed. This resulted in the removal of the data from 5 participants (2 male left-handers and 3 female left-handers) (n=79).

Table 4.2: Mean time (in seconds) taken for participants to move the first disk of the Tower of Hanoi (with standard deviations in parentheses) with outliers 2.5 standard deviations or more above the mean removed.

	Left	**Right**	**Overall**
Male	3.3 *(2.0)*	1.5 *(1.1)*	2.4 *(1.5)*
Female	3.4 *(2.0)*	1.5 *(0.9)*	2.5 *(1.4)*
Overall	3.3 *(2.0)*	1.5 *(1.0)*	

The above table shows the mean time taken by each group to touch or move the first disk on the Tower of Hanoi with the data removed from those participants who scored 2.5 standard deviations above or below the mean in order to control for variance within the sample. The table shows that female left-handers now took the longest time to move the first disk followed by male left-handers. Male right-handers and female right-handers still scored lower than the left-handed groups. Left-handers overall still took longer to move the first disk than right-handers and males took slightly longer than females to move the first disk.

With this variance removed the effect of handedness on time to move the first disk was still significant F(1, 75) = 27.89, p<0.01 with the mean time for left-handers (3.3 seconds, Sd 1.96) more than twice that of the right-handers (1.5 seconds, Sd 1.01).

Table 4.3: Mean number of moves taken by participants to solve the Tower of Hanoi (with standard deviations in parentheses).

	Left	**Right**	**Overall**
Male	9.0 *(3.1)*	9.2 *(3.0)*	9.1 *(3.0)*
Female	10.4 *(4.6)*	14.2 *(5.5)*	12.3 *(5.0)*
Overall	9.8 *(3.8)*	11.7 *(4.2)*	

The above table shows the number of moves taken by participants to solve the Tower of Hanoi and on average left-handed males took the least number of moves to solve it (9 moves) followed by right-handed males who took an average of 9.2 moves. Left-handed females took an average of 10.4 moves to solve the task and the right-handed females who took 11.7 moves took the highest number of moves on average. Right-handers took more moves on average to solve it than left-handers and females took more moves on average than males.

A 2 x 2 (handedness (left Vs. right) by sex (male Vs female)) between subjects ANOVA was carried out on the mean number of moves taken to complete the Tower of Hanoi task. There was a significant main effect of sex $\underline{F}(1,80) = 11.53$, $\underline{p}<0.01$ with males taking significantly fewer moves to solve the task than females (average of 9.1 moves Vs. 12.3 moves). There was also a significant effect of handedness $\underline{F}(1,80) = 4.58$, $\underline{p}<0.05$ with left-handers taking significantly fewer moves to solve the Tower of Hanoi than right-handers (average of 9.8 moves Vs. 11.7 moves). The interaction between handedness and sex approached significance $\underline{F}(1,80) = 3.85$, $\underline{p}=0.053$.

This marginal effect was analysed further by conducting two additional ANOVAs, one for male subjects and one for female subjects. For the males the effect of handedness did not reach significance $\underline{F}(1,35) = 0.028$, $\underline{p}>0.05$, with left-handers taking a similar number of moves, on average, to right-handers (9 Vs. 9.2). For the females, however, there was a significant effect of handedness $\underline{F}(1,45) = 6.878$, $\underline{p}<0.012$, with left-handed females taking significantly fewer moves than right-handed females (10.4 Vs. 14.2) to complete the task.

Table 4.4: Mean execution time (completion time minus initiation time) (in seconds) taken by participants to solve the Tower of Hanoi (with standard deviations in parentheses)

	Left	**Right**	**Overall**
Male	22.4 *(13.2)*	24.0 *(10.6)*	23.2 *(11.9)*
Female	27.2 *(17.5)*	41.1 *(29.8)*	34.1 *(23.6)*
Overall	24.8 *(15.3)*	32.5 *(20.2)*	

The above table shows the time taken by participants to complete the Tower of Hanoi task when the ‘planning’ time or time taken before making the first move is not included. The table shows that right-handed females took the longest time to solve the task followed by left-handed females. Right-handed males took less time that the two female groups to solve the task and left-handed males solved the task in the shortest time. Males solved the task quicker than females and left-handers solved the task quicker than right-handers. All standard deviations were relatively large which indicated that the time taken to solve the Tower of Hanoi within each group varied to a great extent.

A 2 x 2 (handedness (left Vs. right) by sex (male Vs female)) between subjects ANOVA was carried out on the mean time taken to complete the Tower of Hanoi task (complete time minus ‘planning/initiation time’). There was a significant main effect of sex $\underline{F}(1,80) = 6.97$, $\underline{p}<0.05$, with males completing the task faster than females. The effect of handedness approached significance $\underline{F}(1,80) = 3.74$, $\underline{p}=0.057$ and the interaction between handedness and sex was not significant $\underline{F}(1,80) = 2.49$, $\underline{p}>0.05$.

Table 4.5: Mean time (Total time taken to solve TOH including ‘planning’/‘initiation’ time) (in seconds) of participants to solve the Tower of Hanoi (with standard deviations in parentheses)

	Left	**Right**	**Overall**
Male	29.2 *(14.1)*	25.5 *(11.1)*	27.3 *(12.6)*
Female	32.3 *(19.9)*	44.3 *(30.7)*	38.3 *(25.3)*
Overall	30.8 *(17.0)*	34.9 (20.9)	

The above table shows the total time taken from when the Tower of Hanoi was unveiled to the participant until it was completed. The table shows that right-handed females took the longest on average to solve the Tower of Hanoi when ‘thinking’ or 'planning' time was also included in the solution time. Left-handed females took an average of 32.34 second to complete the Tower of Hanoi including 'initiation time. Left-handed males took an average of 29.17 seconds and the quickest time to complete the Tower of Hanoi including 'initiation' or 'planning' time, were achieved by the right-handed males who took an average of 25.49 seconds. On average, males took less time than females to complete the Tower of Hanoi and left-handers took less time on average than right-handers. All standard deviations were relatively large which indicated that the total time taken to solve the Tower of Hanoi within each group varied to a great extent – especially within the right-handed female group.

A 2 x 2 (handedness (left Vs. right) by sex (male Vs female)) between subjects ANOVA was carried out on the mean time taken to complete the Tower of Hanoi task (completion time including initiation time). There was a significant main effect of sex $F(1,80) = 5.54$, $p<0.05$, with males completing the task faster than females. The effect of handedness failed to reach significance $F(1,80) = 0.787$, $p>0.05$ and the interaction between handedness and sex was not significant $F(1,80) = 2.807$, $p>0.05$.

The main findings of Experiment 1 were:

- Left-handers took significantly longer to move the first disk on the Tower of Hanoi than right-hander. This was also the case when all outliers were removed.

- There was a significant main effect of sex on the number of moves taken to solve the task with males taking significantly fewer moves than females.

- There was a significant main effect of handedness on the number of moves taken to solve the task with left-handers taking significantly fewer moves than right-handers.

- When initiation time was not included in the total completion time there was a significant main effect of sex with males completing the task faster than females. The main effect of handedness approached significance (0.057) with left-handers completing the task faster than right-handers.

- When initiation time was included in the total completion time there was a significant main effect of sex with males completing the task faster than females. There was no main effect of handedness.

4.8. Discussion

In line with predictions, and in accord with previous work with primates, the left-handers were slower than the right-handers to initiate a response to a novel task. This finding supports the view that left-handers possess a more cautious cognitive style and that they are more likely to consider their actions before taking them (Hopkins & Bennett, 1994; Cameron & Rogers, 1999; Rogers, 1999). This indicates that hemispheric dominance possibly influences motor response style in humans.

The difference in time to initiate responding (or ‘thinking’ or ‘planning’ or ‘initiation’ time as it has been termed over the course of the thesis), between the left and right-handers suggests that the two groups adopted a different approach strategy to this novel task. Superficially it appeared that left-handers tended to study the problem before beginning it. This hesitation made by left-handers before beginning the task concords with the work of Cameron and Rogers (1999) who found that right-handed marmosets took less time to respond to novel objects compared with left-handed marmosets. The work of Hopkins and Bennett (1994), with chimpanzees, also supports the findings that left-handers are slower to approach novel stimuli than right-handers and that the right hemisphere seems to be associated with a more cautious cognitive style compared to the left-hemisphere which might be associated with a more bold and impulsive cognitive style. Thus a point which should also be addressed is that perhaps left-handers are not slower to respond but right-handers are actually quicker to respond and are therefore more impulsive. This issue is considered in sections 4.9 to 4.13 of this chapter.

Goel et al*.* (2001) suggest that completion of the TOH requires participants to plan ahead before making moves. The possibility that left-handers planned more is suggested by the finding that they solved the TOH in significantly fewer moves than the right-handers. Clearly, additional time devoted to planning could have resulted in this performance enhancement. Although superior performance on the TOH may indicate greater planning it does not necessitate its occurrence, as Phillips et al., (2001) have found little relationship between planning and performance on the TOH.

If left-handers planned more than the right-handers this may have influenced the results of the present study. It is possible that the left-handers took more time to make the first move because they decided to plan more than the right-handers. Thus, a decision to plan directly caused the delay in the left-handers first move. However, there is no evidence in the handedness literature to suggest that left-handers have a greater tendency to plan in comparison to right-handers and so the issue of planning in left- and right-handers must be researched further (see chapter 6). Moreover, even if left-handers planned for longer it would remain unclear what the underlying cause of the decision to plan might be. A suggestion, consistent with the existing literature, is that left-handers take longer to make a motor response in a novel situation due to increased caution and behavioural inhibition (Rogers, 1999; Hopkins & Bennett, 1994).

It can be noted that, while a decision to plan may not have caused the left-handers to delay their first move, the presence of that delay provided the left-handers with additional time to plan if they chose to use it in that way. This may be the reason why the left-handed females, for example, took fewer moves to complete the TOH task than the right-handed females. Thus, it is possible that greater planning enabled the left-handers to solve the TOH in fewer moves than the right-handers, although the cause of the delay may not have been due to planning.

It was also found that the male participants completed the TOH task in fewer moves and faster than the female participants. They did not, however, take longer to initiate their first move in comparison to the females, which suggests that they did not spend more time planning their solution compared to the females. It is possible that, as males have been reported to have superior visuo-spatial abilities than females (e.g. Siegel-Hinson & McKeever, 2002), this enabled them to solve this task more efficiently.

Another argument that could explain differences in response initiation between the left and right-handers found in the present study is that it was caused by the use of a visuo-spatial planning task. It has been suggested that right hemisphere dominance is associated with superior spatial abilities (Annett, 1992; Bishop, 1990). While evidence for a relationship between handedness and visuo-spatial abilities has been mixed and inconsistent (Annett, 2002) it remains a possibility that the visuo-spatial nature of the task caused the differences in response initiation. For example, it might be the case that when confronted with a visuo-spatial task, participants who have strong visuo-spatial abilities delay responding and rely on visuo-spatial imagery to partially solve the task prior to making a move. As a consequence the delay in the left-handers could have been a direct result of their superior spatial ability. While the results of the present study do not discount this argument, additional findings (see chapter 6) suggest that this is not the case.

A delay in making a response in a novel situation, or to a novel task, may convey obvious survival advantages. A more conservative approach strategy may be clearly safer than a bolder and more dangerous approach strategy. Thus, the consistent and continuing presence of left-handedness within human populations, and its presence in other primates, may be due to the fact that there are some important advantages associated with being left-handed and it is not a semi-pathological state as often presented in the literature (Harris & Carlson, 1988). The effect of different approach strategies is probably most evident during food gathering and foraging. In some dangerous situations, a cautious approach is advantageous because it is safer, whereas in other situations, where there is little danger, the safer approach looses out to a bolder approach because the bold individuals will get most of the food. Clearly, selection pressure would favour individuals with a naturally cautious, right-hemisphere dominant approach style, in some situations. This may account for the continuing presence of left-handedness in human populations.

Converging evidence from a number of fields suggests that the right-hemisphere is more involved in processing negative emotional information and that right-hemisphere activation is associated with temperamental shyness, anxiety, and behavioural inhibition in human infants (Schmidt et al*.,* 1999), and behavioural inhibition in primate's motor responses to novel objects (Hopkins & Bennett, 1994; Rogers, 1999; Cameron & Rogers, 1999). Thus, research consistently indicates that right hemisphere dominance, or activation, can result in behavioural inhibition. As behavioural inhibition is a key characteristic of increased anxiety (Gray, 1982) it is possible that increased anxiety in the left-handers caused them to delay their initial move. The approach behaviour exhibited by left and right-handers could be attributed to personality differences between the two groups. A common finding of research on hand preference and personality is that left-handers seem to be more anxious than their right-handed counterparts (e.g. Orme, 1970; Hicks & Pellegrini, 1978; Davidson & Schaffer, 1983; Dillon, 1989). If this is the case then this may help explain the hesitation made by left-handers when presented with a novel situation or object, i.e. they may be more apprehensive about the situation than right-handers. Orme (1970) found that left-handers tended to worry more while one of Dillon's (1989) key findings was that left-handers are worried by factors such as how they do at school and time pressures. Left-handers may therefore be more susceptible to worry about their performance on the TOH and therefore think about it more before tackling it. Also, as it appears that the right hemisphere may be associated with negative emotions and the left hemisphere with positive emotions then the valence hypothesis needs to be further examined with respect to differences between left- and right-handers. Jansari et al*.* (2000) conducted a study of emotional processing but only used right-handed participants and concluded that the valence hypothesis was supported when identifying positive and negative emotional faces (see chapter 5 for more details).

An interpretation of the findings of this study is that a dominant right hemisphere may elicit negative emotions, such as increased anxiety, in participants who are confronted with novelty. Thus, left-handers may show increased levels of state anxiety, but not trait anxiety, when confronted with a novel task. It is possible that inconsistent results in the literature, with regard to anxiety and laterality, may have been due to previous studies failing to discriminate between trait and state anxiety. The present findings suggest that left-handers may only exhibit greater anxiety in particular states and situations, but may not have greater trait anxiety (see chapters 6 and 7 for details of these studies).

4.9. Impulsivity – Experiment 2

4.9.1. Definitions of Impulsivity

There are numerous existing definitions of impulsivity in the literature. However, there is also a lack of agreement within this literature on how impulsivity can be conceptualised (Finn, Justus, Mazas & Steinmetz, 1999). Barratt (1985) said that one of the principal problems of impulsivity was that there is no generally accepted definition of it. When defining impulsivity, Evenden (1999) pointed out that definitions will vary from one culture to another and over time and would depend on the age of the person involved. Evenden (1999) concludes by saying that one reason that there is confusion over the definition of impulsivity is that there is not only one type of impulsive behaviour.

According to Helmers, Young and Pihl (1995) definitions of impulsivity vary across studies, some examples of definitions include '*the failure to evaluate a situation as risky or dangerous'* (Eysenck & McGurk, 1980), '*the inability to plan ahead'*, (Eysenck & Eysenck, 1977) and '*the failure to withhold a response that will lead to punishment or a deficit in passive avoidance learning'* (Gray, 1983), (cited in Helmers et al., 1995). According to Evans, Searle and Dolan (1998) there are two approaches to impulsivity. Evans et al. (1998) argue that the first type of impulsivity is one that is concerned with dealing with the tendency to act 'on impulse' whereas the other approach is concerned with individual's reports of their impulses and behaviours. Evans et al. go on to state that the individual may feel an increasing level of arousal before committing an impulsive act.

Barratt & Patton (1983) defined impulsivity as acting without adequate reflection, spur of the moment reactions, taking risks and trying to get things done quickly. Patton, Stanford and Barratt (1995) said that impulsiveness could be split into three sub-traits, these were motor impulsiveness, defined as *'acting without thinking'*, cognitive impulsiveness, defined as *'making quick cognitive decisions'* and non-planning impulsiveness, defined as *'present orientation or lack of futuring'* p769.
Dickman's (1990) research focused on impulsivity as a personality trait. Dickman (1990) proposed that two types of impulsivity existed, functional impulsivity and dysfunctional impulsivity. Functional impulsivity is associated with enthusiasm and adventurousness and is thought to be beneficial to the individual. The other type of impulsivity suggested by Dickman (1990) was dysfunctional impulsivity. Dickman described dysfunctional impulsives as people who have a tendency to engage in behaviours that have negative consequences.

Thus impulsivity can be defined in a number of ways but a common definition appears to be one of acting without little foresight or without thinking about any negative consequences in most cases to the individual (e.g. Patton et al. (1995)). It is this definition of impulsivity that will be considered for the following study.

4.9.2. Measuring impulsivity

The evaluation of impulsivity has been based on the use of many different instruments (self-reports scales, rating scales and performance/behavioural measures). Barratt (1983) states that the best way to evaluate impulsiveness is to use one single measure. However, one problem with many existing measurements of impulsivity, according to Carrillo-de-la-Pena, Otero and Romero (1993), is that they do not appear to evaluate or measure the same things (see section 4.9). This led Carrillo-de-la-Pena et al. to conclude that there is a lack of agreement across the different measurements of impulsivity and this could cause problems with the validity of some of the instruments used. One reason why self-report scales of impulsiveness are mainly used is, according to Barratt & Patton (1983) because tests of impulsiveness do not correlate well together.

One of the most widely used measurements of impulsivity is the Barratt Impulsivity Scale (BIS). The Barratt Impulsivity Scale was developed initially to separate impulsiveness from anxiety (Evenden, 1999). The BIS 11 is a thirty item self-report scale designed to measure general impulsiveness (Patton at al., 1995). Barratt (1994) suggests that there are three sub-traits in the BIS 11, "ideomotor" impulsiveness, which involves acting without thinking, a careful planning sub-trait involving paying attention to details and a future orientated "coping stability". Ideomotor impulsivity and planning related impulsivity have been consistently identified in previous versions of the BIS. A total score is calculated for each participant on the BIS and this is their impulsivity score (see sections 4.11. and 4.12. for details of the BIS used as a self-report measurement of impulsiveness in the current study.

Other measurements of impulsivity exist that do not consist of self-report questionnaires. The Matching Familiar Figures Test (MFFT) (Kagan, 1966) consists of a series of ten figures in which the subject is required to identify one of six very similar pictures to a 'target' picture (cited in Helmers et al., 1995). According to Miller and Byrnes (1997) this is one of the most widely used measures of impulsivity. The computerised impulsiveness-matching program used in the current study was an adapted version of the Matching Familiar Figures Test (see section 4.11 for details of this). As previously mentioned this task was used, as it is one of the most widely used measures of impulsivity which is not a self-report measurement. However, stimuli from Cooper and Podgorny (1976) were adapted and used, as they were suited to the matching aspect of the task. Additional behavioural measures include The Porteus Maze (Porteus, 1965) which consists of measuring the number of times the pencil is lifted or touches the boundaries of the maze (cited in Helmers et al*.,* 1995) and The 'Draw a Line Slowly' Task (Rohrbeck & Twentyman, 1986 cited in Helmers et al., 1995), which is a test that measures inhibition of motor activity. The subject is required to draw a line from the top to the bottom of a very thin column without crossing the edges as slowly as possible and the time taken to do so is recorded (cited in Helmers et al*.,* 1995).

4.9.3. General impulsivity

Dickman (1990) believes that impulsivity should not always be thought of as a negative concept. He states that when an experimental task is very simple, a high impulsive person's quick responses will have a very small cost in terms of the number of errors made (Dickman & Meyer, 1988). Dickman and Meyer (1988) proposed that highly impulsive people claim that they act with little foresight but it has been found that impulsives often respond slower than non-impulsive participants in experimental tasks. It has also been suggested that highly impulsive individuals spend less of the preparation time focusing on the task that they are about to complete. It has been suggested that low impulsives are superior on tasks which require fixation of attention, but Dickman and Meyer (1988) suggests that on a task where attention has to be switched very quickly, then high impulsives will perform better (Evenden, 1999). Also, males on average score higher than females on impulsiveness and therefore demonstrate a higher base rate of risk taking behaviour (Patton et al*.,* 1995).

4.10. Aims, rationale and hypotheses of the impulsivity study

Cameron and Rogers (1999) found that left-handed marmosets took longer to respond to novel objects than right-handed marmosets. As it was found that left-handers took longer to respond then it was proposed that right-handers were therefore, on average, responding more quickly and thus were more impulsive in their approach to objects. Therefore the following study (section 4.4.) was set up firstly to see if right-handers reported themselves to be more impulsive than left-handers (using the Barratt Impulsiveness Scale version 11, Patton et al., 1995) and secondly, when presented with a computerised matching task whether they would be quicker in their responses than left-handers. A mixed design was used where left-handed and right-handed male and female participants completed a matching task and the Barratt Impulsiveness Questionnaire.

The reason for using the computerised matching task was that it was a common and reliable measurement of impulsivity. The stimuli were adapted from an impulsivity study by Cooper and Podgorny (1976) but these researchers had only used right-handed participants. Similarly, the Barratt Impulsiveness Scale is the most often used self-report impulsivity scale and this has been extensively tested both for reliability and validity.

For the matching task the independent variable was the similarity of the shape being presented to that of the target stimuli. The dependent variables were the time taken (in milliseconds) to match the shapes (impulsivity measurement) and the number of errors made when matching the stimuli. The dependent variable on the Barratt Impulsiveness Questionnaire was the total score of participants' ratings for the thirty questions (self report impulsivity measurement).

It was hypothesised that right-handers would have higher self-report impulsivity scores than left-handers and right-handers would respond more quickly (or faster) on the computerised matching task.

4.11. Method: Impulsivity Study (BIS and Matching Task)

4.11.1. Participants

84 participants took part in this study, 37 were male and 47 were female. All participants were staff and students of the University of Abertay. 42 participants were left-handed (23 females and 19 males) and 42 participants were right handed (24 females and 18 males). Handedness was measured using the adapted version of Peters' (1998) handedness questionnaire. All participants had normal colour vision and normal or corrected-to-normal visual acuity.

4.11.2. Materials and Apparatus

a) Matching Task

A Power Macintosh computer with a colour monitor and a standard keyboard was used to present the stimuli and measure response latency (in milliseconds) and accuracy (number of errors made). The software used for creating and running the experiment was PsyScope (Cohen, MacWhinney, Flatt, and Provost, 1992).

The matching task consisted of 80 trials (10 practice trials and 70 experimental trials). The stimuli were adapted from Cooper and Podgorny's (1976) alternative test forms shapes (see appendix 3 for the full set of shapes). These shapes consisted of five target shapes that differed in the complexity of their design. The simplest shape had six points and the complexity ranged over eight points, twelve points and sixteen points to the most complex shape which had twenty-four points (See figure 4.1. for an example). Each target shape had 7 different reflected versions of it (see figure 4.2. for one sequence) ranging from very similar to the target shape to a complete reflection of it (see Cooper and Podgorny, 1976, for details of this procedure). The five target shapes were each matched up twice with their identical shape and twice with each of the 7 reflections of it (thus resulting in 80 stimuli). The order of these pairs was randomly presented on screen (10 trials were used as practice trials and 70 as experimental trials). During each trial a small star (*) was presented on screen to alert the participant that a stimulus was about to appear and then one of the target shapes was presented for 500 ms that was then followed by a black square (acting as a mask) for a further 500 ms and then a second shape. The participants pressed ‘B’ on the keyboard if they thought the second shape (which was either one of the reflections of the target shape or the target shape itself) matched the first shape and pressed the ‘N’ key if they thought there was a mismatch (see figure 4.3 for examples of a match and a mismatch). The second shape remained on the screen until a response was made. Once a full trial was completed the process began again with another stimulus and shape pairing. Prior to completing the matching task participants were given a set of instructions detailing what they were required to do (see appendix 4). The instruction sheet contained details of one sequence that the participant was going to be presented with and how they should respond. The participant was told that when they pressed a key to begin they would see a star (*) flashing briefly in the centre of the screen, this would indicate that they were about to be presented with a stimulus. The stimulus would consist of an abstract black shape in a circle that would be flashed in the centre of the screen. The stimulus would then be replaced by a black square again flashing briefly (500 ms) on the screen and finally another shape that would either be the same or similar to the stimulus would be presented. If the participant thought that the shape was the same as the stimulus then they were instructed to press the key ‘B’ and if they thought that the shape was different from the stimulus the they were instructed to press the key ‘N’. To aid the understanding of what participants should expect they were given a diagram of one sequence of the task.

Figure 4.2: The five different target shapes adapted from Cooper & Podgorny (1976)

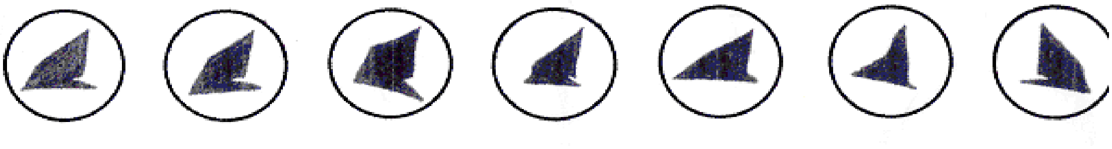


Figure 4.3: One full sequence ranging from the target stimuli (on the left) through to the complete reflection (on the right).

Match

Mismatch

Figure 4.4: A matching and non-matching sequence of the matching task stimuli.

b) Barratt Impulsiveness Scale

The Barratt Impulsiveness Questionnaire (version 11) was used (see appendix 5). This consisted of thirty questions measured on a four-point scale ranging from rarely/never, occasionally, often, to almost always/always. The questions asked included ‘I squirm at plays and lectures’, ‘I don’t pay attention’, ‘I concentrate easily’, ‘I am a steady thinker’ and ‘I act on impulse’. The statements were given scores of four for almost always/always, three for often, two for occasionally and one for rarely/never. Questions 4, 5, 13, 14, 15, 16, 17, 19, 20, 21 and 26 were reverse questions and therefore were scored one for rarely/ never, two for occasionally, three for often and one for almost always/always. Therefore the more impulsive a person was the higher their score would be and the less impulsive a person was then the lower their score would be.

4.11.3. Procedure

Each participant was firstly given the adapted Peter's handedness questionnaire (1998) so that their hand preference could be measured and results could be analysed accordingly (see chapter 3, section 3.7 for details of this). Participants were then informed that they were going to be given a self-report questionnaire and were asked to respond to each of the 30 statements on the Barratt Impulsivity Scale (version 11). Participants were not directly informed that this scale was measuring impulsivity but the title on the questionnaire cited that it was an impulsivity scale (see appendix 5). Participants were asked to indicate which one of four scaled responses (rarely/never; occasionally; often and almost always/always) best reflected themselves in relation to each impulsivity question – for example, in response to "*I concentrate easily*" if this was not the case then the participant should respond with either the 'occasionally' or 'rarely/never' response. Upon completing each of the thirty statements, participants were then asked to complete the next part of the study.

Participants were informed that the next part of the experiment would be done using the computer and were asked if they had any form of visual impairment that might affect their performance on the task. If the participant indicated that their vision was suitable to participate then they were presented with an instruction sheet that outlined what the matching program would entail (see appendix 4). If the participants indicated that they understood what they had to do (They were also given the opportunity to ask any questions if they did not understand something) and were happy to continue then they were informed that they would be given a practice task. The practice trials consisted of 10 trials and upon completion of these if the participant was comfortable to continue then they were given the 70 experimental trials to complete. If a participant indicated that they were not happy after the practice trials they were given the opportunity to complete the practice trials again or were told that they were free to withdraw from the experiment at any time (no participants chose this option). When they completed this task participants' scores were recorded giving details of whether they were correct or wrong, the reaction time in milliseconds of how long it took the participant to respond and whether the shape was the same or different to the stimulus. The ten practice trials were omitted from the analysis. After the participant had completed the matching task they were given an explanation about the experiment.

4.12. Results

4.12.1. Hand preference

Table 4.6: Mean hand preference scores of participants (with standard deviations in parentheses)

Sex and hand preference	Mean hand preference score
Left-handed male	-27.4 (*14.5*)
Left-handed female	-28.5 (*11.3*)
Right-handed male	32.9 (*8.7*)
Right-handed female	32.5 (*9.1*)

Table 4.1. shows that left-handed females, on average, had slightly stronger left-hand preferences than left-handed males (-28.48 vs. –27.42 respectively) and left-handed males also had more variable hand preference scores than left-handed females. There was very little difference between right-handed male and right-handed female's scores although right-handed females had more variable scores than right-handed males

4.12.2. Barratt Impulsiveness Scale (BIS)

Table 4.7: Mean Barratt Impulsiveness Scale (BIS) scores of participants (with standard deviations in parentheses)

Sex and hand preference	Mean BIS score
Left-handed male	70.4 *(13.2)*
Left-handed female	69.0 *(10.9)*
Right-handed male	68.2 *(9.4)*
Right-handed female	65.2 *(11.2)*

Table 4.2 shows the mean Barratt impulsiveness scale scores of all participants. It shows that, on average, left-handed males report themselves to be the most impulsive group followed by left-handed females and right-handed males. The least impulsive group, on average, is the right-handed females. The most variable group is the left-handed males followed by right-handed females; left-handed females (and the least variable group are the right-handed males.

A 2 x 2 (handedness (left Vs. right) by sex (male Vs female)) between subjects ANOVA was carried out on participants’ responses to the Barratt Impulsiveness Scale. This revealed no significant main effect of hand preference F(1, 80)=0.821, p>0.05, and no significant main effect of sex F(1, 80)=1.583, p>0.05. In addition, the interaction between hand preference and sex was not significant F(1, 80)=0.110, p>0.05.

4.12.3. Matching Task

Table 4.8: Mean reaction times (in milliseconds) of participants for the matching task (with standard deviations in parentheses)

	Left	**Right**	**Overall**
Male	1005.9 *(243.5)*	899.1 *(321.1)*	952.5 *(282.3)*
Female	990.1 *(222.1)*	886.0 *(201.1)*	938.0 *(211.6)*
Overall	998.0 *(232.8)*	892.5 *(261.1)*	

The above table shows that left-handed males took the longest, on average, to respond to the matching task stimuli followed by left-handed females. Right-handed males took less time to respond than left-handed males or females but were slower, on average, than right-handed females. Overall, males took longer to respond than females and left-handers took longer to respond than right-handers.

In order to examine these differences a 2 x 2 (handedness (left Vs. right) by sex (male Vs female)) between subjects ANOVA was carried out on the mean reaction time (in milliseconds) for the matching task. There was a significant main effect of hand preference F(1, 80) = 3.843, p=0.05 (or p=0.025 one-tailed) with left-handers taking significantly longer, on average, to respond to the shapes than right-handers. The effect of sex was not significant F(1, 80) = 0.207, p>0.05 and the interaction between hand preference and sex also was not significant F(1, 80) = 0.019, p>0.05.

Table 4.9: Mean number of errors made by participants on the matching task (standard deviations in parentheses)

	Left	**Right**	**Overall**
Male	9.3 *(4.8)*	9.4 *(5.1)*	9.3 *(5.0)*
Female	9.7 (5.7)	9.4 *(4.9)*	9.5 *(5.3)*
Overall	9.5 *(5.2)*	9.4 *(9.5)*	

The above table shows that all groups, on average, made a similar amount of errors on the matching task. Left-handed females made most errors and left-handed males made the least number of errors but the difference between the highest number of errors made by one group and the lowest number made was minimal. Overall, males made fewer errors than females and right-handers made fewer errors than left-handers but these differences were very minimal.

A 2 x 2 (handedness (left Vs. right) by sex (male Vs female)) between subjects ANOVA was carried out on the number of errors made on the matching task. The effect of sex was not significant $\underline{F}(1, 80) = 0.014$, $\underline{p}>0.05$ and the effect of hand preference was not significant $\underline{F}(1, 80) = 0.001$, $\underline{p}>0.05$. The interaction between hand preference and sex was also not significant $\underline{F}(1, 80) = 0.056$, $\underline{p}>0.05$.

The main findings of Experiment 2 were:

- There were no significant main effects of sex or handedness on the self-report impulsivity scores. However, left-handers reported themselves to be more impulsive than right-handers.

- Left-handers took significantly longer to respond to the matching task than right-handers. There were no sex effects.

- There were no main effects of handedness or sex on the number of errors made on the task.

4.13. Discussion

In line with predictions the left-handers were slower than the right-handers to initiate a response on the computer-matching task. This finding supports the view that left-handers perhaps possess a more cautious cognitive style and that they are more likely to consider their actions before taking them (Hopkins & Bennett, 1994; Cameron & Rogers, 1999; Rogers, 1999). This indicates that hemispheric dominance possibly influences motor response style in humans. However, very little work has been carried out with handedness and impulsivity and therefore it is difficult to explain these findings.

With respect to the self-report measurement of impulsivity (the Barratt Impulsivity Scale) right-handers reported themselves to be less impulsive than left-handers, thus the prediction that right-handers would be more impulsive than left-handers was not supported. Also, although the difference between the self-report impulsivity scores of left- and right-handers was in the opposite direction than that predicted, the difference was not significant. The impulsivity-matching task was designed to measure participants' reaction times and test for differences between left- and right-handers. It was found that there was a significant main effect of hand preference on the reaction times with left-handers having significantly slower reaction times than right-handers. This therefore supports the hypothesis that right-handers are more impulsive than left-handers and also relates to the hypothesis that left-handers will take longer to respond than right-handers on a problem-solving task as predicted for the Tower of Hanoi study. Therefore, although the self-report behaviour of the left- and right-handers did not suggest that there was any difference in impulsivity between them, the matching task designed to test reaction times and impulsiveness of the participants did suggest that there was a difference and this difference was in the direction that was predicted. However, one issue that may confuse the argument a little is that of novelty. Although the participants would not have completed the exact task before as it was designed specifically for the experiment, they may have completed some form of similar reaction time task to the current task. Thus is it cannot be guaranteed that novelty may be a contributing factor to the differences found in this task compared to those found in the Tower of Hanoi task. The issue of novelty will be further examined in Chapter 7 and discussed further in Chapter 8.

4.14. Conclusion

To conclude, the present findings reported in the Tower of Hanoi study and the Impulsivity study demonstrated that left-handers showed inhibitory behaviour in response to a novel task. This finding adds to the existing evidence that suggests that left-handedness is associated with increased anxiety and avoidance behaviour in novel situations. An important implication of these findings is that differences in cognitive processing and motor behaviour, between left and right-handers, may be partly due to differences in emotional states expressed by novel performance tasks.

Each of the possibilities that have been outlined in the discussion for the Tower of Hanoi study (section 4.2) will be considered in more detail in subsequent chapters where studies have been devised to test each possible explanation of what caused the delay in response to a novel problem in left-handers but not in right-handers. The issue impulsivity was examined in section 4.9 onwards of this chapter, emotional processing will be examined in chapter 5; planning will be examined in chapter 6 through a series of tasks and the issues of novelty and stress will be addressed in chapter 7.

Chapter 5: Emotional Processing

5.0 Aims of Chapter

One possible explanation of the Tower of Hanoi study reported in Chapter 4 was that there was a possible difference in emotional processing between left- and right-handers that might account for the differences in the way that they interact with the world. In Chapter 4 it was found that there was a difference in the time taken to move the first disk of the Tower of Hanoi and left-handers on average took significantly longer to do this than right-handers. Thus possible explanations were considered as to why this delay in left-handers occurred. One reason cited was that there might be a difference in the emotional processing of left- and right-handers and the Valence-Specific hypothesis was used to explain this. Thus, in this chapter a more detailed investigation of possible differences between left- and right-hander's emotional processing will be conducted using a partial replication of Jansari, Tranel and Adolph's (2000) free-viewing laterality task.

5.1. The right hemisphere hypothesis of emotion and the valence specific hypothesis of emotion

Many studies have suggested that the right hemisphere of the brain has a greater role in the processing of emotional information than the left hemisphere (Ley & Bryden, 1979; Levy, Heller, Banich & Burton, 1983; Christman & Hackworth, 1993; Leslie, Johnson-Frey & Grafton, 2004). This research has used both brain-damaged and normal participants and has examined the role of the right hemisphere in both the perception and expression of affect. For example, patients with right hemisphere damage are more impaired than those with left hemisphere damage at recognising emotions conveyed by facial expressions (Adolphs, Damasio, Tranel, & Damasio, 1996). In addition, it is believed that emotions are expressed more intensely on the left side of the face because the right hemisphere has a greater role in the control of emotional expression (Sackeim, Gur, & Saucy, 1978; Heller & Levy, 1981; Kowner, 1995).

With normal participants the majority of studies in this area have used the divided visual field technique to present faces with different emotional expressions. In support of findings from patient studies it has been found that there is a right hemisphere advantage (left visual field) in the perception and interpretation of emotional expressions (Ley & Bryden, 1979; Mandal & Singh, 1990; Strauss & Moscovitch, 1981). Leslie et al. (2004) asked participants to view or imitate a series of emotional faces and found that when the emotional faces were viewed that the right hemisphere was activated however, when the participant was imitating a series of faces (both positive and negative) there was bilateral activation of the hemispheres. The view, however, that the right hemisphere is preferentially involved in the processing of all emotional information has been questioned on a number of occasions. Many studies have suggested that hemispheric biases in the processing of emotional information may depend on the valence of the emotion conveyed by that information (Tucker, 1981; Ahern & Schwartz, 1979, 1985; Reuter-Lorenz & Davidson, 1981; Davidson 1992). For example, Reuter-Lorenz and Davidson (1981) found that when happy faces were presented to the left hemisphere they were perceived more quickly compared with sad faces. Conversely sad faces presented to the right hemisphere were perceived faster than happy faces. They concluded that there was a valence-specific laterality effect, with a left hemisphere advantage for the perception of positive emotions and a right hemisphere advantage for the perception of negative emotions. The findings of the Tower of Hanoi experiment in Chapter 4 were explained through the possibility of difference in temperament and behaviour influenced by the dominant hemispheres of left- and right-handers. Therefore it is possible that because left-handers have a more dominant right hemisphere they are more heavily driven and influenced by the inhibitory or emotional nature of the right hemisphere. Additionally, if the valence specific hypothesis of emotional processing is supported, then more specifically left-handers might be driven more by the negative emotional influences exhibited by the right hemisphere. This pattern is the opposite for right-handed individuals.

However, the validity of the valence hypothesis is a source of debate within the literature. A number of earlier studies have not supported Reuter-Lorenz and Davidson’s (1981) results. For example, Ley and Bryden (1979) in a dichotic listening task obtained a left ear advantage (right hemisphere) for the emotional judgement of messages, regardless of the emotional content of the message (whether it was happy, sad, angry, or neutral). In addition, other studies have suggested that both hemispheres are involved in the processing of positive emotions whereas the processing of negative emotions is lateralised in the right hemisphere (Mandal, Tandon & Asthana, 1991). For example, Borod, Koff, Perlman-Lorch, and Nicholas (1986) found that patients with right hemisphere damage were more impaired at perceiving negative emotions, but not positive emotions, than were patients with left hemisphere damage. More recently Asthana and Mandal (2001) found right hemisphere superiority in the perception of sad facial expressions but no lateralisation effects for the perception of happy expressions. These results suggest that the processing of negative emotions is more lateralised in the right hemisphere whereas positive emotions are processed bilaterally.

Other work, however, supports the view that hemispheric differences in the processing of emotional information depend upon the valence of the specific emotion (Davidson, 1992; Davidson, 1993). Evidence for valence-specific laterality effects have been obtained for both the expression of emotions (Ross, Homan & Buck, 1994) and experiencing emotions (Jones & Fox, 1992). Moreover, Davidson, Mednick, Moss, Saron, and Schaffer (1987) found that the perceived intensity of happy and sad facial expressions depends upon the hemisphere they are presented to, with faces being perceived as happier if they are presented to the left hemisphere. However, this effect may depend upon the handedness of the participants as Heller and Levy (1981) found that right-handed, but not left-handed, participants perceived faces as happier when presented in the left visual field. Finally, a study by Jansari et al. (2000) provides further support for the valence-specific hypothesis. This study differed from previous work in that it examined laterality effects for emotional processing under free-viewing conditions. They used a task similar to that employed by Reuter-Lorenz and Davidson (1981), which required participants to discriminate emotional expressions in pairs of faces. The faces were morphed so that the differences in emotional expression between the faces ranged from very subtle to clear. In support of the valence hypothesis Jansari et al. found more accurate discrimination of faces with positive emotional expressions when they were presented on the right hand side than when they were presented on the left hand side. Conversely, greater accuracy in discrimination was found for faces with negative expressions when they were presented on the left hand side rather than the right hand side. These findings suggest that laterality effects in emotional processing are valence-specific and that they are present under free-viewing conditions.

One explanation for the often-contradictory findings within the literature has been proposed by Van Strien and Van Beek (2000) who suggest that the different results may have been caused by the different types of task used. Borod (1993) proposed that the posterior regions of the right hemisphere are specialised for identifying the type of emotion conveyed by stimuli (e.g. facial expression, prosody) by extracting the meaning of the emotion cues (e.g. smile, intonation pattern). This interpretation occurs in the posterior regions of the right hemisphere irrespective of the valence of the emotion. However, when experiencing emotions, Borod (1993) suggests that the anterior region of the left hemisphere is preferentially involved in experiencing positive emotions whereas anterior regions of the right hemisphere are involved in experiencing negative emotions. Van Strien and Van Beek (2000) argue that studies that have required participants to match emotional expressions of faces will show a right hemisphere advantage because posterior regions of the right hemisphere can carry out this predominantly perceptual task. However, in discrimination tasks such as those used Reuter-Lorenz and Davidson (1981), which require participants to judge which of two images of the same face expresses an emotion, then anterior regions of each hemisphere are utilised. In this case valence–specific laterality effects emerge because in order to do the task successfully anterior regions of the hemispheres are used to experience the particular emotion conveyed by the face and successfully make the discrimination.

If Van Strien and Van Beek's account is correct then the more perceptual an emotion judgement task is then the less likely it will be that there will be a valence-specific laterality effect. However, the more a task relies on the judgement of emotional expressions then the more likely it will be that a valence-specific laterality effect emerges. Some support for this view comes from a study conducted by Safer (1981) who found a left visual field superiority when participants had to judge whether two facial emotions were the same or not. Importantly the left visual field advantage increased when participants were instructed to empathise with the expressed emotion rather than simply verbalise what the emotion was.

5.2. Gender and emotional processing

One reason why evidence in support of the valence hypothesis has been inconsistent may be because most studies have ignored the influence of the participant's gender. The majority of research that has examined differences in brain lateralisation between males and females has indicated that lateralisation of certain types of processing is more pronounced in males than in females. It appears that in males there is a right hemisphere advantage for non-verbal tasks and a left hemisphere advantage for verbal tasks, whereas females show less clear laterality effects on these tasks (Hellige, 1993; Iaccino, 1993; Hausmann & Gunturkun, 1999; Davidson, Cave a& Sellner, 2000 ; Inglis and Lawson, 1981).

Given that sex differences in lateralisation exist it is possible that hemispheric functioning differs between males and females for the processing of emotional stimuli (Eviatar, Hellige, & Zaidel, 1997; Sanz-Martin & Loyo, 2001). For example, Ladavas, Umilata, and Ricci-Bitti's (1980) found that females showed a left visual field superiority in discriminating emotions while males show no consistent asymmetries in emotional discrimination. In addition, Burton and Levy (1989) found that females, but not males, perceived faces with negative emotions fastest when presented in the left visual field and faces with positive emotions fastest when presented to the right visual field. These results indicate that females are more lateralised for emotional processing than males. Findings by Van Strien and Van Beek (2000) support this view. They examined the influence of sex and handedness on ratings of emotion in laterally presented cartoon faces. They found no effect of handedness but found that sex influenced ratings of emotion, with females rating neutral and mildly positive faces as more positive when they were presented in the right visual field compared to when they were presented in the left visual field. For the males the visual field did not affect how they rated the faces. These results, and those of Burton and Levy (1989), suggest that the valence hypothesis may depend upon the sex of the subject, with only females showing the valence-specific laterality effect. It is also possible that some of the conflicting results within the literature may have been caused by gender differences in emotional processing. Unfortunately, in Reuter-Lorenz and Davidson's original study the number of male and female participants was not reported and thus sex effects were not examined.

Van Strien and Van Beek's results, however, conflict with those of Jansari et al. (2000) who found the valence-specific laterality effect in both male and female participants. The different results could be due to different tasks used, with Van Strien and Van Beek presenting cartoon faces briefly whereas Jansari et al. presented real faces under free viewing conditions. Thus, the issue of whether the valence specific laterality effect is sex specific is unresolved. One of the purposes of the present study was to determine whether the valence-specific effect applies only to female participants, when completing the same free-viewing task as used by Jansari et al. (2000), or is limited to restricted viewing conditions.

5.3. Handedness and emotional processing

A further factor that may influence asymmetries in emotional processing is the handedness of participants. Differences in cortical organisation and processing between left- and right-handers have been reported and it is conceivable that these differences influence the lateralisation of emotional processing (Everhart, Harrison, & Crews, 1996). Many studies have avoided the handedness issue by selecting only right-handed participants (e.g. Esslen, Pascual-Marqui, Hell, Kochi & Lehman, 2004). While findings have been inconsistent, there is some evidence to suggest that right- and left-handers may have different asymmetries for emotional processing. For example, Reuter-Lorenz, Givis, and Moscovitch (1983) found that left-handers who did not show an inverted handwriting posture had an opposite pattern of valence asymmetry from right-handers and inverted left-handers. In addition, Everhart, et al. (1996) showed that left-handers had a right visual field bias for rating neutral expressions more negatively. This suggests that the processing of negative emotions is more strongly lateralised in the left hemisphere for left-handers. In contrast, however, Van Strien and Van Beek (2000) found no influence of handedness on the rating of emotional expressions as conveyed by cartoon faces. Thus, it is unclear whether handedness influences asymmetries in emotional processing. Moreover, it is likely that there are complex interactions between handedness, sex, and cortical organisation (Eviatar et al., 1997), which may only be clarified when these factors are studied in relation to one another.

To summarise, while some results indicate that the right hemisphere is predominantly involved in the processing of all emotions (Ley and Bryden, 1979), substantial evidence suggests that each hemisphere has a bias for processing emotions of a particular valence (Reuter-Lorenz & Davidson, 1981; Jansari et al*.* 2000; Davidson, 1992; 1993; Van Strien & Van Beek, 2000). It is also possible that there is a valence-specific laterality effect for females but not males (Van Strien and Van Beek, 2000), with females preferentially using the right hemisphere to process negative emotions and the left hemisphere to process positive emotions. Conflicting findings in this area may have been caused by some studies only using male participants (Asthana & Mandal, 2001) or failing to analyse the influence of sex (Reuter-Lorenz & Davidson, 1981). Finally, the effect of handedness on the lateralized processing of emotional expressions have produced inconsistent findings, with some studies reporting an effect (Reuter-Lorenz et al., 1983; Everhart et al., 1996) whereas other have found no effect (Van Strien & Van Beek, 2000).

5.4. Experiment 3 – Discrimination of emotional faces

In view of the contradictory findings within the literature the aim of the present study is to extend previous work and examine the effects of sex, and handedness on the lateralised processing of emotional expressions. The main purpose of the study is firstly to determine whether the valence-specific laterality effect applies to left- and right-handers on emotional processing in free viewing conditions. This effect is also investigated with males and females. Secondly, if there is a difference between emotional processing in left- and right-handers then can it be linked to possible cognitive or behavioural differences between the handedness groups?

As the effect of handedness on lateralised emotional processing has revealed conflicting results in the literature no clear predictions can be made. However, it is proposed that if there are any differences present that left-handers will be more accurate and quicker when processing negative faces while right-handers will be more accurate and quicker when processing positive faces. Also, it is predicted that valence specific effects would be present in female participants but not males (this is in accordance with Van Strien & Van Beek's, 2000 findings). The findings of Van Strien and Van Beek stated that clearer valence effects emerge when the comparisons of emotional expression are more subtle rather than obvious, thus, the largest effects may be more likely to occur when the discrimination between two faces is at its most difficult (for example, in the current study a 'happy' neutral face vs. a happy face morphed at the 5% level rather than a morph at the 25% level).

The independent variables in the current study are the levels of morphing of the emotional faces (with 5 levels: 5%; 10%; 15%; 20% & 25%), the side of presentation on screen of the emotional faces (with 2 levels: left hand side of the screen and right hand side of the screen) and the valence of the faces (with 2 levels: positive emotional faces (the positive emotions were happy and surprise) and negative emotional faces (the negative emotions were sad, disgust, fear and anger)). The dependent variables in the current study are the accuracy of identifying the emotional faces (measured in number correct) and the reaction time (in milliseconds) taken to respond to the emotional faces.

5.4.1. Rationale for experiment 3

It has been proposed that a difference in approach strategies towards a novel task might have been caused by differences in hemispheric specialisation in left- and right-handers (e.g. Rogers, 1999). More specifically, the dominant right hemisphere of left-handers is associated with inhibitory behaviour and the dominant left hemisphere of right-handers is associated with exploratory and approach behaviour. In accordance with this the valence hypothesis of emotional processing proposes that the left hemisphere is specialised for positive emotions and the right hemisphere is specialised for negative emotions. Therefore if the valence hypothesis is supported then it would be expected that left-handers would display a more negative and inhibitory behavioural style and right-handers would display a more positive and impulsive behavioural style caused by their right hemisphere and left hemisphere dominance respectively. Previous studies examining emotional processing have predominantly use right-handed participants (e.g. Jansari et al, 2000) and therefore patterns of emotional processing and potential differences between left- and right-handers are unclear.

It is hypothesised that if there is evidence to support the valence specific hypothesis, left-handers will identify more negative faces both faster and more accurately when presented on the left of the screen. Additionally, right-handers will identify positive faces both faster and more accurately when presented on the right hand side of the screen. If the right hemisphere hypothesis is supported then it would be expected that left-handers would identify emotions faster than right-handers but not necessarily more accurately.

5.5. Method

5.5.1. Participants

78 participants were used in this study. 35 were right-handed (17 males and 18 females) and 43 were left-handed (19 males and 24 females). All participants were staff and students of the University of Abertay Dundee. All had normal colour vision and normal or corrected-to-normal visual acuity.

5.5.2. Materials and Apparatus

a) Hand Preference

Hand preference was measured using the adapted version of Peters' (1998) handedness inventory (appendix 2). The mean handedness score of left-handers in this study was -24.79 (12.7) and the mean handedness score of right-handers was 37.95 (11.31).

b) Discrimination task

Ekman & Friesen's (1976) pictures of facial affect were used as stimuli. The same male face (J.J.) was used to create all of the stimuli - the neutral expression and the six emotions (two of which were positive (happiness, surprise) and four of which were negative (fear, sadness, disgust and anger)). (See appendix 8 for a copy of Ekman & Friesen's unmorphed stimuli).

In replication of Jansari et al., the Morph 2.5 software (Gryphon Software, 1997) was used to create the stimuli by morphing the neutral face with the emotional face. The morphing procedure consisted of identifying corresponding features on both faces. Once these features had been identified the morphing process was carried out and the two faces were merged to create one morphed image. The morphing process was carried out on each of the six emotional expressions and five different levels of morphing were used (5%, 10%, 15%, 20%, and 25%). For example, the happy expression was morphed at 5% with the neutral expression, so 5% of the morph was the happy expression and 95% was the neutral expression. At this level of morphing the expression was extremely subtle, showing a very faint emotion. The highest level of morphing consisted of 25% of an emotional expression and 75% of the neutral expression (See figure 5.2 for examples of these morphing levels and appendix 9 for a full set of morphed pictures). Jansari et al. used the same 5 morph levels and reported that there was a ceiling effect after the third level (15%) thus it was decided to keep the morphing levels in the current study constant with Jansari et al.'s. study. The 5 morphs for each of the 6 emotional expressions gave a set of 30 morphed faces (see appendix 9). These 30 morphed faces were then put in to a Superlab (version 1.4) program and were arranged so that 60 different stimuli were created (see appendix 10). For each emotion the morphed face at each level (5%-25%) was placed on the left hand side of the screen with the neutral face on the right and then the emotive face was placed on the right hand side of the screen with the neutral face on the left. The corresponding emotion label was placed at the centre of the top of the screen and the participant was asked to identify which face showed that emotion (they responded either ‘left’ or ‘right’ using specified keys). Thus, for each emotion 10 different stimuli were created (for example a happy face morphed at the 5% level would be presented firstly on the left of the screen and the label ‘happy?’ would be added and then the same process would occur with the 5% happy morph face on the right hand side of the screen. This would then occur for each morph from 10% to 25% on the left hand side and the right hand side of the screen giving 2 stimuli per morph level emotion). A total of 60 stimuli were therefore created. Additionally, in order to examine if there was any effect of the emotion label given on how participants responded, 2 control stimuli were included per emotion. These control stimuli consisted of 2 identical neutral faces side by side with one of the six emotion labels at the top (for an example see figure 5.1. and for a full set of control stimuli see appendix 11). Thus, for the emotion ‘happy’ 2 neutral faces side by side were created and the ‘happy’ label was added beside them. This was done twice and added to the existing ‘happy’ stimuli. These control stimuli were also created for the remaining 5 emotions giving a final total of 72 stimuli in the program. The Superlab program randomised the order that the stimuli were presented in. A short practice trial was created that consisted of 6 random trials so that the participant could familiarise themselves with the process and the appropriate response keys.

An instruction sheet detailing what the participant would be required to do was also used. The instruction sheet showed an example of a pair of faces and the participant was informed that they would be shown a pair of faces on the computer screen with one of six emotion labels and that they had to decide whether the face on the left hand side or the face on the right hand side of the screen showed that emotion. Participants were told that there were two positive emotions, either happy or surprise, and four negative emotions, sad, anger, fear and disgust. For a full copy of these instructions see appendix 12.

A Compaq laptop computer with a coloured screen and standard keyboard was used to present the face stimuli and measure accuracy. The software used for creating and running the experiment was Superlab Pro v1.2 for Windows.

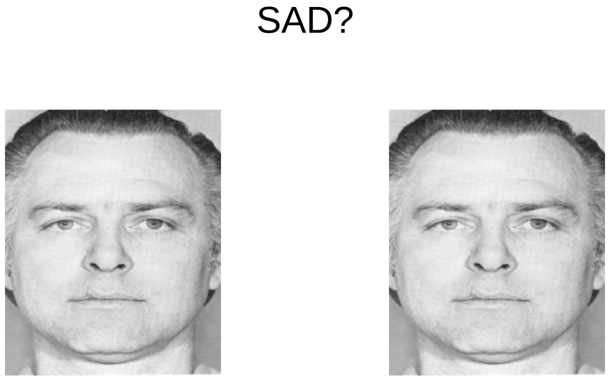


Figure 5.1: An example of a double neutral control trial.

Both pictures are identical and show the neutral face without any morphing. The emotional label ‘sad’ is added so that the participant is forced to choose whether they think that the face on the left or the face on the right is depicting the emotion ‘sad’.

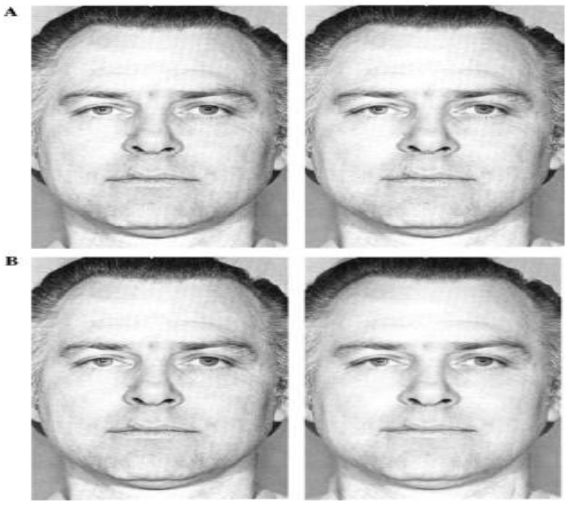


Figure 5.2: Examples of stimuli. Pair A shows a neutral face on the left and a happy face on the right at the 5% morph level. Pair B shows a neutral face on the left and a happy face on the right at the 25% morph level.

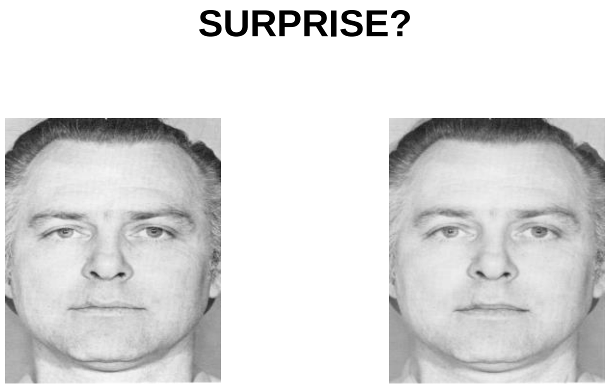


Figure 5.3: The face on the left hand side shows a neutral face while the face on the right hand side of the screen shows a surprise face morphed at the 25% level.

The participant is shown this and asked to identify whether the face on the left hand side or the right hand side of the screen shows the emotion ‘surprise’.

5.5.3. Procedure

Participants were presented with a set of instructions that outlined what the task would entail. An example of one pair of faces and the relevant emotion was shown to the participant and they were informed that they would perform six practice trials before completing the full program. For each trial the participants were presented with two faces. The faces were presented side by side and each face was 16 cm x 11 cm and the participants sat approximately 40 cm from the screen. On the screen, directly above the mid-point between the two faces, a label indicating one of the six emotions was presented simultaneously with the faces (see figure 5.3. for an example). The participants were instructed to select the face which best depicted the emotion corresponding to the emotion label. They were instructed to press ‘Z’ if they thought the emotion face was on the left, and press ‘M’ if they thought it was on the right. After each response the stimuli were removed from the screen and a mask was presented for 700 ms until the next trial began.

There were 72 experimental trials. For 60 trials one of the two faces was a neutral face and the other face was an emotion morph expressing the same emotion as the emotion label. To counterbalance the side of presentation, each one of the 30 morphs was shown twice, once to the left of the neutral face and once to the right of the neutral face. A further 12 control trials were also included to determine whether there was a response bias in participants, with them preferentially selecting the right or left side. These trials consisted of presenting two identical neutral faces with an emotion label. Even though the faces did not differ the participants were required to select the face that they thought best depicted the emotion label. Each of the emotion labels was presented twice. The order of presentation of the 72 trials was randomised. After completing the discrimination task the participants completed the handedness questionnaire. The whole session took approximately 15 minutes.

5.6. Results

Analysis was partially based on Jansari et al.'s. procedure. However, Jansari et al. only analysed the first 3 morph levels for each emotion whereas in the current study all 5 levels of the morphs were analysed. Also, the participants in Jansari et al.*'s*. study responded to the faces verbally but in the current study participants responded using the computer program thus the current study has a series of reaction time data which was analysed. Jansari et al.'s' control tasks were also different from the double neutral trials that were carried out and thus the analysis of these trials was not based on their analysis. Finally, when analysing the data emotions were regarded as either positive or negative (valence) rather than as single emotions (for example sad, fear or anger).

5.6.1. Accuracy data

Table 5.1: Mean accuracy scores (in percentages) for each condition at each of the five levels of morphing (ranging from 5% to 25%).

	Left Handed		**Right Handed**	
	Female	**Male**	**Female**	**Male**
Positive Left	45, 70, 77, 85, 91	68, 71, 84, 81, 79	55, 69, 67, 69, 86	71, 62, 82, 76, 94
Positive Right	77, 79, 85, 89, 96	66, 71, 79, 74, 79	58, 78, 78, 88, 91	82, 76, 82, 88, 97
Negative Left	53, 64, 64, 68, 76	59, 58, 53, 66, 71	58, 68, 65, 71, 75	48, 51, 72, 62, 76
Negative Right	37, 46, 54, 67, 76	61, 45, 62, 67, 71	42, 42, 53, 60, 80	59, 53, 65, 73, 82
MEAN	53, 65, 70, 77, 85	63, 61, 69, 72, 75	53, 64, 66, 72, 83	65, 61, 75, 74, 87
Total mean accuracy	70%	68%	67.6%	72.4%

Table 5.1 shows that overall the most accurate group was the right-handed males (with an average accuracy level of 72.4%) followed by the left-handed females (70%

accuracy) and the left-handed males and the right-handed females scored, on average, around the same level of accuracy overall (68%). Overall, males scored slightly higher on accuracy levels of discriminating emotions than females (70.2% vs. 68.8%) and right-handers were slightly more accurate overall than left-handers (70% vs. 69%). Overall morph levels show that on the 5% morph level regardless of the emotion being shown (valence) or the side of the screen that the emotional picture was presented on that right-handed males were most accurate at spotting the emotion (an average of 65%) followed by left-handed males (63%) and left-handed females and right-handed females were both accurate at choosing the 5% morphed emotion face, on average, 53% of the time. Left-handed females were most accurate at spotting the emotion at the 10% morph level (65%) followed by right-handed females (64%) and left-handed males and right-handed males were accurate at identifying the 10% emotion morphs 61% of the time. The most accurate group identifying the 15% morph level emotional faces was the right-handed males (75% accuracy) and the least accurate group was the right-handed females (66% accuracy). The most accurate group identifying the 20% morph level emotional faces was the left-handed females (77% accuracy) and the least accurate group was the right-handed females and the left-handed males (72% accuracy). Finally, overall, the most accurate group identifying the 25% morph level emotional faces was the right-handed males (87% accuracy) and the least accurate group was the left-handed males (75% accuracy).

With regard to the valence of the emotion, on average, all groups were more accurate at identifying the positive emotions than the negative emotions. With respect to the side of the screen that the face was presented on, positive faces presented on the right side of the screen were more accurately identified than positive faces presented on the left hand side of the screen. This pattern (or the opposite pattern) was not so apparent when negative faces were presented on the left hand side and the right hand side of the screen. Accuracy scores were similar regardless of the side of the screen that the negative faces were viewed on.

In order to examine these differences a 2 X 2 X 2 X 2 X 5 (sex (male Vs. female) handedness (left Vs. right) side (left Vs. right) valence (positive Vs. negative) morphing (5%, 10%, 15%, 20%, 25%)) mixed-model ANOVA was conducted on the mean accuracy data. Sex and handedness were between-subject factors and side, valence, and morphing were within-subject factors.

This showed a significant main effect of valence, F(1, 74) = 79.66, p<0.0001, with participants more accurately classifying positive emotions (mean = 77%) compared to negative emotions (mean = 61%). As expected there was also a main effect of morphing, F(4, 296) = 40.43, p<0.00001, reflecting greater accuracy in detecting emotions as the emotional expression became stronger (see table 5.1). There was also a significant two-way interaction between morphing and sex F(4, 296)= 4.37, p< 0.0020. This was due to the females being significantly less accurate than the males at the 5% morph level F(1, 74) = 10.40, p<0.0019, (females 53%: males 64%), but being as accurate as the males at the 10%, 15%, 20%, and 25% morph levels (p > 0.05). There were no other significant main effects or interactions.

Table 5.2: Mean accuracy scores (in percentages) for each condition collapsed across levels of morphing. (Standard deviations are in parentheses).

	Left Handed		**Right Handed**	
Emotion & side of presentation	**Female**	**Male**	**Female**	**Male**
Positive Left	74 *(19)*	77 *(13)*	69 *(13)*	77 *(16)*
Positive Right	85 *(15)*	73 *(24)*	78 *(22)*	85 *(13)*
Negative Left	65 *(14)*	61 *(20)*	66 *(19)*	62 *(13)*
Negative Right	55 *(17)*	61 *(20)*	56 *(15)*	66 *(13)*

The above table shows that right-handed males and left-handed males were the most accurate groups, on average, at identifying positive emotional faces when they were presented on the left hand side of the screen. When the positive emotional faces were presented on the right hand side of the screen right-handed males and left-handed females were the most accurate, on average, at identifying them (85% accuracy level). Right-handed females were most accurate at identifying negative faces on the left hand side of the screen (an average accuracy level of 66%) and right-handed males were most accurate at identifying negative faces on the right hand side of the screen (an average accuracy level of 66%). Each group had a higher accuracy level, on average, for identifying positive emotions rather than negative emotions.

To examine these differences a 2 X 2 X 2 X 2 (sex (male vs. female), handedness (left vs. right), side (left vs. right), valence (positive vs. negative) mixed-model ANOVA was conducted. The main effects of handedness, sex, and side, failed to reach significance (all F's < 1). However, there was a significant two-way interaction between side and valence, F(1, 74) = 8.17, p<0.0055, which was qualified by a significant three-way interaction between side, valence, and sex, F(1, 74) = 7.67, p< .0071. This three-way interaction was examined by conducting two further ANOVAs, one for the male participants and one for female participants. These are shown in figures 5.4. and 5.5. below.

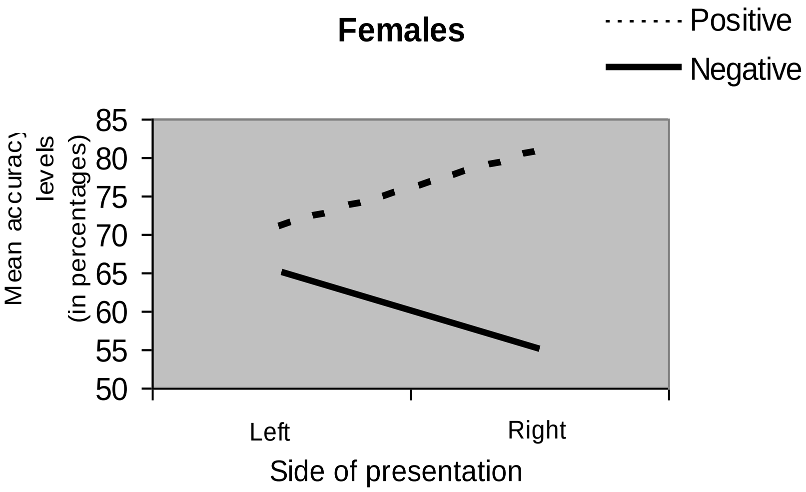


Figure 5.4: Female's discrimination accuracy as a function of side and emotional valence (positive, negative).

Analysis of the performance of the females showed a significant effect of valence, F(1, 40) = 55, p <0.0001, reflecting greater accuracy for detecting positive emotional expressions (mean = 76%) compared with negative emotions (mean = 61%). In addition, for the female participants, there was a significant side X valence interaction, F(1, 40) = 15.44, p< 0.0003, which was examined further by conducting two additional ANOVAs, one for negative emotions and one for positive emotions. The analysis of negative emotions in the female participants revealed a significant effect of side, F(1, 40) = 10.66, p< 0.0022, demonstrating that females were significantly more accurate at detecting negative emotions when they were presented on the left side (mean = 65%) compared to when they were presented on the right side (mean = 55%). Similarly, for positive emotions the female participants also showed a significant effect of side, F(1, 40) = 5.92, p< 0.019, reflecting greater accuracy at detecting positive expressions presented on the right side (mean = 82%) compared to the left side (mean = 72%). Thus the female participants demonstrated the valence-specific laterality effect under free viewing conditions (figure 5.4).

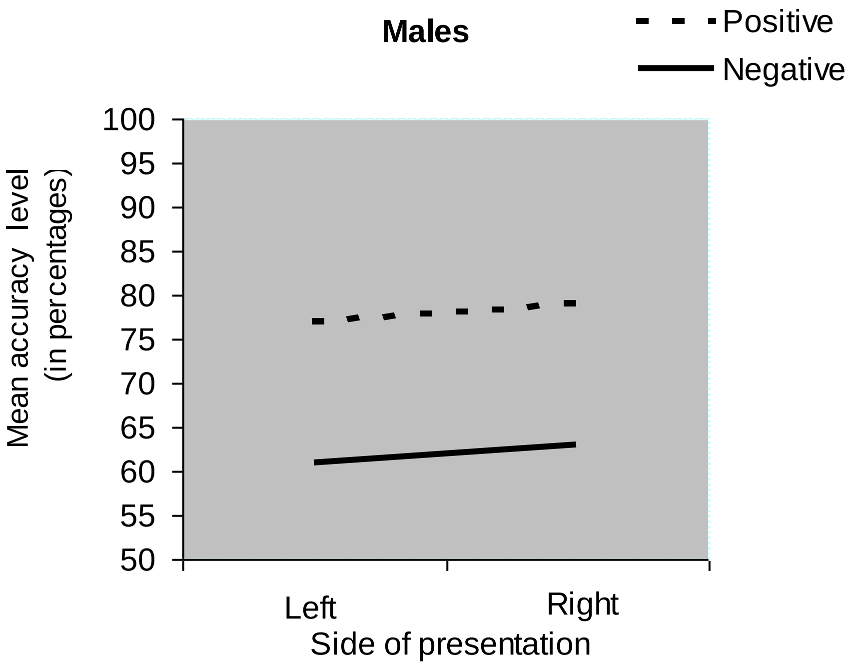


Figure 5.5: Male's discrimination accuracy as a function of side and emotional valence (positive and negative).

The analysis of the performance of the male participants also showed a significant main effect of valence, F(1, 34) = 29.63, p<0.0001, which was due to greater accuracy at classifying positive (mean = 78%) versus negative (mean = 62%) emotions. However, in contrast to the females, the male participants failed to show a significant valence X side interaction, F(1, 34) = 0.01, p >0.05, with the accuracy of the males at detecting each type of emotion being unaffected by the side that the faces were presented at (figure 5.5). Therefore, the significant 3-way interaction between side, valence, and sex, obtained in the main analysis, was due to the female participants, but not the males, showing the valence-specific laterality effect.

However, there were no clear handedness effects found in this analysis.

5.6.2. Reaction time data

Table 5.3: Overall mean reaction times (in milliseconds) for positive and negative emotions (valence) presented on the left and right hand side of the screen (with standard deviations in parentheses).

	Side		
	Left	**Right**	**Total**
Positive	3782 *(2182.91)*	3777 *(1993.45)*	3780 *(2088.2)*
Negative	4440 *(2462.68)*	4253 *(2511.64)*	4346 *(2487.2)*
Total	4111 *(2322.8)*	4015 *(2252.55)*	

The above table shows the mean reaction times overall for valence and the side of the screen that the emotional face was presented on. Overall, the reaction times for identifying positive emotions were on average quicker than identifying negative emotions (3779.54 vs. 4346.25 milliseconds).

To examine these overall differences a 2 X 2 (valence (positive vs. negative) and side (left vs. right) within subjects ANOVA was carried out. There was a significant main effect of valence F(1, 77) = 31.979, p<0.01 with positive emotions being identified significantly faster than negative emotions. There was no significant main effect of side F(1, 77) = 1.287, p>0.05 and the interaction between valence and side failed to reach significance F(1, 77) = 0.707, p>0.05.

Table 5.4: Mean reaction time scores (in milliseconds) for each condition collapsed across all levels of morphing (with standard deviations in parentheses) for each sex and handedness group.

	Left Handed		**Right Handed**	
	Female	**Male**	**Female**	**Male**
Positive Left	3538 *(1292.4)*	4643 *(3792.2)*	3424 *(1177.3)*	3615 *(1608.4)*
Positive Right	3467 *(1172.5)*	4762 *(3498.8)*	3529 *(1278.5)*	3449 *(937.8)*
Negative Left	3961 *(1454.9)*	5829 *(4206.8)*	3842 *(1527.5)*	4314 *(1326.4)*
Negative Right	4134 *(1560.9)*	5670 *(4288.3)*	3270 *(1207.7)*	4016 *(1479.5)*

The above table shows the mean reaction time scores for each sex and handedness group in relation to the valence of the emotion shown and the side of the screen that it was presented on. On average, the right-handed females were the fastest at identifying positive faces on the left hand side of the screen and left-handed males were the slowest at identifying positive faces on the left. Right-handed males responded the quickest to positive faces on the right hand side of the screen but left-handed females and right-handed females had similar mean reaction times to this group

Table 5.5: Overall sex and handedness mean reaction time scores (in milliseconds) for valence and side (with standard deviations in parentheses).

	Female	**Male**	**Left**	**Right**
Positive Left	3488 (1229.6)	4144 (2946.1)	4012 (2684.4)	3514 (1380.1)
Positive Right	3494 *(1206.0)*	4124 *(2641.6)*	4022 *(2503.6)*	3491 *(1115.5)*
Negative Left	3909 *(1470.6)*	5093 *(3204.2)*	4762 *(3066.1)*	4065 *(1435.7)*
Negative Right	3752 *(1465.6)*	4867 *(3305.8)*	4793 *(3095.7)*	3622 *(1376.1)*

The above table shows that females were quicker than males on average at identifying positive faces on the left hand side of the screen and that right-handers were quicker than left-handers at identifying positive faces on the left of the screen.

In order to examine the differences presented in tables 5.4 and 5.5. a 2 X 2 X 2 X 2 (sex (male vs. female), handedness (left vs. right), side (left vs. right), valence (positive vs. negative) mixed-model ANOVA was conducted. The main effect of side failed to reach significance F(1, 74) = 1.239, p>0.05. The main effect of handedness approached significance F(1, 74) = 2.865, p=0.095 and the main effect of sex approached significance F(1, 74) = 3.404, p=0.069. The main effect of valence was significant F(1, 74) = 33.616, p<0.01 with reaction time being significantly faster for positive faces than negative faces. The two way interaction between valence and sex was significant F(1, 74) = 7.051, p<0.05 and the two way interaction between valence and handedness was also significant F(1, 74) = 4.903, p<0.05. The two-way interaction between valence and side failed to reach significance F(1, 74) = 1.347, p>0.05 and the three way interaction between valence, handedness and sex also failed to reach significance F(1, 74) = 0.017, p>0.05. See figures 5.6. and 5.7. below).

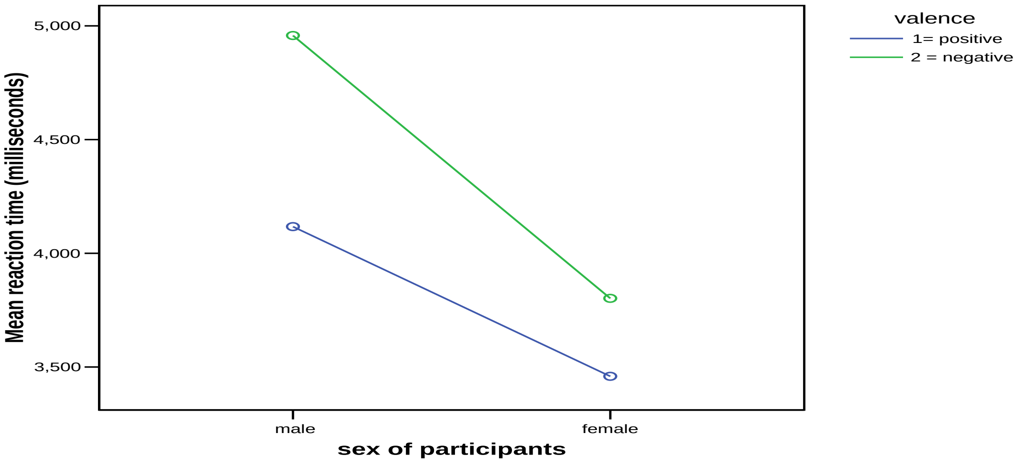


Figure 5.6: Interaction plot of sex and valence on the mean time taken to identify the emotional faces.

The two-way interaction between sex and valence was further examined by carrying out pairwise comparisons firstly for males and then for females. There was a significant difference between male's reaction times for positive faces and negative faces t(35) = 4.790, p<0.01 with reaction times being faster for positive than negative faces (4134 vs. 4980 milliseconds respectively). There was also a significant difference between female's reaction times for positive and negative faces t(43) = 3.026, p<0.01 with female's reaction times being faster for positive faces than negative faces (3491 vs. 3830.4 milliseconds respectively).

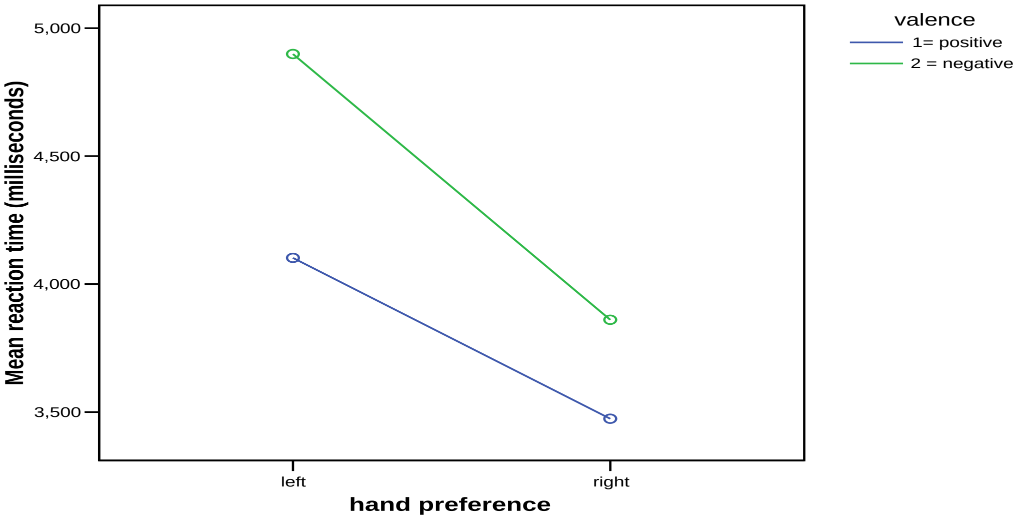


Figure 5.7: Interaction plot of handedness and valence on the mean time taken to identify the emotional faces.

The two-way interaction between handedness and valence was also examined using pairwise comparisons. There was a significant difference between left-hander's reaction times for positive faces and negative faces t(41) = 5.102, p<0.01 with reaction times being faster for positive than negative faces (2.514 vs. 4777.1 milliseconds respectively). There was also a significant difference between right-hander's reaction times for positive and negative faces t(36) = 2.515, p<0.05 with right-hander's reaction times being faster for positive faces than negative faces (3502.8 vs. 3843.6 milliseconds respectively).

5.6.3. Control condition – double neutral trials

For the control trials the two faces were identical but the emotion label differed and the participants were required to select the side that they thought the 'emotional' face was on. As the faces were identical there should have been no systematic differences between the sides chosen, with participants selecting either side 50% of the time on average.

Table 5.6: Response scores (in percentages) for the double neutral control condition

	Side chosen	
	Left	**Right**
Positive label	41%	59%
Negative label	56%	44%

Table 5.6. shows that when the label given to the two neutral control faces was positive (happy or surprise) then 41% of participants indicated that the emotional face was on the left hand side of the screen while 59% of participants indicated that the emotional face was on the right hand side of the screen. When the two neutral faces were given a negative label (sad, disgust, fear or anger) then 56% of participants indicated that the emotional face was on the left hand side of the screen while 44% of participants indicated that the emotional face was on the right hand side of the screen. When comparing the side of the screen chosen, the left hand side of the screen was chosen more often to identify negative emotions (56% of participants chose the left hand side of the screen to identify negative emotions whereas only 41% of participants chose the left hand side of the screen to identify positive emotions) and the right hand side of the screen was chosen more often to identify positive emotions (59% of participants chose the right hand side of the screen to

identify positive emotions whereas only 41% of participants chose the right hand side of the screen to identify negative emotions vs. 44%).

A 2 X 2 X 2 X 2 (sex (male Vs. female) handedness (left Vs. right) side (left Vs. right) valence label (positive Vs. negative)) mixed-model ANOVA was conducted on the response data for the control trials. The main effects of sex, side, handedness, and valence label failed to reach significance (all F's <1). However there was a significant interaction between valence label and side, F(1, 74) = 9.42, $p< 0.01$, demonstrating that the emotional label influenced the side selected even when the faces were identical (see table 5.6 & figure 5.8).

The valence label X side interaction was analysed further by conducting separate analyses for each valence label. For the negative label there was a significant effect of side, F(1, 74) = 3.84, $p<0.05$, with participants selecting the left side more than the right side (56 % Vs. 44 %). For the positive label there was also a highly significant effect of side, F(1, 74) = 7.23, $p<0.001$, with participants selecting the right side more frequently than the left side (59 % Vs. 41%). Thus, the valence of the label caused a response bias in participants when the faces did not differ in emotional expression, with participants selecting the face on the left more frequently when the label was negative and the face on the right more frequently when the label was positive.

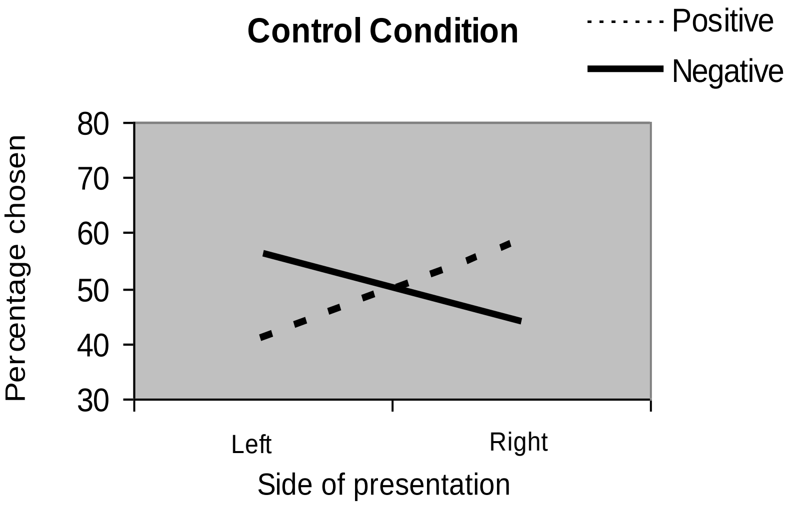


Figure 5.8: Percentage of faces chosen on each side in double neutral as a function of side and valence label (positive, negative).

The main findings of experiment 3 were:

- There were no overall main effects of handedness on either accuracy or reaction time for positive or negative emotional faces.

- All groups (male, female, left- and right-handers) were significantly more accurate at identifying positive emotions than negative emotions.

- Positive faces presented on the right hand side of the screen were identified significantly more accurately than when they were presented on the left side by female participants. This effect was not found in male participants.

- Participants identified the more strongly morphed faces (15%; 20% & 25% morphs) significantly more accurately than they identified the weaker morphed faces (5% & 10% morphs).

- Males were significantly more accurate at identifying the emotions when morphed at the 5% level than females but there were no differences between the accuracy of males and females on any other morph levels.

- Positive emotions were identified significantly faster than negative emotions for all sex and handedness groups.

- There was no significant main effect of side on the time taken to identify the emotions.

- In the control condition there was an effect of the emotion label on the face that the participant chose even though both faces were identical. When a positive emotional label was presented participants selected the face on the right side of the screen significantly more than they selected the face on the left side of the screen. When a negative emotional label was presented participants selected the face on the left side of the screen significantly more than they selected the face on the right side of the screen.

- The main finding in this study was that females showed a valence specific laterality effect. With respect to handedness effects the study proved fairly inconclusive.

5.7. Discussion

Overall it was found that there were no clear handedness differences on the discrimination of both the accuracy and the time taken to identify emotional faces. Therefore the hypotheses the right-handers would be faster and more accurate at identifying positive faces on the right hand side of the screen than left-handers was not supported. Also, the hypothesis that left-handers would be faster and more accurate at identifying negative faces presented on the right hand side of the screen was not supported. However, it was found that all participants were more accurate at discriminating positive emotions than negative emotions in general showing that the expressions of happiness and surprise were easier to identify than the expressions of disgust, fear, anger, and sadness. This replicates Jansari et al*.'s* (2000) results which also found participants to be more accurate at identifying positive emotions. It was also found that participants identified positive emotions significantly faster than they identified negative emotions. This was the case regardless of the sex or hand preference of the participant.

It was found in this study that females showed the valence-specific laterality effect whereas the males did not. Females discriminated negative expressions more accurately when they were presented on the left-hand side and discriminated positive expressions more accurately when they were presented on the right-hand side. However, there was no effect of the side that the emotional faces were presented on on reaction time. Discrimination of facial expressions by the male participants was unaffected by side of presentation (see Rodway, Wright, & Hardie, 2003, for a full explanation of results). These results replicate those of Van Strien and Van Beek (2000) however they used a restricted viewing, emotional ratings task, whereas the current study used a free viewing system. The findings also demonstrate that Van Strien and Van Beek's results were not caused by the use of cartoon faces as the use of real faces in this study resulted in the same pattern of results. An important implication of these results is that previous reports of a valence-specific laterality effect, for example by Reuter-Lorenz and Davidson (1981), may have been caused by female participants within their sample, which remained undetected because the effect of sex was not analysed. Finally, the results do not support the view that the right hemisphere selectively processes negative emotions and both hemispheres are involved in processing positive motions, as suggested by Asthana and Mandal (2001).

The findings of this study partially replicate Jansari et al*.'s* (2000) results by showing that laterality effects can be obtained in free viewing conditions. An important difference is that in this study the valence-specific laterality effect was limited to the female participants. As more participants were used in the present experiment compared to Jansari et al*.'s* (78 Vs. 28) the difference in results might have been due to a difference in power between the studies. However, Van Strien and Van Beek (2000) only used 32 participants and found evidence of the valence-specific laterality effect for the female participants but not the males. It is possible that Van Strien and Van Beek's emotional rating task, which consisted of presenting cartoon faces for 150 ms, is more sensitive than the free viewing task used by Jansari et al*.,* and in this study. Thus, it remains possible that the sex specific nature of the valence-specific laterality effect only emerges when a study has enough power.

The finding that reaction times were significantly faster for positive faces than negative faces is supported by Hartikainen, Ogawa and Knight (2000) who found that reaction times to pleasant (or positive) stimuli were significantly faster than reaction times to unpleasant (or negative) stimuli. Burton and Levy (1989) found that females, but not males, perceived faces with negative emotions fastest when presented in the left visual field and faces with positive emotions fastest when presented to the right visual field. However, in the current study there was no significant effect of sex on the time taken to respond to the emotional faces, although females responded faster on average for both positive and negative emotional faces than males. There was also no effect of the side (of the screen) that the face was presented on the reaction time taken to respond regardless of the sex of the participant and thus this fails to support Burton and Levy's argument that negative emotions would be perceived fastest when presented in the left visual field and positive emotions would be perceived fastest when presented to the right visual field

Very few studies have examined handedness with respect to emotional processing and some studies (such as Jansari et al., 2000) only use right-handed participants.
In the current study handedness did not influence the lateralised processing of emotional expressions. This finding replicates Van Strien and Van Beek's results (but with a larger number of participants and under free viewing conditions) and indicates that left- and right-handers do not differ in the way that they process emotional expressions. Previously Everhart et al. (1996) found that handedness influenced the evaluation of the emotional content of faces when presented in different visual fields. However, in Everhart et al*.'s* study handedness only affected the rating of neutral stimuli, rather than faces with emotional expressions. Thus, the present findings do

not conflict with Everhart et al*.'s* findings, and they suggest that the lateralised processing of emotional information is not affected by handedness.

A possible explanation of Everhart et al*.'s* (1996) results is that handedness does not influence the processing of emotional expressions but can increase the intensity and type of emotions felt in various situations. For example, it has been found that right-hemisphere activation is associated with negative emotional states. Thus, temperamentally anxious human infants, who exhibit shyness and behavioural inhibition to a novel situation, show greater right-hemisphere frontal activation compared to left frontal activation (Fox, Henderson, Rubin, Calkins &Schmidt, 2001; Schmidt, Fox, Schulkin & Gold, 1999; Schmidt & Fox, 1996, Calkins, Fox & Marshal, 1996). If right-hemisphere activation (and possibly left-handedness) is associated with stronger emotional states (Hellige, 2001), then left-handers may be more inclined to rate neutral stimuli as having greater emotional content, as in Everhart et al.'s (1996) study.

As only the female participants showed the valence-specific laterality effect this suggests that females are more lateralised, than males are, for both the perception and interpretation of emotional expressions. This result is in concordance with other findings (E.g. Burton & Levy, 1989; Van Strien & Van Beek, 2000; Voyer & Rogers, 2002; Bourne, 2005). If females are more lateralised for perceiving emotional expressions then it might be expected that they may show superiority in emotional discrimination in comparison to males. Although other studies using auditory stimuli have indicated that this may be the case (Voyer & Rogers, 2002), the present results found no evidence for a female superiority in accuracy. In fact, while there was no overall difference in accuracy between males and females, the males were superior when the emotional discrimination was most difficult (5% morphing). This indicates that males may be more sensitive than females to extremely subtle changes in emotional expression.

An important finding of the present study is that for the control trials the emotional label caused a bias in responding to faces that were identical. If the emotion label was positive the participants selected the right side more frequently than the left side. Conversely, if the emotion label was negative the participants selected the left side more than the right side. A probable explanation of this finding is that participants associated the left side with 'negative' and the right side with 'positive' and when they were required to guess their responses reflected this bias. The association of left with 'bad' and right with 'good' is a strong association that has been prevalent throughout history and within many cultures. For example, it is traditional for ‘evil’ characters in the theatre to always exit and enter the stage on the left, whereas ‘good’ characters use the right side of the stage (Coren, 1992). Moreover, in practically every culture being left-handed has been viewed negatively with each culture’s term for left-handed carrying negative connotations (e.g. worthless in old English, clumsy in French, sinister in Italian) (Springer & Deutsch, 1993). Although the association between left and ‘bad’ is likely to have occurred unconsciously in participants it is plausible that this caused the bias in responding to identical faces.

A further implication of these findings is that the more difficult the emotional discrimination is, either due to brief presentation, or subtle differences between stimuli, then the more participants will guess and the more likely it is that the response bias will occur. The valence-specific laterality effect may emerge when the difficulty of a task is increased so that participants guess more frequently. As previously mentioned, Van Strien and Van Beek (2000) also suggest that the valence-specific laterality effect emerges when a task requires a difficult discrimination of emotions, rather than an easier perceptual matching of emotions.

The present results, however, provide mixed support for the response bias hypothesis. If increased discrimination difficulty increases the response bias, then the valence-specific laterality effect should have interacted with the degree of morphing, with a larger effect for the most difficult discrimination level. This interaction was short of significance in the main analysis and was due to valence-specific laterality effects at the 5% and 10% morph levels, but no such effect at the 15%, 20%, and 25% levels. This result therefore supports the view that a response bias for difficult discriminations may contribute to the valence-specific effect.

A final factor which may have influenced the present findings is that the stimuli were of a male face. The valence-specific effect may have been present in females because the males were either less able, or less willing, to analyse the emotional expression of a male face and this is perhaps why no difference was found between left- and right-handers. However, this is unlikely because the male participants were as accurate as the females at discriminating emotions. Also, it can be noted that Van Strien and Van Beek (2000) and Jansari et al. (2000) used male faces as stimuli. Thus, the different findings between these studies cannot be due to the use of male faces. Finally, as suggested by Van Strien and Van Beek, it appears unlikely that the use of male faces has affected results in this area because other studies have found that the sex of the face does not interact with the sex of the participant (e.g. Hugdahl, Iverson & Johnsen, 1993; Cutler, Gilgen & Gilpin, 1985).

To conclude, the present study found that the valence-specific laterality effect, in free viewing conditions, only applied to female participants and there were no effects of handedness. This suggests that females are more lateralised for the processing of emotional facial expressions than are males, with the left hemisphere devoted to processing positive emotions and the right hemisphere devoted to processing negative emotions. Conflicting findings within the literature may have been caused, in part, by ignoring the influence of sex on emotional processing. It is possible that the sex specific nature of the valence laterality effect is apparent when the task is sensitive, or when a large number of participants are used. Moreover as a free viewing task was used the results suggest that these findings apply to natural viewing conditions.

However, there was no evidence that handedness influences the lateralised processing of emotional information. Evidence for a role of handedness has been weak and inconsistent and the present findings, and those of Van Strien and Van Beek, strongly suggest that handedness does not influence the lateralised processing of facial affect. These findings have an effect on the current body of research. It was suggested in Chapter 4 that a difference in emotional processing by left- and right-handers might be one reason for why there was a difference in response styles observed towards novel objects by left- and right-handers. In order for this idea to be supported it would have been expected that left-handers would have been more accurate and faster at identifying negative emotional faces (particularly on the left hand side of the screen) and right-handers would have been more accurate and faster at identifying positive emotions (whether this depends on the side of the screen would be dependent on whether the right hemisphere hypothesis or the valence-specific hypothesis was supported).

However, failure to find a difference between the emotional processing on a series of faces between left- and right-handers does not rule out that left- and right-handers react to novel objects differently due to some form of emotional response difference. The findings of this study suggest that left- and right-handers perceive and recognise emotions similarly, however, this does not necessarily mean that they experience emotions similarly and this could be an important factor in determining differences in response styles which needs to be further investigated. A link between emotional processing and inhibitory or avoidance behaviour could be an important factor in this study. As the right hemisphere is regarded to be the ‘emotional hemisphere’ of the brain then it is suggested that left-handers will respond more emotionally than right-handers (again the type of emotion – positive or negative- or all emotions depends on whether the right hemisphere hypothesis or the valence specific hypothesis is supported) (Davidson, 1993). As the right hemisphere is linked to inhibitory and avoidance behaviour and the left hemisphere is associated with approach and more impulsive behaviour then this may still be a contributing factor in what caused the delay in the novel problem-solving task in Chapter 4. Any differences in emotional responses between left- and right-handers may have been caused by something much more specific such as anxiety or inhibitory behaviour and these issues will be examined in Chapter 7.

Finally, the participants demonstrated a response bias when required to discriminate between identical faces, suggesting that the left-hand side is associated with negative emotions whereas the right side is associated with positive emotions. This response bias requires further investigation as it may have contributed both to valence-specific laterality effects and the conflicting results within the literature. Future research needs to be aware that this response bias can produce laterality effects that are not caused by differences in the way the hemispheres process emotional information.

Thus, in relation to the proposition that possible differences between the emotional processing of left- and right-handers may have influenced their behaviour in relation to the solving of the Tower of Hanoi problem in Chapter 4 it appears that these differences, at least from the present study, are not apparent. As previously stated in Chapter 4 two conflicting theories have been proposed to explain the role of the hemispheres in emotional processing. The Right-Hemisphere Hypothesis suggests that all emotional information is processed by the right hemisphere (Borod, 1993) while the Valence-Specific Hypothesis suggests that the left hemisphere is specialised for processing positive emotions whereas the right hemisphere is specialised for processing negative emotions (Silberman & Weingartner, 1986; Jansari et al., 2000). It was proposed that if the valence hypothesis is supported then it could possibly be assumed that the right hemisphere is associated with avoidance behaviour (negative emotions) and the left hemisphere with approach behaviour (positive emotions) (Davidson, 1993). However, it appears from the current study that there is no clear handedness pattern to support the valence hypothesis and thus it is difficult to draw conclusions or support the emotional processing argument when considering possible reasons for differences in behaviour towards the solving of the Tower Hanoi and other problem solving tasks.

Chapter 6: Cognitive abilities and planning

6.0. Aims of Chapter

One explanation for the difference in the response of left- and right-handers towards a novel problem in Chapter 4 (the 3-disk ToH task) was that perhaps left- and right-handers were approaching the problem differently and that those solving it more effectively were people who made a plan either before or during the solving. Thus the aim of this Chapter is to investigate this potential explanation further. This chapter will outline a number of different tasks that were designed to examine whether there was any evidence of planning by participants before they responded to a task. More specifically, if any planning was observed then were there any differences between left- and right-handers? Different types of planning tasks will be discussed (for example, a sorting task, which like the Tower of Hanoi (Chapter 4) was a ‘manual’ task (although that task also had a slight spatial element to it and so there is the possibility that the results were due to a superior right hemisphere spatial ability in left-handers). In order to examine whether there was a difference in planning strategies between the two groups, two tasks of planning were devised along with an additional task of spatial ability in order to examine whether the type of task used was also a contributing factor. This Chapter will mainly concentrate on the methods and results for each of these studies and findings will be discussed. As there was a detailed overview of planning in Chapter 4 (section 4.3.1) then this will not be covered again in this section. However a brief outline of planning and motor planning will be given.

6.1. Introduction

6.1.1. Planning

As outlined in Chapter 4, section 4.3.1. planning can be defined as a process that requires mental thinking, evaluation and a resulting action so as to effectively meet some future goal (Scholnick & Friedman, 1993; Gilhooly, Phillips, Wynn, Logie & Della Sala,1999). How people think about a novel object or situation may be concerned with how they approach it. Some people may have a greater tendency to consider a situation and plan what they might do before approaching and responding whereas others may respond immediately. However, for the purposes of this chapter a review of planning will not be given as a detailed summary of planning research and definitions are given in Chapter 4, section 4.3.1. One potential reason given for the difference found between the difference in approach behaviour of left- and right-handers towards a novel task (the 3-disk Tower of Hanoi) outlined in Chapter 4 was that left-handers might be planning a solution or at least their first few moves before making their first response. This idea was also thought to be feasible as left-handers took significantly fewer moves to solve the task than right-handers and therefore left-handers planning their first few moves could have influenced this more effective solution. Therefore In order to test this idea further a series of tasks were devised to investigate whether there was any evidence of planning.

6.1.2. Motor planning

As previously stated (see chapter 4) it has been proposed that planning a right-handed movement is always faster than planning a left-handed movement, perhaps due to a form of attentional asymmetry in motor planning. Thus a delay in motor planning with the left hand is hypothesised to cause a delay in response initiation in left-handers. The difficulty with this reported finding is that evidence suggests that movement planning is faster with the left hand in right-handed participants (Barthelemy & Boulinguez, 2001). Therefore, right-handed participants are faster at pointing and reaching when using their left hand in goal directed movements, suggesting 'right *hemisphere dominance for movement planning*' (Barthelemy & Boulinguez, 2001, p1). If it is the case that the right hemisphere is dominant for movement planning then it would be expected that left-handers exhibit more planning behaviour than right-handers because of the contralateral control of the hemispheres.

A further argument that could explain differences in response initiation between left and right-handers is the type of task used. For example the Tower of Hanoi is considered to be a visuo-spatial planning task whereas the sorting task (used in this current study) is not. It has been suggested right hemisphere dominance is associated with superior spatial abilities (Annett, 1992; Bishop, 1990). While evidence for a relationship between handedness and visuo-spatial abilities has been mixed and inconsistent (Annett, 2002) it remains a possibility that a visuo-spatial task could cause differences between left- and right-handers in response initiation. For example, it might be the case that when confronted with a visuo-spatial task, participants who have strong visuo-spatial abilities delay responding and rely on visuo-spatial imagery to partially solve the task prior to making a move. As a consequence the delay in the left-handers could have been a direct result of their superior spatial ability (this possibility is examined in this chapter, section 6.10. – see experiment 6).

6.2. Current studies

The following section will outline 3 experimental studies designed in order to investigate possible planning differences between left- and right-handers. In addition, the final study will examine possible spatial differences between the 2 groups.

6.2.1. Rationale and hypotheses for experiment 4 – manual sorting task

In the manual sorting task (experiment 4) participants will be asked to make categories out of a series of cards (20 in total). This task further investigates the response style behaviours of left- and right-handers when given a novel task. This study will aim to both investigate and add further support to the findings reported in experiment 1 (Chapter 4, section 4.3.). The manual sorting task was used, as it is still important to use a manual task in order to investigate the original findings found on the Tower of Hanoi study. However, as the Tower of Hanoi is a strong spatial task then this could have affected the findings in the first experiment due to the nature of the task and therefore a task that could be easily solved but without a strong spatial component was used. Therefore, the manual sorting task was devised as it was felt that part of a solution could be planned if this was what the participant wanted to do and also it did not have a large spatial element to it and had more of a sequencing element.

The dependent variables for this task were the time taken to move the first card (in seconds) and the total time taken to complete the task (in seconds). The most important dependent variable here is how long the participant takes to move the first card, as this will be how initiation time is defined.

It is hypothesised, based on the findings of experiment 1, that left-handers will take longer to move the first card than right-handers and that there will be no difference in the time taken to solve the task by left- and right-handers.

6.3. Method - Experiment 4 - Manual Sorting Task

6.3.1. Participants

80 participants took part in this study (38 were right handed (18 males and 20 females) and 42 were left-handed (18 males and 24 females). All subjects were staff and students of the University of Abertay Dundee. All participants had normal coloured vision and normal or corrected-to-normal visual acuity.

6.3.2. Materials and Apparatus

An instruction sheet was given which informed participants that they were going to be presented with a series of 20 cards and that their task was to sort them in to 4 categories each with 5 cards in it. Participants were also informed that each category should follow a rule determined by them and that they would be asked to write down the rules for each category at the end of the task (see appendix 17 for a copy of this). 20 individual coloured cards measuring 14.5cm by 10cm were used. The cards contained pictures of 20 different animals ranging from a cat to a monkey (see figure 6.1 below and appendix 16 for a full set of the cards). A board measuring 89cm x 54cm was used to place the cards into categories on. This was split into four sections and labelled category 1, category 2, category 3 and category 4 (see appendix 18). A stopwatch was used to time how long the task took and how long the participant took to move the first card of the task. Finally, a data sheet was used to record the time it took the participant to move the first card and to make all four categories (see appendix 19). Participants were also asked to write down the rule of each category on the recording sheet along with details of their name, course and hand preference.

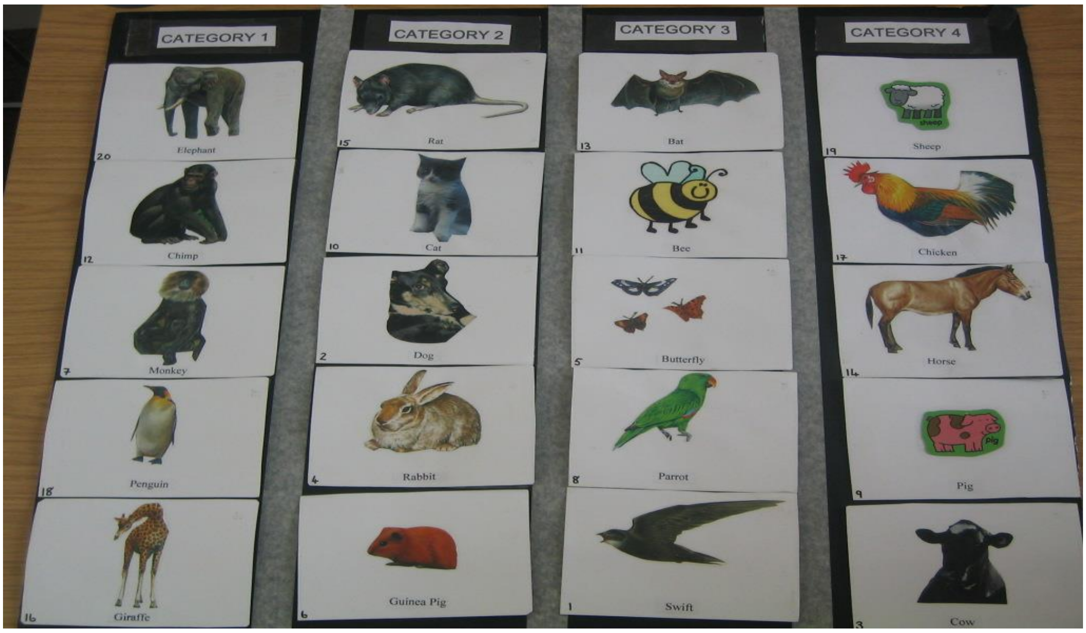


Figure 6.1: 20 manual sorting cards and the sorting board

6.3.3. Procedure

Participants were presented with a set of instructions outlining what they were going to be asked to do for the manual sorting task (see appendix 17). They were informed that they were going to be presented with a series of 20 cards and that their task was to sort them in to 4 categories each with 5 cards in it. Participants were also informed that each category should follow a rule determined by themselves and that they would be asked to write down the rules for each category at the end of the task. The cards consisted of twenty pictures of different animals and each card had a picture of the animal and its name in words at the bottom of the card (see appendix 16 for copies of the stimuli). The set of cards was laid out on a table and concealed with a large board in order to keep them novel to the participant. When the participant indicated that they understood what was required, the board concealing the cards was removed and the stopwatch was started. The time taken to move the first card was written on the recording sheet. Once the participant had completed the task and had satisfactorily placed the cards into four categories, the time taken to complete this was recorded. The participant then had to write down the four rules that applied to the four categories that they had made. It should be noted that there were a number of possible solutions to this task rather than a single solution.

6.4. Results: Experiment 4: Manual sorting/categorisation task

Table 6.1: Mean time taken (in seconds) to move the first card of the sorting/categorisation task (with standard deviations in parentheses).

	Left-handed	**Right-handed**	**Total**
Male	15.5 *(24.1)*	4.3 *(3.8)*	9.9 *(17.9)*
Female	6.1 *(4.0)*	3.6 *(2.9)*	5.0 *(3.7)*
Total	10.2 *(16.5)*	3.9 *(3.3)*	

Table 6.1 shows that left-handed males took the longest time on average to start the sorting task (with a mean time of 15.5 seconds) and they took more than twice the time taken by left-handed females who took the second longest to start (6.1 seconds). Right-handed males started the task 4.3 seconds while right-handed females were quickest to start the task in an average of 3.6 seconds. Left-handers took more than twice as long to begin the task than right-handers (10.2 seconds vs. 3.9 seconds) and males rook almost twice as long to begin the task than females (9.9 vs. 5.0 seconds). The variance within the right-handed males and females and the left-handed females is all similar but the left-handed males have a large standard deviation and thus this could be attributed to one or two participants who might have taken a much longer time than the rest of the group to begin the task.

In order to examine these differences a 2 X 2 (handedness (left v right) by sex (male v female) between subjects ANOVA was carried out on the time taken to move the first card of the sorting task. There was a significant main effect of hand preference F(1, 76) = 6.649, p<0.05, with left-handers taking significantly longer to move the first card than right-handers (10.8 seconds v 3.95 seconds). The effect of sex approached significance F(1, 76) = 3.502, p=0.065 and the interaction between sex and handedness failed to reach significance F(1, 76) = 2.711, p>0.05.

As the standard deviation for the left-handed males in the previous table was very large compared with the rest of the groups (24.1) two outliers were removed. These both belonged to left-handed male participants. The times taken by these two participants to make the first move on the card-sorting task were 84.7 and 75.4 seconds. With these participant’s data removed the table below shows the average times taken by each group to move the first card on the card-sorting task.

Table 6.2: Mean time taken (in seconds) to move the first card of the categorisation task (with standard deviations in parentheses) (with outliers removed).

	Left-handed	**Right-handed**	**Total**
Male	7.4 *(5.3)*	4.3 *(3.8)*	5.75 *(4.8)*
Female	6.1 *(4.0)*	3.6 *(2.9)*	5.0 *(3.7)*
Total	6.66 *(4.6)*	3.9 *(3.3)*	

The above table shows that with outliers removed left-handed males still took the longest to move the first disk on the card-sorting task. Left-handed females and right-handed males followed this. Right-handed females took the least time to begin the task. Left-handers took longer to make the first move than right-handers and males took longer to make the first move than females.

In order to examine these differences a 2 X 2 (handedness (left v right) by sex (male v female) between subjects ANOVA was carried out on the time taken to move the first card of the sorting task (with outliers removed). There was a significant main effect of hand preference $\underline{F}(1, 74) = 9.384$, $\underline{p}<0.01$, with left-handers taking significantly longer to move the first card than right-handers (6.66 seconds v 3.9 seconds). The effect of sex was not significant $\underline{F}(1, 74) = 1.050$, $\underline{p}>0.05$ and the interaction between sex and handedness failed to reach significance $\underline{F}(1, 74) = 0.142$, $\underline{p}>0.05$.

Table 6.3: Mean time taken (in seconds) to complete the categorisation task (with standard deviations in parentheses).

	Left-handed	**Right-handed**	**Total**
Male	117.0 *(54.0)*	76.3 *(32.0)*	96.7 *(48.4)*
Female	80.7 *(44.4)*	97.4 *(49.0)*	88.3 *(46.8)*
Total	96.2 *(51.4)*	87.4 *(42.7)*	

The above table shows that left-handed males took the longest to complete the task followed by right-handed females (117 and 97.4 seconds respectively). Left-handed females and right-handed males were the quickest to complete the task (80.7 and 76.3 seconds respectively). Overall, left-handers took longer to solve the task than right-handers (96.2 v 87.4 seconds) and males took longer than females to solve the task (96.7 v 88.3 seconds). When the outliers from the two left-handed males were removed this reduced the mean time taken by left-handed males to complete the task to 106.8 (47.9) seconds but this was still slower than all other groups. The total time taken by left-handers once the outliers were removed was 91.1 (47.0) seconds (again this was still slower than the total time taken by right-handers) and the total time taken by males was 90.7 (42.5) seconds, which was marginally slower than the time taken by females (88.3 seconds)

In order to examine these differences a 2 X 2 (handedness (left v right) by sex (male v female) between subjects ANOVA was carried out on the time taken to complete the sorting task. There was no significant main effect of hand preference F(1, 76) = 1.359, p>0.05 and no significant main effect of sex F(1, 76) = 0.552, p>0.05 however the interaction between sex and handedness was significant F(1, 76) = 7.830, p<0.01.

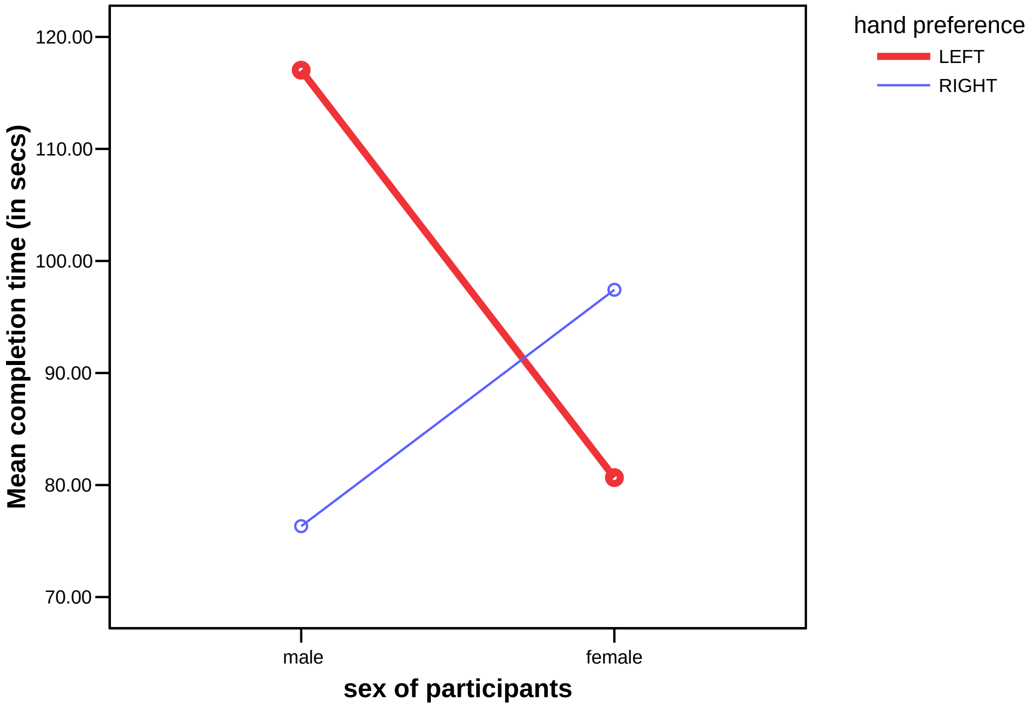


Figure 6.2: Interaction plot showing the time taken (in seconds) by males and females and left- and right-handers to solve the card-sorting task.

The above plot shows that right-handed males took less time to solve the card-sorting task than right-handed females. However, left-handed males took more time to solve the card-sorting task than left-handed females. Thus the interaction is caused by the inverse performance of the handedness groups within the sexes. Right-handers perform better in the male group whereas left-handers perform better within the female group. The biggest difference occurs between the left- and right-handers within the male group.

A one-way ANOVA was conducted to see if the difference between left- and right-handed males on the time taken to solve the card-sorting task was significant. It was found that there was a significant difference with male right-handers taking significantly less time to solve the task than male left-handers F(1, 25) = 7.569, $p<0.01$.

An additional one-way ANOVA was carried out with left- and right-handed females. It was found that the difference between the two groups in the time taken to solve the task was not significant F(1, 43) = 1.413, $p>0.05$. Therefore the difference between the left- and right-handed males had an effect on the significant interaction.

Table 6.4: Mean time taken (in seconds) to complete the categorisation task minus initiation time (with standard deviations in parentheses).

	Left-handed	**Right-handed**	**Total**
Male	101.5 *(44.4)*	72.1 *(30)*	86.8 *(40.2)*
Female	74.5 *(42.4)*	93.8 *(48.9)*	83.3 *(45.9)*
Total	86.1 *(44.8)*	83.5 *(43.2)*	

The above table shows that when the initiation time is taken away from the completion time that left-handed males still take the longest to complete the task followed by right-handed females then left-handed females and right-handed males solved this the quickest.

In order to examine these differences a 2 X 2 (handedness (left v right) by sex (male v female) between subjects ANOVA was carried out on the time taken to complete the sorting task minus the initiation time. There was no significant main effect of hand preference F(1, 76) = 0.288, $p>0.05$ and no significant main effect of sex F(1, 76) = 0.077, $p>0.05$ however the interaction between sex and handedness was significant F(1, 76) = 6.556, $p<0.05$.

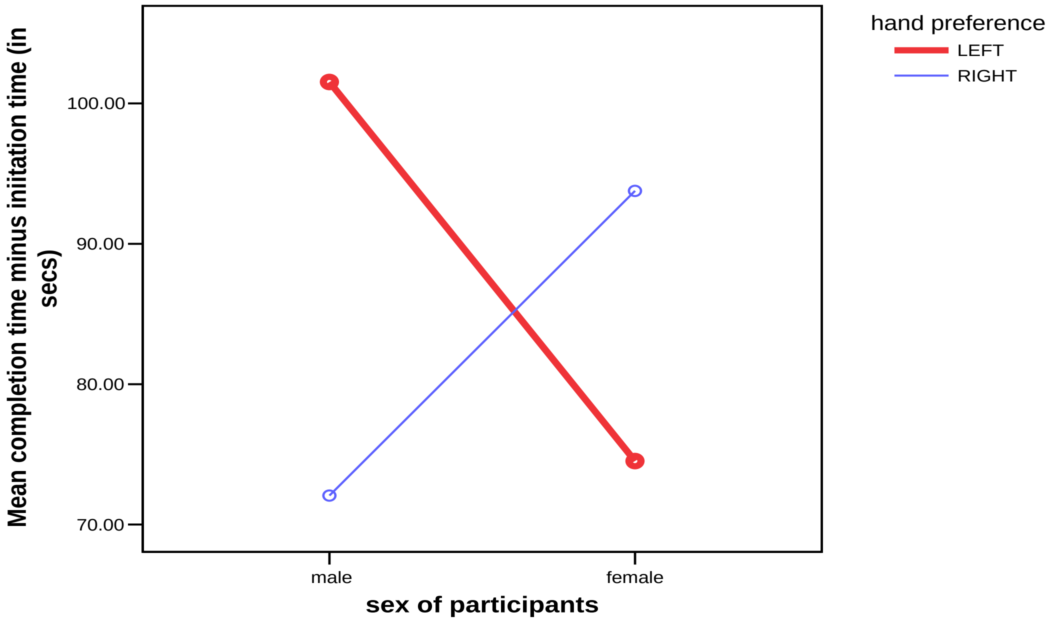


Figure 6.3: Interaction plot showing the time taken (in seconds) by males and females and left- and right-handers to solve the card-sorting task minus the initiation time.

The above plot shows that right-handed males took less time to solve the card-sorting task when initiation time was not included than right-handed females. However, left-handed males took more time to solve the card-sorting task than left-handed females. Thus the interaction is caused by the inverse performance of the handedness groups within the sexes. Right-handers perform better in the male group whereas left-handers perform better within the female group. The biggest difference occurs between the left- and right-handers within the male group.

The main findings of Experiment 4 were:

- Left-handers took significantly longer to move the first card than right-handers
- This was also the case when all outliers were removed
- There were no effects of sex or handedness on the time taken to complete the task
- There was a significant sex X handedness interaction on the time taken to complete the task where right-handed males solved the task significantly faster than left-handed males. There was no difference between females on the time taken to solve the task

6.5. Experiment 4: Discussion

It was hypothesised for the sorting task that left-handers would take longer than right-handers to move the first card of the task. This hypothesis was supported with left-handers taking significantly longer to move the first card than right-handers. Two participants in the left-handed male group were outliers in the sample and upon removing their data from the analysis the results still showed a significant difference between left- and right-handers on the time taken to move the first card of the task. It was also hypothesised that left-handers would complete the task significantly faster than right-handers. This hypothesis was not supported and the direction of the results was the opposite of that predicted with right-handers solving the task, on average, faster than left-handers. Males took more time, on average, to solve the sorting task.

Since this task has a visuo-spatial element then the results of the time taken to complete the task were perhaps somewhat surprising. Males often outperform females at visuo-spatial tasks (e.g. Annett, 2002) and this was not found to be the case in the current study. Superior performance on a visuo-spatial task between was reported in chapter 4 where males outperformed females during the Tower of Hanoi task (a visuo-spatial task). It would also be expected that left-handers would exhibit a superior visuo-spatial performance than right-handers and this was the case in the Tower of Hanoi study reported in chapter 4. However, this was not found to be the case in the current study as right-handers completed the task faster both overall and when initiation time was not included in the completion time. However, these differences were not significant. Further investigation of visuo-spatial abilities and sex and handedness are considered in the computer program part of these three studies (study 3).

Another possible reason for the significant difference occurring between left- and right-handers on the time taken to move the first card could again be due to the fact that the task was novel. As the participants had never seen the cards to be sorted before and were instructed that the cards could be organised in any manner they wished in their categories (as long as they attributed a viable rule to these) then the task was considered novel to the participants.

Similarly to the Tower of Hanoi findings (see chapter 4, sections 4.3. – 4.7. for details) there was a significant difference between left- and right-handers on the time taken to make the first response but not on the time taken to solve the sorting task. This therefore suggests that it was unlikely that planning was occurring in the time before making the first response. If planning was occurring it would be expected that the group who was planning for longer would also solve the task significantly faster. However, in this case the left-handers took longer to start the task but right-handers solved it, on average, in less time thus is it unlikely that the time taken before making the first response was spent planning. Again, the work of Gilhooly et al. (1999) can aid in the explanation of why right-handers took less time to start the task but completed it faster. It is possible that right-handers were planning during the task and therefore completed the task faster than left-handers. However, there was no way to examine this concept specifically since the task did not have a final goal state or require an optimal number of moves. If the task had had an optimal number of moves then the time taken between executing each move could have been examined to see if there was any evidence of a plan being made in addition to measuring the number of moves taken to solve a task. The only way that this could be achieved on this task would be to have counted the number of times each participant moved the cards to form their categories but this measurement was not recorded.

Additional strategies that may have occurred during this initial delay could again have been connected to the stress and anxiety argument that suggests that novel tasks have a more adverse effect on left-handers and increase their anxiety levels. Alternatively, participants may have been surveying the cards and looking to see what each card depicted but did not necessarily form any sort of groupings within the set of cards during this time and thus this would not have made a difference to the time taken to complete the task.

6.6. Experiment 5: ‘Fastest Finger First’ Task

6.6.1. Introduction

This study is based on the ‘fastest finger first’ game on the television programme ‘Who wants to be a millionaire’ where contestants have to answer a question by arranging a series of responses in order (for example – ‘put the following words in to alphabetical order…’). The computer program in this study gives a random series of both 3 and 6 response questions (in order to see if a more complex task affects the results or the planning of the responses) and the participant has to arrange these in order according to the question. The participant is shown the question on the screen first and they have to press the space bar when they are comfortable with what the question asks and want to see the answers. This is done in order to see if one of the groups will study the question for longer. The independent variable in this study is the number of options that the questions have (either 3 or 6) and the dependent variables for this task are the time taken to read/consider the question before seeing the answers (in milliseconds), the time taken to respond to the first answer after being presented with them (in milliseconds), the time taken to sequence all of the answers (in milliseconds) and the number of questions answered correctly.

6.6.2. Rationale and hypotheses for experiment 5

This is based on the concept of the ‘fastest finger first’ sequencing task on ‘Who wants to be a millionaire’. This task is included as an extension to the manual sorting task (experiment 4, section 6.3.). However, this task differs from the manual-sorting task as it focuses more on sequencing a series of answers, there is only one solution to each task and it varies the complexity of the questions between 3 and 6 responses. The reason for using this task was that previous experiments in this thesis had suggested that there was a difference in initiation time between left- and right-handers. However, only on some of the tasks was there a performance difference. Therefore these performance differences could have been caused by participants, for instance, planning a solution during the initiation time. With this in mind this experiment aims to examine responses towards two conditions, one that would require relatively more planning than the other (3 options and 6 options). If there is evidence of planning then a longer initiation time would be expected in the 6 option condition. If there is no difference then evidence of planning is not supported.

It was hypothesised that left-handers would read the question for longer than right-handers. The reason for this hypothesis was that it was thought that left-handers would be more anxious about the novelty of the question and want to feel comfortable with what was being asked (particularly as the questions alternated in what they were asking, for example some asked them to put things in alphabetical order while other questions asked for responses in reverse alphabetical order). It is also hypothesised that left-handers will take longer to respond to the 3 option questions than right-handers and it is hypothesised that left-handers will take longer to respond to the 6 option questions than right-handers. Also, it is hypothesised that left-handers will solve each task faster than right-handers (particularly if there is evidence of planning). Finally, if there is evidence that left-handers are taking longer to respond to the questions (illustrated by the time taken to make their first response) then it is hypothesised that left-handers will get more questions correct than right-handers both for 3 and 6 options.

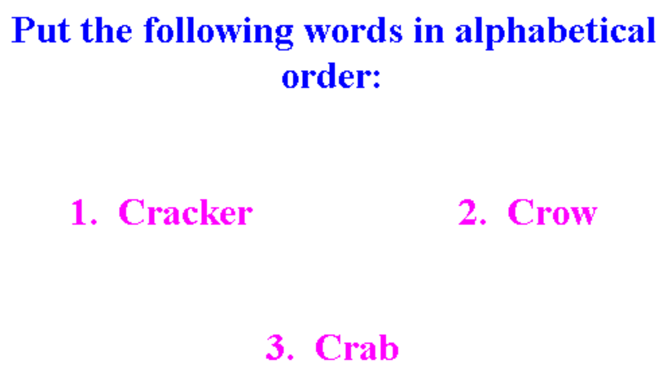
6.7. Method – experiment 5

6.7.1. Participants

80 participants took part in this study (40 male and 40 female). Of these, 40 participants were left-handed (20 males and 20 females) and 40 participants were right-handed (20 males and 20 females). All participants had normal colour vision and normal or corrected-to-normal visual acuity.

6.7.2. Materials and Apparatus

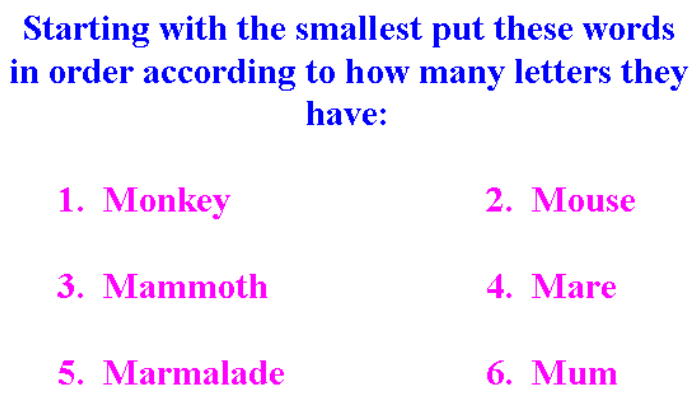
A Compaq laptop computer with a coloured screen and standard keyboard was used to run the sequenced answers computer program. The software used to run the program was Superlab Pro v1.2 for windows. 20 stimuli were prepared in Microsoft paint. These stimuli consisted of a question and a series of answers which the participant had to sequence in the correct order to answer the question. The questions were written in point size 22 Ariel font and were made bold and coloured blue. The answers were also prepared in point size 22 Ariel font and were bold but these were coloured pink and centred. Half of the questions had 3 answers to sequence (these were numbered 1 to 3) and half of the questions had 6 answers to sequence (these were numbered 1 to 6) (see appendix 14 for details of these stimuli). Each question was displayed on its own in the centre of the screen to allow the participant to read it. When they were happy with what the question asked they pressed any key to reveal the answers that had to be ordered in relation to the question. The number keys 1 to 6 were used as response keys and were labelled with orange and yellow stickers with the corresponding numbers on them. Finally, an instruction sheet detailing that the participant was going to see a series of questions which asked them to sequence the responses according to what the question asked was given (see appendix 13). The instructions also informed the participant that the number of responses would either be 3 or 6 and an example of a 3-response question and a 6-response question was given.



Put the following words in alphabetical order:

1. Cracker
2. Crow
3. Crab

Figure 6.4: An example of a 3-response question from the ‘Fastest Finger First’ task



Starting with the smallest put these words in order according to how many letters they have:

1. Monkey
2. Mouse
3. Mammoth
4. Mare
5. Marmalade
6. Mum

Figure 6.5: An example of a 6-response question from the ‘Fastest Finger First’ task

6.7.3. Procedure

Participants were given a set of instructions detailing what the ‘fastest finger first task’ would entail. They were informed that they were going to be shown a series of questions that ask for the responses to be ordered in a number of different ways (according to the question). The instructions also stated that half of the questions would have 3 responses and the other half would have 6 responses but that the questions would be presented randomly. Participants were then told that they would be shown the question on its own first and when they were happy to continue and reveal the responses then they had to press any key. The keys on the computer were numbered 1 to 6 and participants were informed that they had to use the corresponding number keys to make their responses. The participants were then given an example of a 3-option question and a 6-option question. Finally, participants were asked if they had any questions about the study. When they felt comfortable with what they had to do for the task they pressed a key to begin the 20 trials. On completion of this task participants were thanked for their participation and were informed of the purpose of the study.

6.8. Results: Study 1 ‘Fastest Finger First’

6.8.1. Time spent looking at the question

Table 6.5: Mean time spent looking at the question (in milliseconds) by each sex and handedness group (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	4180 (*1181.3*)	4801 (*721.3*)	4491 (*951.3*)
Female	4047 (*1168.3*)	4537 (*1243.5*)	4292 (*1205.9*)
Total	4113 (*1174.8*)	4669 (*982.4*)	4391 (*1078.6)*

The above table shows that, on average, right-handed males looked at the question the longest, followed by right-handed females then left-handed males. Left-handed females looked at the question for the shortest amount of time. Also, males looked at the question longer than females and right-handers looked at the question longer than left-handers.

In order to see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 0.402, p>0.05. There was no main effect of handedness F(1, 72) = 3.146, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 0.043, p>0.05.

6.8.2. First response (initiation time)

Table 6.6: Mean time taken (in milliseconds) to make the first response to questions with 3 options by each sex and handedness group (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	6309 *(3851.0)*	5648 *(2102.7)*	5978 *(2976.9)*
Female	6700 *(3856.9)*	6118 *(2008.7)*	6409 *(2932.8)*
Total	6504 *(3853.9)*	5883 *(2055.7)*	

The above table shows that for questions that contained 3 options to be ordered as answers, left-handed females, on average, took the longest to make their first response to the question followed by left-handed males and then right-handed females. Right-handed males responded the quickest. Left-handers overall took longer to make their first response than right-handers and females took longer than males to make their first response.

In order to see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 0.345, p>0.05. There was no main effect of handedness F(1, 72) = 0.720, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 0.003, p>0.05.

Table 6.7: Mean time taken (in milliseconds) to make the first response to questions with 6 options by each sex and handedness group (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	6643 (*4427.2*)	6359 (*3130.8*)	6501 (*3779.0*)
Female	7440 (*4842.0*)	7673 (*3498.9*)	7557 (*4170.5*)
Total	7041 (*4634.7*)	7016 (*3314.8*)	

The above table shows that for questions that contained 6 options to be ordered as answers, right-handed females, on average, took the longest to make their first response to the question followed by left-handed females and then left-handed males. Right-handed males responded the quickest. There was very little difference between the first response times of left-handers and right-handers and females took longer than males to make their first response.

In order to see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 1.229, p>0.05. There was no main effect of handedness F(1, 72) = 0.001, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 0.073, p>0.05.

Table 6.8: Mean first response times (in milliseconds) for each sex and handedness group along with totals for 3 and 6 options (with standard deviations in parentheses).

	Left Male	**Right Male**	**Left Female**	**Right Female**	**Total**
3 options	6309 *(3851.0)*	5648 *(2102.7)*	6700 *(3856.9)*	6118 *(2008.7)*	6194 *(2984.5)*
6 options	6643 *(4427.2)*	6359 *(3130.8)*	7440 *(4842.0)*	7035 *(3343.3)*	6869 *(3935.8)*

The above table shows that for each group the first response times to the questions with 6 options were longer than the first response times for the questions with 3 options. The total times showed that overall the first response times for 6 options were, on average, longer than the first responses to the questions with 3 options.

A 2 x 2 x 2 mixed model ANOVA was carried out with type of question the within factor (3 options or 6 options) and sex and handedness the between factors. A significant main effect of question was found $F(1, 69) = 11.92$, $p<0.01$ where first response times to the 6 option questions were longer than first response times to the 3 option questions (6869.5 ms vs. 6194.2 ms respectively). However, the main effect of sex failed to reach significance $F(1, 69) = 0.8333$, $p>0.05$ as did the main effect of handedness $F(1, 69) = 0.158$, $p>0.05$. The interaction between sex and handedness also failed to reach significance $F(1, 69) = 0.033$, $p>0.05$ Therefore, the number of options to the questions had an effect on first response time but sex or handedness played no part in this effect – it appeared to be the complexity rather than sex or handedness.

6.8.3. Number Correct

Table 6.9: Mean number correct for each sex and handedness group along with totals for 3 and 6 options (with standard deviations in parentheses).

	Left Male	**Right Male**	**Left Female**	**Right Female**	**Total**
3 options	12.6 *(2.0)*	13.6 *(1.6)*	12.7 *(1.9)*	12.6 *(2.2)*	12.9 *(1.9)*
6 options	11.7 *(2.5)*	13.1 *(1.6)*	12.2 *(2.9)*	12.5 *(2.6)*	12.3 *(2.5)*
Total	12.1 *(2.3)*	13.4 *(1.6)*	12.7 *(2.4)*	12.6 *(2.4)*	

The above table shows that on 3 options the right-handed males scored the highest number correct followed by left-handed females then right-handed females and left-handed males scored the lowest on the 3 option questions. Right-handed males also scored the highest on the 6 option questions followed again by left-handed females then right-handed females and left-handed males again had the lowest number correct. In total, right-handed males scored the highest number of questions correct on average. The next highest score was achieved by left-handed females then right-handed females and left-handed males scored the lowest number correct, on average, overall.

To see if these differences were significant a 2 x 2 (sex vs. handedness) ANOVA was carried out. For 3 options, there was no main effect of sex F(1, 72) = 0.821, p>0.05. There was also no main effect of handedness F(1, 72) = 0.955, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 1.577, p>0.05. For 6 options there was no main effect of sex F(1, 72) = 0.015, p>0.05, no main effect of handedness F(1, 72) = 2.34, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 0.885, p>0.05.

A 2X2 (sex vs. handedness) ANOVA was also conducted for the average number of questions correct over 3 and 6 options. There was no main effect of sex (1, 72) = 0.295, p>0.05 and no main effect of handedness F(1, 72) = 2.25, p>0.05 and the interaction between sex and handedness failed to reach significance F(1, 72) = 1.58, p>0.05.

In addition, a 2 x 2 x 2 mixed model ANOVA was carried out with type of question as the within factor (3 options or 6 options) and sex and handedness the between factors. The main effect of question on the number correct approached significance F(1, 69) = 3.583, p=0.063 where the number correct for the 6 option questions were lower than the number of questions correct for the 3 option questions (12.86 vs. 12.34 respectively on average). However, the main effect of sex failed to reach significance F(1, 69) = 0.295, p>0.05 as did the main effect of handedness F(1, 69) = 2.246, p>0.05. The interaction between sex and handedness also failed to reach significance F(1, 69) = 1.575, p>0.05 Therefore, the number of options for the questions approached a significant effect on the number of questions correct but sex or handedness played no part in this effect – it appeared to be the complexity rather than sex or handedness.

6.8.4. Total time taken

Table 6.10: Mean total time taken (in milliseconds) for male and female, left and right-handers to answer questions with 3 options (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	7761 (*4281.0*)	7667 (*2496.3*)	7717 (*3503.8*)
Female	8472 (*4307.2*)	7675 (*1945.5*)	8084 (*3350.6*)
Total	8116 (*4251.0*)	7671 (*2196.6*)	

The above table shows that left-handed females, on average, took the longest to answer each question with 3 options. Left-handed males, right-handed females and right-handed males all took similar times, on average, to solve the 3 option questions. Females took longer than males, on average, to solve the 3 option questions and left-handers took longer to solve the questions than right-handers.

To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 0.196, p>0.05. There was no main effect of handedness F(1, 72) = 0.301, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 0.187, p>0.05.

Table 6.11: Mean total time taken (in milliseconds) for male and female, left and right-handers to answer questions with 6 options (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	14094 (7675.3)	13760 (2955.5)	13936 (5858.2)
Female	14977 (8129.5)	14515 (3551.4)	14752 (6249.4)
Total	14536 (7810.9)	14148 (3250.1)	

The above table shows that left-handed females, on average, took the longest to answer each question with 6 options. Right-handed females took the next longest followed by left-handed males and right-handed males took the least amount of time to solve the 6 option questions. Females took longer than males, on average, to solve the 6 option questions and left-handers took longer to solve the questions than right-handers.

To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 0.323, p>0.05. There was no main effect of handedness F(1, 72) = 0.077, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 0.002, p>0.05.

Table 6.12: Total time taken (in milliseconds) for male and female, left and right-handers to answer questions overall (with standard deviations in parentheses). (3 and 6 options averaged).

	Left	**Right**	**Total**
Male	14808 (*8008.8*)	14547 (*3566.7*)	14678 (*5787.8*)
Female	15960 (*8225.8*)	14933 (*3595.2*)	15447 (*5910.5*)
Total	15384 (*8117.3*)	14740 (*3580.9*)	

The above table shows that left-handed females, on average, took the longest to answer each question when the time for 3 and 6 options was averaged. Left-handed males, right-handed females and right-handed males all took similar times, on average, to solve the 3 and 6 option averaged questions. Females took longer than males, on average, to solve the averaged 3 and 6 option questions and left-handers took longer to solve the questions than right-handers.

To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 0.266, p>0.05. There was no main effect of handedness F(1, 72) = 0.187, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 0.066, p>0.05.

Table 6.13: Comparison of mean total time taken per option to answer the questions between 3 options and 6 options (with standard deviations in parentheses).

	Left Male	**Right Male**	**Left Female**	**Right Female**	**Total**
3 options	7761 *(4281.0)*	7667 *(2496.3)*	8472 *(4307.2)*	7675 *(1945.5)*	7894 *(3257.1)*
6 options	14094 *(7675.3)*	13760 *(2955.5)*	14977 *(8129.5)*	14515 *(3551.4)*	14336 *(5577.9)*

The above table shows that for each group the mean total time for the questions with 6 options were longer than the mean total time for the questions with 3 options. The total times showed that overall the times for 6 options were, on average, longer than the mean total time for the questions with 3 options.

A 2 x 2 x 2 mixed model ANOVA was carried out with type of question as the within subjects factor (3 options or 6 options) and sex and handedness the between subjects factors. A significant main effect of question was found F(1, 69) = 261.336, p=0.000 where mean total time taken to answer the 6 option questions was significantly longer the mean total time taken to answer the 3 option questions (14336.8 ms vs. 7894.1 ms respectively). However, the main effect of sex failed to reach significance F(1, 69) = 0.288, p>0.05 as did the main effect of handedness F(1, 69) = 0.147, p>0.05. The interaction between sex and handedness also failed to reach significance F(1, 69) = 0.036, p>0.05 Therefore, the number of options to the questions had an effect on total completion time although this is a straightforward logical explanation.

6.8.5. Total time minus planning time

Table 6.14: Mean time taken to solve the question minus 'initiation time' (first response time) for male and female, left and right-handers for questions with 3 options (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	1451 *(742.2)*	2019 *(1564.4)*	1735 *(1153.1)*
Female	1772 *(715.8)*	1556 *(444.1)*	1664 *(580.0)*
Total	1611 *(729.0)*	1788 *(1004.1)*	

The above table shows that when first response time was removed from total time taken to solve the question (for 3 options) right-handed males took the longest to solve the question although their scores had much greater variance as the standard deviation was more than double that of the other groups. Right-handed females, left-handed females and left-handed males all took similar times to solve the questions when 'initiation time' was removed. This indicates that right-handed males have, on average, a shorter initiation time, as their total time to complete the whole question when initiation time is included was the shortest along with right-handed females. Males and females solved the questions in similar times when 'initiation time' was removed and left and right-handers also solved the questions in similar times when the 'initiation time' was removed.

To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex $\underline{F}(1, 72) = 0.103$, $\underline{p}>0.05$. There was no main effect of handedness $\underline{F}(1, 72) = 0.632$, $\underline{p}>0.05$ and the interaction between sex and handedness also failed to reach significance $\underline{F}(1, 72) = 3.120$, $\underline{p}>0.05$.

Table 6.15: Mean time taken to solve the question minus 'initiation time' (first response time) for male and female, left and right-handers for questions with 6 options (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	7451 *(3529.8)*	7400 *(2799.7)*	7426 *(3164.8)*
Female	7536 *(3720.5)*	6842 *(1281.2)*	7189 *(2500.9)*
Total	7494 *(3625.2)*	7121 *(20340.5)*	

The above table shows that when first response time was removed from total time taken to solve the question (for 6 options) right-handed males, left-handed females and left-handed males all took similar times to solve the questions when ‘initiation time’ was removed. Right-handed females took the shortest time when initiation time was removed. Males and females solved the questions in similar times when ‘initiation time’ was removed and left and right-handers also solved the questions in similar times when the ‘initiation time’ was removed.

To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 0.113, p>0.05. There was no main effect of handedness F(1, 72) = 0.278, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 0.208, p>0.05.

Table 6.16: Mean time taken to solve the question minus ‘initiation time’ in milliseconds (first response time) for male and female, left and right-handers overall (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	4451 (2035.5)	4710 (1830.2)	4580 (1932.8)
Female	4654 (2075.7)	4199 (758.9)	4426 (1417.3)
Total	4553 (2055.6)	4454 (1294.5)	

The above table shows that overall (when total time minus ‘initiation time’ is averaged across 3 and 6 options) right-handed males took the longest to complete the questions closely followed by left-handed females and then left-handed males. Right-handed females completed the questions in the fastest time when initiation time was taken away from total time. Males and females took similar time to answer the questions when initiation time was taken away. Also, left- and right-handers completed the questions in very similar times.

To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 0.138, p>0.05. There was no main effect of handedness F(1, 72) = 0.056, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 0.741, p>0.05.

Table 6.17: Comparison of mean total time minus initiation time between 3 options and 6 options (with standard deviations in parentheses).

	Left Male	**Right Male**	**Left Female**	**Right Female**	**Total**
3 options	1451 *(742.2)*	2019 *(1564.0)*	1772 *(715.8)*	1556 *(444.1)*	1700 *(866.5)*
6 options	7451 *(3529.8)*	7400 *(2799.7)*	7536 *(3720.5)*	6842 *(1281.2)*	7307 *(2832.8)*

The above table shows that for each group the mean total time minus initiation taken to solve the questions with 6 options were longer than the time minus initiation time for the questions with 3 options. The total times showed that overall the mean total time minus initiation time for 6 options was, on average, longer than the total time minus initiation for the questions with 3 options.

A 2 x 2 x 2 mixed model ANOVA was carried out with type of question as the within subjects factor (3 options or 6 options) and sex and handedness the between subjects factors. A significant main effect of question was found F(1, 69) = 307.091, p=0.000 where mean total time minus initiation time for the 6 option questions was significantly longer than total time minus initiation for the 3 option questions (7307.8 ms vs. 1700 ms respectively). However, the main effect of sex failed to reach significance F(1, 69) = 0.138, p>0.05 as did the main effect of handedness F(1, 69) = 0.056, p>0.05. The interaction between sex and handedness also failed to reach significance F(1, 69) = 0.741, p>0.05 Therefore, the number of options to the questions had an effect on total time taken minus initiation time to solve each question, however, this is a straightforward common sense argument that responding to more options will take longer.

6.8.6. Time per response

Table 6.18: Mean time per response for male and female, left and right-handers for questions with 3 options (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	2587 (1427.0)	2555 (832.1)	2571 (1129.6)
Female	2824 (1435.7)	2558 (648.5)	2691 (1042.1)
Total	2705 (1431.4)	2557 (740.3)	

The above table shows that each of the four groups took a similar time, on average, to make each individual response to the question for 3 options. Left-handed females took slightly longer but left-handed males, right-handed males and right-handed females took very similar times, on average, per response. Males and females also took similar times per response, on average. Females took slightly longer per response than male. Left-handers took slightly longer per response than right-handers.

To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex $F(1, 72) = 0.659$, $p>0.05$. There was no main effect of handedness $F(1, 72) = 0.585$, $p>0.05$ and the interaction between sex and handedness also failed to reach significance $F(1, 72) = 0.666$, $p>0.05$.

Table 6.19: Mean time per move for male and female, left and right-handers for questions with 6 options (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	2819 (1535.1)	2752 (591.1)	2785 (1063.1)
Female	2995 (1625.9)	2903 (710.3)	2949 (1168.1)
Total	2907 (1580.5)	2827 (650.7)	

The above table shows that each of the four groups took a similar time, on average, to make each individual response to the question for 6 options. Left-handed females took the longest but left-handed males, right-handed males and right-handed females also took very similar times, on average, per response. Males and females also took similar times per response, on average. Females took slightly longer per response than males and left-handers took slightly longer per response than right-handers.

To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex $F(1, 72) = 0.571$, $p>0.05$. There was no main effect of handedness $F(1, 72) = 0.783$, $p>0.05$ and the interaction between sex and handedness also failed to reach significance $F(1, 72) = 0.965$, $p>0.05$.

Table 6.20: Mean time per move for male and female, left and right-handers overall (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	2703 *(1461.0)*	2653 *(635.6)*	2678 *(1048.3)*
Female	2909 *(1504.2)*	2730 *(656.4)*	2820 *(1080.3)*
Total	2806 *(1491.5)*	2692 *(646.0)*	

The above table shows that when averaging the time per response for 3 and 6 options left-handed females took the longest time per response, they were closely followed by right-handed females and left-handed males. Right-handed males took the shortest time per move on average. Females took slightly longer, on average, per response than males and left-handers took slightly longer per response than right-handers.

To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 0.272, p>0.05. There was no main effect of handedness F(1, 72) = 0.176, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 0.057, p>0.05.

Table 6.21: Comparison of mean time per move between 3 options and 6 options (with standard deviations in parentheses).

	Left Male	**Right Male**	**Left Female**	**Right Female**	**Total**
3 options	2587 *(1427.0)*	2555 *(832.1)*	2824 *(1435.7)*	2558 *(648.5)*	2631 *(1085.8)*
6 options	2819 *(1535.1)*	2752 *(591.1)*	2995 *(1625.9)*	2903 *(710.3)*	2867 *(1115.6)*

The above table shows that for each group the mean time per response for the questions with 6 options were longer than the mean time per response for the questions with 3 options. The total times showed that overall time per response for 6 options was, on average, longer than time per response for the questions with 3 options.

A 2 x 2 x 2 mixed model ANOVA was carried out with type of question as the within subjects factor (3 options or 6 options) and sex and handedness the between subjects factors. A significant main effect of question was found $\underline{F}(1, 69) = 13.606$, $\underline{p}=0.000$ where time per response for the 6 option questions were significantly longer than time per response for the 3 option questions (2867 ms Vs. 2631.4 ms respectively). However, the main effect of sex failed to reach significance $\underline{F}(1, 69) = 0.176$, $\underline{p}>0.05$ as did the main effect of handedness $\underline{F}(1, 69) = 0.272$, $\underline{p}>0.05$. The interaction between sex and handedness also failed to reach significance $\underline{F}(1, 69) = 0.057$, $\underline{p}>0.05$ Therefore, the number of options to the questions had an effect on mean time per response but sex or handedness played no part in this effect – it appeared to be the complexity rather than sex or handedness.

The main findings from experiment 5 were:

- There were no effects of sex or handedness on the time taken to look at the question.

- There were no effects of sex or handedness on the time taken to make the first response to a question (both for 3 and 6 options).

- First response times overall were longer for 6 options than 3 options.

- There were more correct responses for questions with 3 options than questions with 6 options (this approached significance).

- There were no sex or handedness effects for the time taken to complete the questions.

See appendix 15 for additional analyses of this task and for analyses using different handedness inventories.

6.9. Experiment 5: Discussion

It was hypothesised for the 'fastest finger first' task (study 1) that left-handers would take longer than right-handers to make their first response to the 3-option questions. It was found that there was no significant difference in the time taken by this group to make the first response and this hypothesis was not supported. However, the findings were in the direction predicted as left-handers took an average of 700 milliseconds longer to make their first response than right-handers. No significant sex differences were found either but females took longer, on average, to make their first response. It was also hypothesised that left-handers would take longer to make their first response to the 6-option questions than right-handers. This hypothesis was not supported, as the first response time taken by each handedness group was, on average, almost identical. Females were slower than males to make the first response to the 6-option questions but this difference was not significant. The final hypothesis for this study was that left-handers would look at the question longer than right-handers before choosing to reveal the answers. This hypothesis was not supported. It was found that right-handers looked at the question for longer than left-handers and this difference was in the opposite direction of what was predicted. It was also found for each sex and handedness group that the time taken to make the first response on the 3-option questions was significantly faster than the time taken to make the first response to the 6-option questions.

One reason for the finding that left- and right-handers took an almost identical time to make their first response to the 6-option questions may be because the sequencing of this number of answers is complex. As an average of 7 seconds occurred before the participant made their first response to 6 option questions, a number of things may have been happening during this time. Participants might have been planning the sequence of answers to the question asked in a similar way to solving a problem solving task such as the Tower of London (e.g. Morris et al., 1997; Goel et al., 2001) or they might have been searching for the first response only during this time. Participants might have been examining what the question asked or simply just have been thinking but making no specific plan to answer the question. Additionally, sequencing 6 options places a moderate load on short-term memory capacity (the participant has to remember which responses they have already used or may make a mistake and use the same response twice) it is therefore unlikely that a full plan is being made before participants are responding (e.g. Eysenck & Keane, 2002). A more probable explanation is that the participant is looking over the relatively complex sequence and identifying the first one or two responses and then using an on-line planning strategy to complete the sequence (and plan the rest of the sequence out as they go along by responding using one or two answers at a time at a steady pace rather than giving the 6 responses in rapid succession which would be more evident if planning had taken place before the first response was made). Phillips et al. (2001) reported that the most accurate solutions often depended on on-line planning during the solving phase rather than planning a solution before beginning a task. This suggests that there would be more evidence of a pattern of responses during the solving if on-line planning was occurring rather than a large delay at the beginning followed by a quick execution time. Thus, as this task was relatively complex it would be expected that this would be the case for the participants regardless of their hand preference. However, the 3-option task would not be expected to place as much of a load on short term memory capacity (Eysenck & Keane, 2002) and the possibility of planning the whole sequence before making the first response would be possible in most cases (especially as both handedness groups took an average of around 6 seconds before making the first response which would suggest again that planning could possibly be happening here). However, left-handers took longer, on average, to make the first response on the 3-option sequence than right-handers did.

One possible explanation for this could be that the simplicity of the task may have affected the performance of the left-handed group (see chapter 7 for additional details). As sequencing the 3 options in this task was relatively simple then the left-handed group may have felt pressurised or anxious to make sure that they did such a simple task correctly. However, there is no existing research that has examined this concept and thus this idea is speculative. The issue of anxiety and performance in left-handers has been examined in a number of studies (see chapter 4 and chapter 7 for more details). Conflicting results have been reported with some studies reporting that left-handers are more anxious than right-handers (e.g. Dillon, 1989) while others report that there is no difference between the two groups (e.g. French & Richards, 1990). However, work by Cameron and Rogers (1999) reported that novel objects could affect the performance of left-handers and that novelty resulted in increased anxiety in many cases. Thus, it would be expected in this series of studies that the more novel tasks could affect the stress levels of the participants and might also contribute to the attitude towards the different tasks that the participant is asked to perform. In the case of the ‘fastest finger first’ task it can be argued whether or not this is a novel task. It is probable that most of the participants taking part in the study had all seen ‘Who wants to be a millionaire’ before and thus most participants would be familiar with the ‘fastest finger first’ game and would be aware of the rules and what the task required. The only thing that differed between the current task and that of the television show (except that the television show only gives one ‘fastest finger first’ question to the contestant) was that in the television show the contestant is asked to put 4 answers in to a sequence and here participants are asked to either put 3 or 6 answers into a sequence.

Therefore in order to take into account the possibility that stress caused by the novelty of the task could have affected the behaviour of the participants before making the first response then it would have to have been ensured that the task was novel to participants. Because this task was not necessarily novel to the participants then this might have been the reason why no differences were found between the two different handedness groups. However, it could also be argued that the task was novel because the format was similar to that used on the television show but the participants had not had experience of responding to the actual question and sequence using a keyboard or similar device (although again this can be argued against as the game exists for games consoles and thus some people will be familiar with this scenario). Another argument that the task was novel is that the experimenter created the questions and thus they were novel to the participant.

When examining overall completion time of the 3 option questions, left-handers took longer than right-handers to complete these. However, when initiation time was not included in this time left-handers completed the questions faster than right-handers. This suggests that left-handers were perhaps thinking about their solution or even their first response before starting to solve the question. However, neither difference was significant. Additionally, as Phillips et al. (2001) suggest, making a plan does not necessarily result in a superior performance and therefore it cannot be assumed that just because left-handers took longer to start but completed the task quicker that this was due to planning. A different pattern was found for the 6 option questions. It was found that left-handers took slightly longer in total to complete the 6 option questions overall and they also took longer when initiation time was not included in completion time. This suggests that even if planning was occurring during the initiation time that is was no more effective in the solution of the task than the performance of the right-handers. Gilhooly et al. (1999) reported that efficient performance on a task depends primarily on planning during the task rather than making a pre-plan before starting the task. Based on this, there was either very little evidence of planning in the current study or if there was any evidence of planning then the left- and right-handers must have been making equally effective (or equally ineffective) plans. In conclusion, although the fastest finger first task can be classed as measuring planning this still may not be the reason for the initial delay that was made by some participants before they began and an alternative reason may be attributed to novelty or stress. It could also be the case that the participant was merely surveying the answers but not specifically planning the sequence to answer the question asked.

6.10. Experiment 6: Computerised Task

6.10.1. Introduction

The final task is a task which examines (amongst other types of questions) the spatial abilities of left- and right-handers. This takes the format of a computerised IQ test. A series of questions regarding numbers and language are also given but the most important questions to investigate spatial ability are the Raven’s Progressive Matrices (RPM) pictures and the 3-D mental rotation questions (see appendix 21). The mental rotation questions are a direct measure of being able to manipulate a series of shapes in space and to be able to form 3-dimensional shapes mentally from the 2-dimensional stimuli. The Raven’s Progressive Matrices are a measure of spatial reasoning and thus this is why they were chosen to include in this task. Walker and Mauney (2004) report that the spatial reasoning and spatial cognition used when solving Raven’s Progressive Matrices is related to a person’s ability to be able to mentally store information and be able to visualise objects and be able to manipulate and rotate these in order to solve the task. The independent variable in this task is the type of problem given, this had four levels: word problem, number problem, Raven’s Progressive Matrices and 3-D mental rotation/shape building. The dependent variables are the time taken to respond to each problem (in milliseconds) and the accuracy of the answers to each problem.

6.10.2. Rationale and hypotheses for experiment 6

Because a difference was found between left- and right-handers in the time taken to begin the Tower of Hanoi in Chapter 4 (a spatial task of planning) it was proposed that one possible explanation for this delay could be planning (whereby participants thought about their strategy or first response before making contact with the apparatus). However, although there was a possible planning difference it could not be ruled out that the difference could be attributed to the spatial nature of the task. Therefore, additional tasks were devised to address this issue. This current study was designed to assess the spatial abilities of left and right-handers (Raven’s Progressive Matrices and space relation problems). It is thought that if one group has superior spatial abilities than the other then this complicates any potential inferences made about left-handers planning more than right-handers and it might just be that left-handers are simply better at solving the task because of its nature. However, reaction times will also be recorded as part of experiment 6 and will be used to see if there is a difference between the times taken to respond to the problems. The reason for using the number based questions and the language-based questions was to investigate firstly whether left- and right-handers differed on the time they took to respond to these. Secondly, as the literature often cites that left-handers have superior mathematical abilities (e.g. Annett, 2002) and that right-handers have superior language abilities (e.g. Bishop, 1990) then this issue will also be investigated as part of this experiment.

It is hypothesised that left-handers will score higher on the number of spatial questions correct than right-handers. It is also hypothesised that left-handers will respond to the spatial questions significantly faster than right-handers. Additionally, it is hypothesised that left-handers will be more accurate on the mathematical questions and that right-handers will be more accurate on the number questions. No predictions are made on the reaction times of these.

6.11. Experiment 6: Method

6.11.1 Participants

A total of 81 participants took part in this study (40 male and 41 female). Of these, 42 participants were left-handed (20 males and 22 females) and 39 participants were right-handed (20 males and 19 females). All participants had normal colour vision and normal or corrected-to-normal visual acuity.

6.11.2. Materials and Apparatus

The state anxiety inventory and the trait anxiety inventory (STAI - Speilberger, 1983) were given to participants before they completed the computer task (see appendices 26a and 26b). However, this is described and discussed as part of Chapter 7 (see sections 7.3. and 7.4. for a description and the results of the STAI). The adapted version of Peter's (1998) handedness inventory was also given (details of this can be found in Chapter 3 and a copy of this can be found in appendix 2).

An instruction sheet for the computer task was given to participants and this informed them that they were going to be presented with 4 different types of tasks which were number questions, word questions, space relation (mental rotation) questions and Raven's Progressive Matrices questions. Participants were given an example of each type of task and informed that they should respond using the appropriate number keys (see appendix 20). The computer program consisted of 36 trials. 10 word trials, 10 number trials, 8 Raven's Progressive Matrices and 8 'Mental Rotation' trials (see appendix 21). The word trials consisted of statements such as 'Hot is to cold as rich is to….' and the participant was given four options with which to answer it. The number trials consisted of a series of numbers such as 1, 2, 3, 4… and the participant had to identify the next number in the sequence (with the aid of 4 choices). For the 'mental rotation' task the participant was shown a folded out shape which could be constructed to make a 3-dimensional shape. The participant had to mentally try and build the shape to obtain the correct answer. Finally, Raven's Progressive Matrices consisted of a series of patterns and the final step was omitted. The participant was given a series of choices as to which response would fit the pattern. The number of choices given ranged from four to eight. The trials were run as part of a Superlab program (version 1.2) and were run on a Compaq laptop. A blank screen was shown for 700 milliseconds after each trial. The stimuli for the word and number trials were adapted from the AH4 (Heim, 1973) and the stimuli for the 3-D shape building was adapted from the Differential Aptitude Tests (form S) (Bennett, Seashore, & Wesman, 1975)

6.11.3. Procedure

Participants were given the Peter's (1998) handedness Inventory to begin the study with. This was given first in order to allow the participants to feel at ease with the experimenter before they were presented with the STAI. Participants were instructed to fill out the handedness questionnaire reporting the hand that they preferred to perform a series of actions with. Half of the participants (males and females and left and right-handers) were given the instructions for the computer task next and the other half of the sample was presented with the state instructions for the STAI (responding to the statements according to how they felt right at that moment). Those who did not receive the instructions for the computer task were told that they were going to complete a computer task but first would be presented with a self-evaluation questionnaire. They were told to read the instructions carefully and complete the questionnaire accordingly. Those who were given the instructions for the computer task first were told to read through the instructions as if they were going to go ahead with the task. When they were familiar with the instructions the participants were presented with the state form of the STAI to do prior to beginning the task. The STAI (state instructions) were presented before and after the instructions for the computer task in order to see if knowing what the task was going to entail would affect the responses to the STAI compared to not knowing what the computer task was going to entail (the results for this can be found in Chapter 7, section 7.4.). When the participants completed the STAI (state) they were given the instructions for the computer task to read through (if they had already read them as part of the post-instruction group they were encouraged to read over them again). When the participants indicated they were happy with the instructions for the task they began. The 36 trials (10 word, 10 number, 8 RPM and 8 3-D folding) were presented randomly and participants had to respond using the number keys on the keyboard. The number choices for the word and number trials ranged from 1 to 4. The 3-D folding shapes were presented as A, B, C, and D on the computer program but participants were instructed to respond using 1, 2, 3, 4 where 1 corresponded with A, 2 with B, 3 with C and 4 with D. The Raven's Progressive Matrices had a number of choices ranging from 4 to 8. For the trials containing 8 answers, participants had to respond using keys 1 to 8. When the computer task was completed the final part of the study involved the trait instructions of the STAI. Again participants were presented with the questionnaire and instructed to read the instructions carefully and respond to the statements according to the instructions. This time the participants had to respond to the statements according to how they generally feel about how the questions related to them. Completion of this signalled the end of the experiment.

6.12. Results: Experiment 6: Computer task

a) Correct responses

Table 6.22: Mean number of correct responses on the mental rotation (3D shape building) questions (with standard deviations in parentheses).

	Male	**Female**	**Total**
Left-handed	3.7 *(1.7)*	3.1 *(1.6)*	3.37 *(1.7)*
Right-handed	2.7 *(1.6)*	2.4 *(1.3)*	2.51 *(1.4)*
Total	3.2 *(1.6)*	2.7 *(1.5)*	

The above table shows that left-handed males and females got more mental rotation questions correct, on average, than right-handed males and females. Also, males got more mental rotation questions correct, on average, than females and left-handers got more mental rotation questions correct than right-handers.

A 2x2 (handedness (left vs. right) by sex (male vs. female)) ANOVA was carried out on the number of correct responses made by participants on the mental rotation part of the computer program. There was a significant main effect of handedness F(1, 77) = 4.701, p<0.05 with left handers (on average) getting more mental rotation answers correct than right handers. There was no significant effect of sex F(1, 77) = 0.609, p>0.05 and also there was no significant interaction F(1, 77) = 0.157, p>0.05.

Table 6.23: Mean number of correct responses made by participants on the number questions (with standard deviations in parentheses).

	Male	**Female**	**Total**
Left-handed	8.5 *(1.2)*	8.6 *(1.1)*	8.5 *(1.1)*
Right-handed	8.2 *(1.6)*	8.3 *(1.7)*	8.2 *(1.6)*
Total	8.3 *(1.4)*	8.4 *(1.4)*	

The above table shows that all groups got, on average, around 8 out of 10 of the number questions correct. Females scored slightly higher than males (a difference of only 0.08) and left-handers scored slightly higher than right-handers (a difference of only 0.17).

A 2x2 (handedness (left vs. right) by sex (male vs. female)) ANOVA was carried out on the number of questions participants answered correctly on the number part of the computer task. There was no significant effect of handedness F(1, 77) = 0.052, p>0.05. There was no significant effect of sex F(1, 77) = 0.061, p>0.05 and there was no significant interaction F(1, 77) = 0.061, p>0.05.

Table 6.24: Mean number of correct responses made by participants on the Ravens Progressive Matrices questions of the computer task (with standard deviations in parentheses).

	Male	**Female**	**Total**
Left-handed	5.5 *(1.5)*	4.6 *(1.8)*	5.1 *(1.6)*
Right-handed	5.3 *(1.8)*	5.1 *(2.0)*	5.2 *(1.9)*
Total	5.4 *(1.6)*	4.9 *(1.9)*	

The above table shows that left-handed males scored, on average, the highest number of Ravens Progressive Matrices correct while left-handed females scored the lowest number, on average. Males got more Ravens Progressive Matrices questions correct, on average, than females and right-handers got slightly more correct, on average, than left-handers.

A 2x2 (handedness (left vs. right) by sex (male vs. female)) ANOVA was carried out on the number of RPM questions participants answered correctly. There was no significant effect of handedness F(1, 77) = 0.779, p>0.05. There was also no significant effect of sex F(1, 77) = 1.287, p>0.05 or any significant interaction F(1, 77) = 0.524, p>0.05.

Table 6.25: Mean number of correct responses on the word questions of the computer task (with standard deviations in parentheses).

	Male	**Female**	**Total**
Left-handed	8.8 *(1.8)*	8.9 *(1.0)*	8.8 *(0.9)*
Right-handed	9.3 *(0.7)*	8.8 *(0.9)*	9.1 *(0.8)*
Total	9.0 *(1.3)*	8.9 *(0.9)*	

The above table shows that each group scored just under an average of 9 questions correct out of 10 except for right-handed males who scored and average of 9.25 questions correct out of 10. Males got slightly more questions correct, on average, than females and right-handers got slightly more questions correct, on average, than left-handers.

A 2x2 (handedness (left vs. right) by sex (male vs. female)) ANOVA was carried out on the number of correct word questions participants answered correctly during the computer task. There was no significant effect of handedness F(1, 77) = 1.048, p>0.05. There was no significant effect of sex F(1, 77) = 0.266, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 77) = 0.484, p>0.05.

b) Reaction times

Table 6.26: Mean reaction time (in milliseconds) taken by participants to complete the questions (regardless of topic) of the computer task (with standard deviations in parentheses).

	Male	**Female**	**Total**
Left-handed	19246 *(5367.4)*	18360 *(8421.8)*	18782 *(7062.5)*
Right-handed	15865 *(5144.4)*	17747 *(5711.9)*	16782 *(5440.1)*
Total	17556 *(5464.3)*	18076 *(7212.1)*	

The above table shows that left-handed males took the longest to respond to all questions on the computer task and right-handed males took the least time, on average, to respond. Males responded, on average, in less time than females and right-handers took less time to respond than left-handers.

A 2x2 (handedness (left vs. right) by sex (male vs. female)) ANOVA was carried out on the overall mean time that participants took to respond to the computer task stimuli. There was no significant effect of handedness $\underline{F}(1, 77) = 1.983$, $\underline{p}>0.05$ and the effect of sex was not significant $\underline{F}(1, 77) = 0.123$ $\underline{p}>0.05$. The interaction also failed to reach significance $\underline{F}(1, 77) = 0.952$, $\underline{p}>0.05$.

Table 6.27: Mean reaction time (in milliseconds) taken by participants to complete the metal rotation questions of the computer task (with standard deviations in parentheses).

	Male	**Female**	**Total**
Left-handed	29076 *(12318.0)*	27965 *(17473.1)*	28494 *(15066.8)*
Right-handed	22080 *(12522.8)*	26511 *(12419.3)*	24239 *(12510.1)*
Total	25578 *(12762.0)*	27291 *(15173.4)*	

The above table shows that right-handed males responded the quickest, on average, to the mental rotation questions and left-handed females took the longest to respond to these questions. Males responded quicker to the mental rotation questions than females on average while right-handers responded quicker to the mental rotation questions than left-handers).

A 2x2 (handedness (left vs. right) by sex (male vs. female)) ANOVA was carried out on the time taken to respond to the mental rotation questions of the computer task. There was no significant effect of handedness F(1, 77) = 1.844, p>0.05 and no significant effect of sex F(1, 77) = 0.285, p>0.05. The interaction between sex and handedness also failed to reach significance F(1, 77) = 0.793, p>0.05.

Table 6.28: Mean reaction time taken by participants to complete the number questions of the computer task (with standard deviations in parentheses).

	Male	**Female**	**Total**
Left-handed	16242 *(5213.0)*	15318 *(6958.3)*	15758 *(6132.8)*
Right-handed	15006 *(4661.7)*	18226 *(7197.7)*	16575 *(6169.5)*
Total	15624 *(4921.2)*	16666 *(7133.5)*	

The above table shows the mean time taken to respond to the number questions. Right-handed males were quickest, on average, to respond while right-handed females took the longest, on average, to respond. Males took less time to respond to the number questions than females on average and left-handers took less time, on average, to respond to the number questions than right-handers.

A 2x2 (handedness (left vs. right) by sex (male vs. female)) ANOVA was carried out on the time taken by participants to respond to the number questions of the computer task. There was no significant effect of handedness F(1, 77) =0.377, p>0.05. There was no significant effect of sex F(1, 77) = 0.712, p>0.05 and there was no significant interaction of sex and handedness F(1, 77) = 2.318, *p*>0.05.

Table 6.29: Mean reaction time taken by participants to complete the Raven's Progressive Matrices questions of the computer task (with standard deviations in parentheses).

	Male	**Female**	**Total**
Left-handed	25751 *(10354.9)*	26181 *(15972.2)*	25977 *(13431.5)*
Right-handed	19246 *(6613.6)*	21243 *(9197.5)*	20219 *(7935.0)*
Total	22498 *(9186.9)*	23893 *(13349.8)*	

The above table shows that left-handed females took the longest, on average, to respond to the Ravens Progressive Matrices questions and right-handed males took, on average, the shortest time to respond. Males took less time to respond to the Ravens Progressive Matrices questions than females and right-handers took less time to respond, on average, than left-handers.

A 2x2 (handedness (left vs. right) by sex (male vs. female)) ANOVA was carried out on the time taken to respond to the RPM questions of the computer task. There was a significant main effect of handedness $F(1, 77) = 5.222$, $p<0.05$ with right-handers responding significantly faster, on average, than left-handers. There was no significant effect of sex $F(1, 77) = 0.235$, $p>0.05$ and there was no significant interaction between sex and handedness $F(1, 77) = 0.098$, $p>0.05$.

Table 6.30: Mean reaction time (in milliseconds) taken by participants to complete word questions of the computer task (with standard deviations in parentheses).

	Male	**Female**	**Total**
Left-handed	9182 *(4446.8)*	7067 *(2286.2)*	8074 *(3603.3)*
Right-handed	7706 *(2739.7)*	7528 *(2198.7)*	7619 *(2459.9)*
Total	8444 *(3721.4)*	7281 *(2230.2)*	

The above table shows that left-handed males took the longest to respond to the word questions, on average and left-handed females took the least time. Females took less time, on average, to respond to the ‘word’ questions than males and right-handers took less time, on average, to respond to the questions than left-handers.

A 2x2 (handedness (left vs. right) by sex (male vs. female)) ANOVA was carried out on the time taken by participants to respond to the word questions of the computer task. There was no significant effect of handedness F(1, 77) = 0.560, $p>0.05$. There was no significant effect of sex F(1, 77) = 2.859, $p>0.05$ and there was no significant interaction between sex and handedness F(1, 77) = 2.038, $p>0.05$.

The main findings of Experiment 6 were:

- When analysing all questions together there were no effects of sex or handedness on the number correct.
- The effect of handedness on the time taken to respond to the questions overall approached significance with right-handers responding faster than left-handers.
- The only significant result when looking at the number correct for each individual type of question was found on the mental rotation questions. Left-handers were significantly more accurate than right-handers. There were no other sex or handedness effects for any of the other types of question.
- The only significant result when looking at the reaction times for each individual type of question was found on the Raven’s Progressive Matrices questions. Right-handers responded significantly faster than left-handers to these questions. There were no other sex or handedness effects for any of the other types of question.

Additional analyses were carried out on these data and this can be found in appendix 22. Additional analyses include some re-analysis using different handedness inventories.

6.13. Experiment 6: Discussion

The computer task was used predominantly in order to examine the visuo-spatial elements of the task. This was done to investigate whether the nature of the task used (visuo-spatial) had any strong effects on the findings. It was hypothesised that left-handers would get more visuo-spatial questions correct than right-handers. This hypothesis was supported for the mental rotation questions where left-handers got significantly more answers correct than right-handers. There was no significant difference between left- and right-handers on the number of Raven's Progressive Matrices questions correct and right-handers scored, on average, slightly higher than left-handers on the number of questions correct. However, it could be argued whether or not there was a strong visuo-spatial element to the Raven's Progressive Matrices task (Walker & Mauney, 2004) and this could therefore affect the responses given (if the RPM is a strong spatial task then it would be expected that left-handers would score higher but it could also be suggested that this is a task of pattern recognition rather than a spatial task and this could therefore support the original predictions). Raven's Progressive Matrices are thought to involve the visual manipulation of a series of stimuli (Walker & Mauney, 2004) and thus it is argued that this is a strong case for the task being considered as a spatial task rather than a task of pattern recognition. It was also hypothesised that left-handers would respond significantly faster to the spatial questions than right-handers. This hypothesis was not supported, however, left-handers did, on average, respond quicker than right-handers to the mental rotation questions. This supports the prediction that left-handers would be superior at solving the spatial questions as they not only solved more questions accurately but they also solved them in less time suggesting that they found this type of question easier as demonstrated by the quicker but more accurate responses given. On the other hand, right-handers got more of the Raven's Progressive Matrices questions correct than left-handers and the average response from right-handers was quicker than that of left-handers, it could be suggested that right-handers show a better ability at this type of task, which could possibly be pattern recognition.

For the 'number' questions and the 'word' questions it was hypothesised that there would be no difference between the two groups for the number of questions correct and for the reaction times to these two types of question. It was found that left-handers, on average, got more 'number' questions correct than right-handers but this difference was not significant. It was found, however, that right-handers got more 'word' questions correct than left-handers but again this difference was not significant. This therefore supports the hypothesis that there would be no difference in the number of correct responses to the ‘number’ and ‘word’ questions. With respect to the time taken to respond to these questions left-handers took longer, on average, to respond to the ‘number’ questions than right-handers and right-handers took longer than left-handers to respond to the ‘word’ questions. These findings were not significant. It has been reported that left-handers have better mathematical abilities than right-handers (e.g. Annett & Kilshaw, 1982) and thus this could help explain why left-handers got more ‘number’ questions correct than right-handers. Left-handers were however slower to respond to these questions than right-handers but this could have occurred due to the fact that the left-handed group were more accurate and took more time to work the answers to the questions out. Right-handers are often said to excel in language tasks due to the dominance of the left hemisphere (e.g. Bishop, 1990; Corballis, 1991) and thus this would potentially explain why the right-handed group scored more correct answers on the ‘word’ questions than the left-handed group.

For the overall responses to the computer task where both correct and wrong responses were measured it was found that left-handers, on average, took longer to respond to the stimuli than right-handers but this difference was not significant. Females also took longer, on average, to respond to the stimuli than males and again this difference was not significant. Left-handers took longer, on average, to respond to each individual type of question with the exception of the number questions than right-handers. Females took longer, on average, than males to respond to each individual type of question except for the ‘word’ questions. However, there were no significant main effects found for the time taken to respond to each of the stimuli except on the Raven’s Progressive Matrices where it was found that right-handers responded significantly quicker, on average, than left-handers.

One reason why there might not have been any differences found was firstly that the task was computerised and thus it is often encouraged in these type of tasks to respond as quickly as possible and thus the participants might have been aiming for quick response times over accuracy. Another reason why there might not have been any differences between the groups might have been because the reaction times included both correct responses and errors and if a participant did not know the answer to one of the questions they might have pressed any key in order to go on to the next question and thus a very fast reaction time would be recorded. If a participant made a number of errors and used this strategy when they were unsure of an answer then this could have resulted in a much quicker average reaction time –

particularly compared to a participant who worked through each answer and took longer to respond.

Although this task was not designed specifically as a planning task it can still be examined with respect to how long participants took to respond to each question. However, as the questions require one specific answer and in many cases the answer needs to be calculated or worked out then it could be argued that this task purely examines the spatial, numerical and language abilities of the participants. The task was designed mainly for the purpose to see if left-handers excelled over right-handers at spatial tasks and it appears that on 3-d mental rotation and shape folding left-handers performed better. Nevertheless, left-handers did not solve the Raven's Progressive Matrices more effectively, which are also thought to demonstrate spatial ability, more effectively. Another reason why there might have been very few differences between all of the groups during this task (both in the number of answers correct and the time taken to respond to the questions) is because the task was not necessarily novel to the participants. Although many of the questions would not have been seen before in the same program, it is possible that most of the participants would have encountered these, or very similar, questions during IQ tests or school tests. Therefore it could be argued that this task was not particularly novel to the participants. One factor that was affected by this was upon giving the participant a set of instructions to brief them on what the task would involve when they saw the mental rotation example, a few participants stated that they could not 'do those kinds of tasks' and thus when they were shown these specific questions possibly did not try to solve them and just guessed the answer quickly. Some participants reported this verbally after they completed the task.

6.14. Overall conclusions

In conclusion, the planning abilities of left- and right-handers were examined here but it is still unclear whether or not a true planning difference exists between the groups. The computer-based task (experiment 6) was designed to examine the visuo-spatial, language and mathematical abilities of the participants. Thus the task was not directly designed as a planning task as in most cases there was only a single correct answer to a question and therefore the response was a reaction time rather than an indication of planning. On the questions such as the Ravens Progressive Matrices planning had to be carried out in order to solve the task to be able to make the choice of which option was the correct answer (there was no sequencing – there was only one correct answer). Therefore this task was perhaps not an adequate measurement of planning. However, on the fastest finger first task the answers had to be put in to a sequence and therefore there was the possibility that some participants might have planned out the sequence in their heads before making their responses while others might have responded using a trial and error strategy. The sorting task was a possible measure of planning as participants had the opportunity to inspect all cards first and make solving decisions without even having to move a card. Other participants may have moved the cards without any thought or planning to try and form appropriate categories. Again, although the sorting task could be classed as a possible measure of planning this still may not be the reason for the delay made by some participants before they began and this could also be attributed to novelty or stress (see chapter 7 for follow up work to this).

Another possible reason why there was a difference in the time taken to start the manual sorting task (experiment 4) but not the ‘fastest finger first’ task (experiment 5) or computer task (experiment 6) could have been influenced by motor planning. As the manual sorting task required the participants to physically move the cards rather than press keys on a computer like the other two tasks did, this might have affected the results. Evidence has suggested that the right hemisphere is dominant for movement planning and therefore it would be expected that because of the contralateral control of the hemispheres that left-handers would show more evidence of planning behaviour than right-handers. It would therefore be expected in a manual task that this behaviour would be demonstrated and the findings of the current study appear to lend support the findings reported by Barthelemy and Boulinguez (2001). In a computerised task, however, this behaviour would not be expected due to the brief responses made using the keys of the keyboard. This is supported by Corballis (1998) who states that motor lateralisation may be important for fast, sequential actions.

Further analysis for this study could be done looking at the time taken to make each response. If the time taken per response in the sequence was faster then it would be thought that planning might have occurred and the answers would have been given rapidly. If the time per answer was longer then this would suggest no evident planning as it would indicate that the participant was looking for each answer after giving the previous response.

It can therefore be concluded that novelty is potentially a very important factor when examining the response styles of left- and right-handers. The type of task is also very important as when the tasks are computerised participants seem to respond much quicker than when the tasks are manual and this might not be a true reflection of how participants would normally respond to these tasks (participants are often instructed to respond quickly to computerised tasks). In the current studies it could be argued that both computerised tasks were not entirely novel to the participants and thus in order to investigate these idea further a completely novel computerised task would have to be devised where the participant was also instructed that accuracy was as important as speed on the task in order to avoid the quick response times. A difference in response time was found between the left- and right-handers on the manual sorting task and this task was novel to the participants as well as a manual task which could have affected how the participants responded to it. However, although left-handers took longer to respond it could be argued that planning was not necessarily occurring during this time as there was no evident sign of this from their completion time (in that they took longer than right-handers). If planning had been occurring during the pause before the first response was made than it would be expected that left-handers would solve the task faster than right-handers and this was not the case as right-handers solved the task, on average, in around 9 seconds faster than left-handers. It therefore seems that a planning explanation is not supported by these tasks but planning cannot be fully dismissed and further experiments need to be carried out using different tasks in order to investigate this (see Chapter 8, section 8.3.). However, It is possible that the left-handers are displaying increased anxiety levels towards a novel task and this potential explanation is investigated in Chapter 7.

Finally, one problem with this discussion in that it is mainly speculative. Because there is currently very little existing research in this area then it is difficult to theoretically justify the present findings and therefore suggestive explanations are made in some areas.

Chapter 7: Novelty, anxiety and performance

7.0. Aims of Chapter

This chapter seeks to further examine the reasons behind why left- and right-handers differed in their responses towards novel problems. More specifically, this chapter will examine the possibility that the difference in response behaviour between left- and right-handers found in Chapter 4 was caused by differences in the anxiety levels of left- and right-handers. This chapter will outline existing personality and anxiety literature with regards to handedness and will also introduce literature on the Behavioural Inhibition System and the Behavioural Activation System as part of a study on behavioural inhibition and behavioural activation and handedness. This study was carried out after the initial self-report anxiety study (see section 7.3. of this chapter). Also outlined in this chapter will be a brief introduction to task complexity and task novelty which forms part of the final experiment. The issue of novelty will be discussed with respect to novel problem solving and literature related to novelty and handedness will be considered. The problem-solving task used to examine task novelty and task complexity will once again be the Tower of Hanoi. However, as this task was extensively described in Chapter 4 an introduction to the task will not be included here. However, a full description and explanation of the specific study will be outlined in section 7.10. of this chapter. Thus 3 separate experiments will be covered in this chapter.

7.1. Context & overview from other chapters

Chapter 4 examined a problem-solving task in humans following previous work carried out by Cameron and Rogers (1999) who found that there was a difference between left- and right-handed primates in their approach to a novel problem-solving task. The task (the 3-disk Tower of Hanoi) in Chapter 4 revealed that there was a difference in the way that left- and right-handers approached the problem in that left-handers took significantly longer to start the problem than right-handers did. Following on from this, possible reasons for why this difference occurred were proposed and a series of studies to test these possible explanations were devised.

The main reasons that were proposed were: 1. There could be a difference in the emotional processing of left- and right-handers that could cause differences in how they react due to the nature of the dominant hemisphere in each group. This could also be affected by which hypothesis of emotional processing is supported (the valence hypothesis and the right hemisphere hypothesis). 2. There could be a difference in planning between the two groups in that one group may be more likely to think the problem through before solving it. Due to the pause by the left-handers before responding (and their more efficient solving of the problem) it was thought that left-handers might have been planning their solutions. 3. There could be a difference in the behaviours and personalities of left- and right-handers in that one group may be more impulsive or extrovert than the other (in this case it was hypothesised that the right-handers would be more impulsive or extrovert) or alternatively one group may be more prone to stress and anxiety than the other group (it was hypothesised that the left-handed groups would exhibit higher anxiety levels). The emotional processing explanation was examined in Chapter 5 and the planning explanation was examined in Chapter 6. Personality was briefly addressed in Chapter 4 by means of an Impulsivity questionnaire and task.

Emotional processing was examined through a discrimination task which required the participants to choose which of two faces showed an emotion, these faces were presented on both the right hand side and the left hand side of the screen (see Chapter 5 for details and results of this). The issue of planning was examined through a series of tasks including a manual sorting task and a computerised sorting task (see chapter 6 for details and results of these). Impulsivity was examined using the Barratt Impulsivity Scale for self-report levels of impulsivity and through a computerised matching task to examine reaction times (see Chapter 4 for details of this). This means that the final issue to be examined is anxiety and this will be examined in the current chapter.

Anxiety (both state and trait anxiety) will be measured using the State-Trait Anxiety Inventory (STAI - Speilberger, 1983). Once again the Tower of Hanoi will be used as the problem solving task but this time additional conditions will be added such as novelty (where each participant will do the Tower twice but one group will complete the 4-disk tower twice while the other group will complete the 3-disk tower first and then the 4-disk tower afterwards). By introducing these conditions novelty is addressed because the participant will either complete the 3- or 4-disk tower and then after completing a few additional tasks they will have to complete another tower.

Therefore, performance on the first tower will be treated as how participants respond to the tower when it is a novel task and the response to the second tower will examine the participant's response to the problem when it is no longer novel. A straight forward comparison can be made when the participant completes the 4-disk Tower of Hanoi both times, however, some might argue that completing the 3-disk Tower of Hanoi followed by the 4-disk Tower of Hanoi does not directly measure the issue of novelty and this will be addressed in sections 7.7. and 7.8.5. (as it may be argued whether or not a 4-disk Tower is a different task completely from the 3-disk Tower or if it is a variant of the same task). The second issue to be addressed using the Tower of Hanoi in this study is that of task complexity. The performance of half of the participants will be examined on the 3-disk Tower of Hanoi against the 4-disk Tower of Hanoi (within the condition) and thus the issue of how participants approach a relatively simple problem compared with a relatively complex problem is addressed. This problem is not only addressed with respect to the differences in strategy (if any) that the participants use but also with the issue of novelty and participant's anxiety levels before completing each tower. Additionally, the approaches by participants between the tasks with respect to task complexity will be examined, as half of the participants will complete the 3-disk Tower of Hanoi first while the other half will complete the 4-disk Tower of Hanoi first.

7.2. Experiment 7: Stress and anxiety Introduction

7.2.1. Stress and anxiety

A common finding of research on hand preference and personality is that left-handers are reported to be more anxious than their right-handed counterparts (e.g. Orme, 1970; Hicks & Pellegrini, 1978; Davidson & Schaffer, 1983; Dillon, 1989). If this is the case then this may help explain previous research findings (e.g. Cameron & Rogers, 1999; Hopkins & Bennett, 1994) that have reported a delay by left-handers when presented with a novel situation or object, i.e. they may be more apprehensive about the situation than right-handers. Therefore with to respect to the current chapter self-report state and trait anxiety measurements will be recorded as part of the studies in order to see if this proposed difference exists.

7.2.2. Personality

Coren (1992) cited previous work carried out by Blau (1946) who stated that left-handers are negative people who refuse to co-operate due to resistance to become right-handed. From this Blau stated that psychiatrists should use the left-handed population to examine personality difficulties. Numerous studies (e.g. Orme, 1970; Stein, 1973; Lester, 1987 & Camposano, Corail & Lolas, 1991) have examined the concept of personality with respect to left- and right-handedness and more specifically, whether or not personality differences exist between the two groups. Orme (1970) and Stein (1973) reported that left-handers generally exhibited more independence than right-handers but they also reported them to be unstable in their characteristics. Lester (1987) reported that left-handed females were less extraverted than right-handed females while Camposano et al. (1991) reported that left-handed males scored significantly higher on the lie scale of the Eysenck Personality Inventory than right-handed males. It has also been reported in numerous studies (e.g. Poreh, 1994; Poreh, Levin, Teves & States, 1997 & Shaw, Claridge & Clark, 2001) that groups who demonstrate a mixed-hand preference often show increased levels of disorders such as schizophrenia. Other studies (e.g. Spere, Schmidt, Riniolo & Fox (in press)) refer to handedness groups as right-handers and non-right-handers and this therefore takes into account groups of mixed-handers. Spere et al. found that mixed-handers had higher levels of shyness than strong right-handers. Only a few studies of handedness and personality related measures have been conducted with the normal population with most focussing on anxiety or depression, thus, a brief overview of personality and handedness will be presented here and more specifically review of the anxiety literature will be presented with respect to handedness.

7.2.3. Handedness and general personality

Coren (1994) reported that personality differences observed between left- and right-handers might be due to the prejudice and discrimination which left-handers experience from some areas of society. Coren added that this prejudice experienced by left-handers might have led to a change in their attitudes with the group displaying lower self-esteem or a more aggressive nature as a consequence. In Coren’s (1994) study left-handers reported themselves as being more arrogant and cunning as well as cold hearted and cruel. Coren (1994) added that left-handers are exposed to numerous situations in society that may lead to an increase in their stress or frustration levels (such as technological or physical problems which prevent them from carrying out every day activities easily – such as using a tin opener). Coren assessed hand preference in his study using the lateral preference inventory (a 4-item questionnaire that asks which hand the individual uses to draw, throw a ball, use a rubber on paper and deal a card). Coren only used participants who used the same hand for all 4 actions (and termed this a consistent right- or a consistent left-hand preference). Coren used the Interpersonal Adjective Scale which consisted of a series of pairs of personality traits and the participant was asked to choose the trait that they thought best described him or her most accurately. Coren found that there were self-reported personality differences between left- and right-handers and more specifically that left-handers reported themselves to be more feisty, forceful and loud. This therefore contradicts the findings which report that left-handers are found to be a more anxious group overall (e.g. Hicks & Pellegrini, 1978).

However, one problem with Coren's study was that the instrument used consisted of a list of forced choice words which may not have necessarily been accurate in their descriptions of some of the participants. The findings of these aforementioned studies could have important implications for the current study and the studies carried out in Chapters 4, 5 and 6. It is possible from the findings on handedness and personality research that left-handers may develop a sense of low self-esteem caused by the constant frustration that they come up against a series of tasks and situations that they often cannot do or certainly cannot do as well as they would have perhaps liked (again with something as simple as using a tin opener). If this is the case then perhaps many left-handers have a belief they cannot perform some tasks efficiently and thus with respect to the studies carried out as part of the thesis they may believe that they will not be very good at a task or may worry that they will not complete it. This may have an effect particularly when the task is relatively straightforward and therefore the pressure on the left-handers may possibly be elevated due to the pressure to be able to complete this.

Studies on personality and handedness have also focussed upon depression. Overby (1994) found that there was a link between handedness and depression. In his study he found that depressed women were at least twice as likely to be left-handed or ambidextrous than right-handed. However, one problem with determining handedness in studies such as that of Overby's is that the participants indicated their hand preferences without having it measured by any form of inventory or test of hand skill therefore resulting in many cases in an inaccurate preference (this can be a problem, see chapter 3). Bruder, Quitkin, Stewart, Martin, Voglmaier and Harrison (1989) reported that there was a higher incidence of left-handedness in groups (especially females) who had mild to moderate levels of depression. They added, however, that, there was a larger representation of strong right-handedness in a sample of people (both males and females) with melancholic unipolar depression compared to a sample of normal controls. However, work by Davidson and Schaffer (1983) contradicted these findings as they reported that there were no significant differences on depression scores among a group of right- and left-handed college students. Davidson and Schaffer (1983) examined the relationship between handedness and depression using the Beck Depression Inventory (BDI). One criticism of these findings was that Davidson and Schaffer did not study the hand preferences of a group of depressed college students and thus the patterns of handedness within this group were ignored.

7.2.4. Anxiety and stress

Numerous studies that have examined personality and handedness have focussed specifically on anxiety in relation to handedness. One common finding is that left-handers are often found to be more anxious than right-handers (e.g. Hicks & Pellegrini, 1978; Orme, 1970). However, there are many conflicting results in this area of research and these are reported in this section. Orme (1970) reported that in a study of young adults that left-handers described themselves to be more introverted and shy than right-handers. Additionally, Hicks and Pellegrini (1978) found that groups of left-handers and mixed-handers were significantly more anxious than groups of right-handers. However, this finding was partially supported and partially dismissed by Wienrich, Wells and McManus (1982) who reported that strongly right-handed and strongly left-handed individuals were found to be significantly more anxious than those with a weak or mixed hand preference of any kind. Wienrich et al. (1982) found that females were significantly more anxious than males. They also found two conflicting results with respect to handedness.

When handedness was considered as a binary factor (left-handers v right-handers) there was no difference found between the two groups' anxiety scores. However, when strength of handedness was considered it was found not that there was a difference between left- and right-handers' anxiety scores but there was a difference between those with strong hand preferences (both left and right) and those with weaker hand preferences (considered in the study as mixed-handedness). Wienrich et al. reported that those with a strong left- or right-hand preference had significantly higher anxiety scores than those who were considered to be mixed-handers (handedness in this study was measured using the Briggs and Nebes (1976) adaptation of Annett's handedness inventory). Wienrich et al. propose that one reason for the difference in anxiety scores between strong left- and right-handers and those of mixed-handers might be because mixed-handers have a tendency to select more neutral responses on questionnaires or use negative responses to questionnaires that used wording such as 'very' or 'always' (Wienrich et al. classifies these statements as extreme wording). Therefore, if mixed-handers are adopting this strategy then the total anxiety scores will be lower due to the neutral and negative responses. Wienrich et al. conclude by proposing that the issue of mixed-handedness should be addressed when examining future work on anxiety with respect to handedness.

Davidson and Schaffer (1983) stated that left-handedness occurs through some form of dysfunction to the left hemisphere and thus this results in a greater susceptibility to anxiousness. French and Richards (1990) propose that there is a discrepancy between the results of Wienrich et al. and of the results of Beaton and Moseley (1984) because only the trait measurement of anxiety is used in their studies. If they had included state measurements of anxiety then the results might have been different. Dillon (1989) hypothesised that the stronger the individual was lateralised to the left the higher their worry score would be. Dillon found that left-handed individuals tended to worry more than right-handers and more specifically they worry about things such as how they are performing at school or college and about their relationships with others. Merckelbach, de-Ruiter and Olff (1989) carried out 2 studies looking at handedness and anxiety. The first study looked at left- and right-handed university students and their responses to the Fear Questionnaire and the Maudsley Obsessive Compulsive Inventory. They found that there was no difference in phobic fears between left- and right-handers in this study. The second study examined patients with anxiety disorder and a group of control participants. It was found that there was no relationship between left-handedness and anxiety.

Work by Beaton and Moseley (1984) failed to support the findings of Hicks and Pellegrini. Beaton and Moseley measured hand preference using Annett's (1970) handedness inventory. They divided their participants in to Annett's 8 sub-groups of hand preference (See chapter 3, section 3.2.4. for details of this) and analysed the handedness data according to these categories. Beaton and Moseley found that there was no relationship between anxiety scores and the hand preference classes. They also found that there was no relationship between anxiety and handedness when the hand used for writing determined handedness. One reason for using classes of hand preference rather than dividing the sample in to left- and right-handers was that previous findings could be examined that found that the strength of hand preference was important when examining anxiety (e.g. Wienrich at al., 1982). One problem with using the 8 classifications of Annett is that there are uneven numbers across the categories and thus proposed hypotheses and analysis is made more difficult. For example there are 127 participants in Beaton and Moseley's sample that fall in to classification 1 (classification 1 is a pure right-hander) while only 10 participants fall in to classification 5 (primarily right-handed with some left hand actions). It should also be noted that Annett (1998) revised her hand classification system and deleted one category (classification 5) leaving 7 categories. Thus, results such as those of Beaton and Moseley could be reanalysed using the new classification system. Another problem is that the number of left- and right-handers are not equal in the sample and thus it is difficult to make handedness assumptions when the group sizes are vastly different. For example, in Beaton and Moseley's study there are 49 left-handed participants in total across the 3 left-handedness categories while there are 198 right-handed participants across the 5 right-handedness categories. Beaton and Moseley addressed the unequal number of participants across the 8 categories by carrying out non-parametric statistics on their data but they did not address the unequal numbers of left- and right-handers and thus it is more difficult to draw conclusions from the data. However, using the writing hand of an individual is not a dependable measure of hand preference as a person may have been forced over to use the right hand rather than the left or they might do most things with the left hand but use the right hand for writing and thus this would be an inaccurate measurement of hand preference and would also be inaccurately reflected in the anxiety score. Beaton and Moseley also stated that it was possible that Hicks and Pellegrini found a difference in anxiety scores between left- and right-handers because there was an imbalance in the ratio of males to females in their sample. As Hicks and Pellegrini did not state the number of males and females then Beaton and Moseley state that there could be a higher number of females than males in the sample thus causing higher anxiety levels (Wienrich et al. reported a significant effect of sex on anxiety in their study with females being significantly more anxious than males).

French and Richards (1990) replicated and extended Beaton and Moseley's (1984) study. Beaton and Moseley reported that there was no relationship between handedness and anxiety using the trait questionnaire of the STAI to measure anxiety and measuring handedness by means of Annett's (1970) questionnaire. French and Richards extended this study by including the state anxiety questionnaire of the STAI as well as using the trait questionnaire. They also addressed the issue that mixed-handers tended to use the neutral responses rather than choose the extreme choices on a questionnaire and stated that there is very little support to back this point up. French and Richards finally addressed the issue of the sample used by Beaton and Moseley. Beaton and Moseley reported that the anxiety scores of their participants were much higher than average and French and Richards noted that in many cases the scores of a number of patients diagnosed with anxiety had much lower scores than the majority of participants used in this study and thus Beaton and Moseley's sample must be questioned. However, Beaton and Moseley (1991) reported in a follow up study that the unusually high anxiety scores scored by their participants was due to a discrepancy in the scoring of the trait questionnaire. Beaton and Moseley had reversed some of the scoring of the items on the trait questionnaire that should not have been reversed and thus this resulted in a much higher trait anxiety score.

French and Richards measured handedness in their study using the Annett (1970) inventory and asked the participants to complete the state and trait anxiety questionnaires of the STAI. Therefore there were 8 different handedness groups in their study (see Chapter 3, figure 3.1. for details of Annett's classifications). Analysis revealed that there was no difference between handedness groups for either state or trait anxiety. French and Richards also looked at the data of the males and females in the group and found that there were no differences between them on their state or trait scores. The final factor that was investigated by French and Richards was the statement that mixed-handers respond using more neutral and less extreme responses. They examined the response patterns made by each participant on the questionnaires (the scale on the state and trait questionnaire is a 4-point scale – see section 7.3. of this Chapter and appendices 23 & 24 for more details of this) and proposed that lack of response to points 1or 4 would indicate more neutral responses. Analysis revealed that there was no difference between the handedness groups on the number of extreme responses given and thus no evidence that the more mixed-handed groups used more neutral responses than those with strong hand preferences (both left and right). This was the case for both the state and trait anxiety scales. French and Richards conclude by stating that in their sample there is no relationship between sex and anxiety or between handedness and anxiety for both state and trait measures.

However, with respect to the response style on the questionnaires and the finding here that there was no difference between the handedness groups and extreme responses, French and Richards concluded by stating that there may be a bias in other handedness questionnaires on how to group mixed-handers and thus different groups may reveal different results. One confound with French and Richard's work is that in order to get a large enough sample to analyse they collected data from five different groups and merged their scores. Beaton and Moseley (1991) reanalysed their original data and found that their data supported that of French and Richards (1990). The reanalysis of the data still supports the original (1984) findings of Beaton and Moseley that there is no relationship between handedness and anxiety. Beaton and Moseley (1991) also examined the response patterns to the trait questionnaire in their study as done previously by French and Richards and found that there was no difference between the response of left-handers and right-handers on this. Consistent left-handers and consistent right-handers were those falling in to categories 1 (right handed) or 8 (left-handed) on the Annett (1970) inventory, participants falling in to categories 2 to 7 were considered to be mixed-handed of some degree. However, this wide classification of mixed-handedness may also result in problems as there is a very big difference between someone in class 2 who uses the right-hand for almost everything except a broom, a spade and a needle and someone in class 7 who uses the left hand for what Annett classes as primary actions (writing, throwing, tennis racket, match, hammer and toothbrush) and uses the right hand for any other action. Finally, Kovac (2000) reported that people with unpronounced or crossed preferences had higher levels of neuroticism and anxiety.

Sex differences and anxiety is a widely researched topic. One common finding is that females are more anxious than males (e.g. Wienrich et al. 1982), however, many researchers have also found that there is no difference in anxiety scores between males and females (e.g. Merckelbach et al., 1989; French & Richards, 1990). However, as this is not the main focal point of the chapter then this will not be expanded upon in any detail.

7.2.5. Measurement of anxiety

Another important factor that has to be taken in to account when examining studies of anxiety is the method used to measure anxiety. This is important as different measurements may give different results. One of the most frequently used scales, as well as one of the most reliable scales, is the State Trait Anxiety Inventory (STAI - Speilberger, 1983). This scale consists of a state anxiety questionnaire which requires the participant to respond to a series of statements about how they are feeling right at that moment in time (for more details of this questionnaire see section 7.3. & appendix 23). The trait anxiety questionnaire gives participants a number of statements to respond to about how they generally feel (see appendix 24). Hicks and Pellegrini (1978) and Wienrich et al. (1982) measured anxiety using the Taylor Manifest Anxiety Scale (1953) while Beaton and Moseley measured anxiety using the Trait scale from the STAI and Dillon (1989) used the student worry survey. The student worry survey consists of 35 items that ask about topics such as school; relationships; health and appearance and social acceptance. Individuals are asked to respond using two five-point scales – the first scale is concerned with the frequency of how often the individual experiences the topic of the statement, this ranges from 0 (never) to 4 (always). The second scale is concerned with intensity and how much or how deeply the statement affects the individual (this again ranges from 0 (never to 4 (a great deal).

Merckelbach et al. (1989) used a fear questionnaire to examine anxiety; they found that there was no difference between left- and right-handers and anxiety scores. However, in many cases again it can be argued that each different questionnaire is measuring a different concept. Beaton and Moseley only used the trait scale of the STAI while Merckelbach et al. used a fear questionnaire which does not necessarily measure anxiety and certainly not anxiety towards a specific task or event. Also, the Taylor Manifest Anxiety Scale is a common measurement of anxiety but does not measure the same concept as the Student Worry scale carried out by Dillon (1989). In order to draw conclusions on handedness and anxiety standardised tests that have been shown to be both reliable and valid measurements of anxiety would need to be used rather than a number of different tests, some of which do not directly measure anxiety.

Wienrich et al. (1982) state that various self-report measurements of anxiety such as the Manifest Anxiety Scale result in higher anxiety scores for females. This could be due to a number of proposed reasons and Wienrich et al. state that one reason is that females more readily take part in psychology experiments. Rosenthal (1965) adds that females who take part in psychology experiments are more anxious than those who do not take part in psychology experiments but he doe not carry out a specific study in order to arrive at this conclusion. However, if certain inventories do result in higher scores for females then this could affect the overall result when combined with handedness and once again the choice of inventory used could result in a different conclusion from a separate study using an alternative inventory. Thus, it is important to be consistent in the measurement used when measuring personality, and more specifically for the purposes of this chapter anxiety, as the choice of measurement may result in different findings.

To conclude, numerous studies have been carried out in order to examine specific personality differences between left- and right-handers and in particular if anxiety differences occur. Findings of these studies have been mixed as a number of studies have reported that anxiety differences do exist with left-handers scoring significantly higher anxiety scores than right-handers (e.g. Orme, 1970; Hicks et al., 1978; Dillon, 1989) while others have reported that there are no differences between anxiety scores of left- and right-handers (e.g. Beaton & Moseley 1984; Merckelbach et al., 1989; French & Richards, 1990). However, most of these studies measure anxiety differently and it is therefore difficult to draw definite conclusions from these results. In order to be able to make firm inferences consistent measurements of anxiety (and in some cases handedness) would have to be undertaken to ensure that valid conclusions could be drawn.

7.2.6. Other aspects of anxiety and handedness

Studies carried out with primates and human infants add support that right hemispheric motor control may be associated with anxiety and shyness, and consequently approach behaviour. Westergaard, Champoux, and Suomi (2001) found that there was an association between left-handed preference and higher levels of the stress hormone cortisol in infant rhesus monkeys. Adding to this, Westergaard, Byrne and Suomi (2000) reported that high cortisol levels at 6 months were predictive of a left-hand bias at both 6 months and 12 months of age. Based on these findings Westergaard et al. argue that greater stress during infancy can cause a left-handed preference in rhesus monkeys.

However, an alternative explanation of this finding might be that left-handedness, and right hemisphere motor dominance, increases anxiety and stress rather than stress causing the hand preference. Additionally, Westergaard, Chavanne, Houser, Cleveland, Snoy, Suomi and Higley (2004) recently reported that there was a positive relationship between handedness scores in female rhesus macaques and concentration levels of the stress hormone cortisol (see Westergaard et al., 2004 for how handedness was measured and indexed). That is, the higher the handedness score (where a positive score indicates a right-hand preference and a negative score indicates a left-hand preference) the higher the level of cortisol is. This contradicts the previous findings of Westergaard et al. (2001) who reported that left-hand preference in infant macaques is associated with higher levels of cortisol.

These findings are supported by results from EEG studies with human infants. Temperamentally anxious human infants who exhibit shyness and behavioural inhibition to novel situations have been found to show greater right-hemisphere frontal activation compared to left frontal activation (e.g. Fox, Henderson, Rubin, Calkins & Schmidt, 2001; Schmidt, Fox, Schulkin & Gold, 1999). Behaviourally inhibited infants show greater right frontal activation as early 4 months (Schmidt & Fox, 1996) and greater right frontal EEG activity has been found to be associated with shyness in 7 year olds (Schmidt, et al., 1999). Additionally, differences in right and left frontal activity at 4 months of age are predictive of sociability in infants during the second year of life (Schmidt & Fox, 1996). These results provide strong converging evidence that indicates that right hemisphere activation, or dominance, is associated with behavioural inhibition in novel situations. The issue of novelty will be discussed in more detail in section 7.10.

7.2.7. Rationale for experiment 7 and hypotheses

Orme (1970) found that left-handers tended to worry more while one of Dillon's (1989) key findings was that left-handers are worried by factors such as how they do at school and time pressures. In order to investigate these findings the current experiment was devised to investigate both state and trait anxiety. Most studies only include data on trait anxiety and therefore it is important to see if the task itself may have an effect on the participants' current anxiety levels (state anxiety). In order to investigate both types of anxiety, Speilberger's (1983) STAI will be used.

This questionnaire used in this current study is a simple self-report measure of state and trait anxiety. Participants will be asked to fill in the STAI (Speilberger, 1983) while taking part in an additional experiment (computerised IQ test – see Chapter 6, section 6.10. for details of this study). Participants are asked to fill out the state anxiety questionnaire before they complete a computerised problem-solving task (half of the participants are given the state questionnaire before they see the instructions and the other half are given the state questionnaire after they see the instructions for the computerised test). Participants will also be asked to complete the Trait anxiety questionnaire during the experimental session and handedness is assessed using the Peters (1998) adapted handedness inventory.

Therefore, in the self-report anxiety task it is proposed that if left-handers are more worried by factors such as how they perform in tests and under time pressure that left-handers will report themselves to be more anxious in the test situation than right-handers (state anxiety questionnaire). With respect to the trait anxiety questionnaire, as many studies report that left-handers are generally more anxious than right-handers, it is hypothesised that left-handers will have higher trait anxiety scores than right-handers.

7.3. Method

The idea of anxiety and handedness was originally carried out in conjunction with the computerised IQ test outlined in Chapter 6, section 6.10. (however, in order to report all anxiety results together and give a comprehensive discussion of the findings the anxiety part of the study carried out in conjunction with the computerised IQ test reported in Chapter 6 will be reported here). Half of the participants were given the STAI before they received the instructions detailing what they would be required to do and the other half of the participants were given the instructions of the task they were required to do first and then were given then STAI to complete. This was done in order to examine whether there was any difference in self-report anxiety levels between the group who were naive as to what the task was going to be and the group that were informed what the task would be.

7.3.1. Participants

81 participants took part in this study. 40 were male and 41 were female. 41 participants were left-handed (20 males and 21 females) and 40 participants were right-handed (20 males and 20 females) as measured by the adapted Peters (1998) handedness inventory.

7.3.2. Materials

State/Trait Anxiety Inventory (STAI, Speilberger, 1983)

The STAI consisted of 20 state questions and 20 trait questions (see appendices 23 and 24, respectively). For the state questions, participants were instructed that they would be given statements that had been used to describe people. They were told to answer the statements according to how they felt ***right at that moment***. They were told that there were no right or wrong answers but not to spend too much time answering each statement. Participants were given four options with which to respond to the statements, they were ‘not at all’; ‘somewhat’; ‘moderately so’ and ‘very much so’. The statements included examples such as ‘I am tense’ and ‘I am relaxed'. The trait questionnaire also contained 20 statements. This time participants were instructed to read the statements and answer them according to how they ***generally feel***. The four previously mentioned options were given again as part of the trait questionnaire. Examples of trait statements included 'I feel nervous and restless' and 'I have disturbing thoughts'. Each STAI item is given a score of 1 to 4. For 10 of the state and 11 of the trait statements, a rating of 4 indicates a high anxiety level response (e.g. 'I feel frightened' and 'I feel upset'). For the other 10 state and 9 trait items on the questionnaire, a high score represents the absence of anxiety (e.g. 'I feel calm' and 'I feel relaxed'). For the absence of anxiety statements the scoring is reversed so they are scored 4, 3, 2, 1 instead of the anxiety present statements which are scored 1, 2, 3, 4. The statements that correspond with the absence of anxiety in the state condition are 1, 2, 5, 8, 10, 11, 15, 16, 19 and 20. The statements that correspond with the absence of anxiety in the trait condition are 21, 23, 26, 27, 30, 33, 34, 36 and 39. Scores for the state and trait scales are obtained by adding the twenty scores that make up each scale (and accounting for the reversed scoring). Scores for each scale can vary between 20 and 80. Space is given on the test form to record the score for each scale.

7.3.3. Procedure

Participants were given the Peter's (1998) handedness Inventory to begin the study with. This was given first in order to allow the participants to feel at ease with the experimenter before they were presented with the STAI. Participants were instructed to fill out the handedness questionnaire reporting the hand that they preferred to perform a series of actions with. Half of the participants (males and females and left and right-handers) were then given the instructions for the computer IQ task (see Chapter 6 for details of this task) and the other half of the sample was presented with the state instructions for the STAI (responding to the statements according to how they felt right at that moment) without receiving any details of what the task was that they would be required to do (the order in which the participants received the instructions for the computer task or the state questionnaire was counterbalanced according to sex and handedness). Those who did not receive the instructions for the computer task were told that they were going to complete a computer task but first would be presented with a self-evaluation questionnaire. They were asked to read the instructions carefully and complete the questionnaire accordingly. Those who were given the instructions for the computer task first were asked to read through the instructions (as if they were going to go ahead with the task at that moment). When they were familiar with the instructions the participants were presented with the state form of the STAI to do prior to beginning the task. The state questionnaire instructions were presented before and after the instructions for the computer task in order to see if knowing what the task was going to entail would affect the responses to the STAI compared to not knowing what the computer task was going to entail. When the participants completed the state questionnaire they were given the instructions for the computer task to read through (if they had already read them as part of the post-instruction group they were encouraged to read over them again). When the participants indicated they were happy with the instructions for the task they began it. The 36 trials (10 word, 10 number, 8 RPM and 8 3-D folding) were presented randomly and participants had to respond using the number keys on the keyboard (see Chapter 6, section 6.10. for details of this task). When the computer task was completed the final part of the study involved the trait questionnaire of the STAI. This was presented to all participants at the end of the computer task. Again participants were presented with the questionnaire and instructed to read the instructions carefully and respond to the statements according to the instructions. This time they had to respond to the statements in the manner of how they generally feel. Completion of this signalled the end of the experiment.

7.4. Results

a) Overall[3] - State Anxiety

Table 7.1: Overall State anxiety scores (with standard deviations in parentheses)

	Male	**Female**	**Total**
Left-handed	36.4 *(9.9)*	35.5 *(8.8)*	35.9 *(9.3)*
Right-handed	31.7 *(6.9)*	29.4 *(5.9)*	31.1 *(6.4)*
Total	34.0 *(8.4)*	32.5 *(8.0)*	

The above table shows that overall (regardless of when the participant completed the State questionnaire in relation to receiving the instructions for the computerised IQ task) the group with the highest state anxiety score was the left-handed males followed by the left-handed females. The group with the lowest State anxiety score was the right-handed females who on average had a state anxiety score of 29.4.

---

[3] Overall means that the state scores taken before the task instructions in half of the participants and after the instructions in the other half of the participants were merged in to a single score.

Males on average had higher state anxiety scores than females (34.01 v 32.51) and left-handers had higher state anxiety scores on average than right-handers (35.92 v 31.08).

In order to examine these differences a 2x2 (handedness (left vs. right) by sex (male vs. female)) between subjects ANOVA was carried out on the state anxiety scores of the STAI. The main effect of handedness was significant $\underline{F}(1, 80) = 8.069$, $\underline{p} < 0.01$ with left-handers showing a significantly higher level of state anxiety than right-handers. The effect of sex was not significant $\underline{F}(1, 80) = 0.502$, $\underline{p} > 0.05$. The interaction also failed to reach significance $\underline{F}(1, 80) = 0.045$, $\underline{p} > 0.05$.

b) Trait Anxiety (overall)

Table 7.2: Overall Trait anxiety scores (with standard deviations in parentheses)

	Male	**Female**	**Total**
Left-handed	42.5 *(10.3)*	42.4 *(9.2)*	42.5 *(9.7)*
Right-handed	38.7 *(8.9)*	39.5 *(8.9)*	39.1 *(8.9)*
Total	40.6 *(9.6)*	40.9 *(9.1)*	

The above table shows that overall left-handed males and left-handed females have the highest trait anxiety scores. These scores are only marginally higher than the average trait anxiety score of right-handed females and right-handed males had the lowest trait anxiety score on average (38.7). Left-handers had a higher average trait anxiety score than right-handers (42.46 v 39.09) and male and female trait anxiety scores were almost identical (average scores of 40.62 v 40.93 respectively).

To examine these differences a 2x2 (handedness (left vs. right) by sex (male vs. female)) between subjects ANOVA was carried out on the trait anxiety scores of the STAI. The main effect of handedness was not significant [$\underline{F}(1, 80) = 2.648$, $\underline{p} > 0.05$]. The main effect of sex was not significant [$\underline{F}(1, 80) = 0.023$, $\underline{p} > 0.05$] and the interaction also failed to reach significance [$\underline{F}(1, 80) = 0.088$, $\underline{p} > 0.05$].

c) State questionnaire analysis: before instructions and after instructions.

41 participants (21 left-handers and 20 right-handers) completed the state anxiety questionnaire before they were given the instructions for the task and 40 participants (20 left-handers and 20 right-handers) completed the state anxiety questionnaire after they were given the instructions for the task.

Completion of state anxiety questionnaire *before* seeing instructions for the computer task

Table 7.3: Mean state anxiety scores of participants who completed the state questionnaire before receiving instructions for the computer task (with standard deviations in parentheses).

	Male	**Female**	**Total**
Left-handed	33.7 *(10.0)*	36.7 *(10.5)*	35.2 *(10.3)*
Right-handed	35.4 *(6.9)*	28.6 *(5.3)*	32.0 *(6.1)*
Total	34.6 *(8.5)*	32.7 *(7.9)*	

The above table shows the mean state scores of participants who completed the state questionnaire **before** receiving any instructions for the task they were going to complete. This shows that left-handed females had the highest state anxiety score followed by right-handed males and then left-handed males. Right-handed females had the lowest state anxiety scores on average suggesting that this group was the least anxious about the current situation out of the four groups. Left-handers had higher mean state anxiety scores than right-handers (35.22 v 32) and males had higher state anxiety scores on average than females (34.55 v 32.67).

In order to examine these differences a 2x2 (handedness (left vs. right) by sex (male vs. female)) between subjects ANOVA was carried out on the state anxiety scores of the STAI. These participants completed the state part of the questionnaire before they saw the instructions for the computer task. The main effect of handedness was not significant [F(1, 40) =1.453, p>0.05]. The main effect of sex was not significant [F(1, 40) =0.501, p>0.05] and the interaction also failed to reach significance [F(1, 40) = 3.397, p>0.05].

Trait anxiety questionnaire scores of participants who completed the state anxiety questionnaire before seeing the instructions for the computer task.

Table 7.4: Mean trait anxiety scores of participants who completed the state questionnaire before receiving instructions for the computer task (with standard deviations in parentheses).

	Male	**Female**	**Total**
Left-handed	37.6 *(10.4)*	43.9 *(7.8)*	40.8 *(9.1)*
Right-handed	39.8 *(7.8)*	39.6 *(11.2)*	39.7 *(9.5)*
Total	38.7 *(9.1)*	41.8 *(9.5)*	

The above table shows the mean trait scores of participants who completed the trait questionnaire before receiving any instructions for the task they were going to complete. This shows that left-handed females had the highest trait anxiety score followed by right-handed males and then right-handed females. Left-handed males had the lowest trait anxiety scores on average suggesting that this group was the least anxious in general out of the four groups. Left-handers had marginally higher mean trait anxiety scores than right-handers (40.76 v 39.7) and females had higher trait anxiety scores on average than males (41.76 v 38.7).

In order to examine these differences a 2x2 (handedness (left vs. right) by sex (male vs. female)) between subjects ANOVA was carried out on the trait anxiety scores of the STAI. These participants had completed the state anxiety questionnaire before they saw the instructions for the computer task. The main effect of handedness was not significant $\underline{F}(1, 40) = 0.129$, $\underline{p} > 0.05$. The main effect of sex was not significant $\underline{F}(1, 40) = 1.085$, $\underline{p} > 0.05$. The interaction also failed to reach significance $\underline{F}(1, 40) = 1.232$, $\underline{p} > 0.05$.

Completion of <u>state anxiety questionnaire</u> *after* seeing instructions for the computer task

Table 7.5: Mean state anxiety scores of participants who completed the state questionnaire after receiving instructions for the computer task (with standard deviations in parentheses).

	Male	**Female**	**Total**
Left-handed	37.4 *(10.8)*	34.1 *(6.6)*	35.8 *(8.7)*
Right-handed	28.8 *(4.1)*	31.3 *(7.2)*	30.0 *(5.6)*
Total	33.1 *(7.4)*	32.7 *(6.9)*	

The above table shows the mean state anxiety scores of participants who completed the state questionnaire **after** receiving instructions for the computer task. Left-handed males had the highest mean state anxiety score followed by left-handed females and then right-handed females. Right-handed males had the lowest mean state scores. Left-handers had higher average state scores than right-handers (35.75 v 30.03) and males had marginally higher mean state scores than females (33.09 v 32.69).

In order to examine these differences a 2x2 (handedness (left vs. right) by sex (male vs. female)) between subjects ANOVA was carried out on the state anxiety scores of the STAI. The main effect of handedness was significant F(1, 39) =5.635, $p<0.05$ with left-handers reporting themselves to have higher state anxiety scores after seeing the instructions for the computer task than the right-handers who saw the instructions. The main effect of sex was not significant F(1, 39) =0.028, $p>0.05$ and the interaction between sex and handedness also failed to reach significance F(1, 39) = 1.444, $p>0.05$.

Trait anxiety questionnaire scores of participants who completed the state anxiety questionnaire after seeing the instructions for the computer task.

Table 7.6: Mean trait anxiety scores of participants who completed the state questionnaire after receiving instructions for the computer task (with standard deviations in parentheses).

	Male	**Female**	**Total**
Left-handed	45.8 *(9.7)*	40.7 *(10.6)*	43.3 *(10.2)*
Right-handed	38.9 *(9.9)*	39.4 *(6.8)*	39.1 *(8.3)*
Total	42.3 *(9.8)*	40.0 *(8.7)*	

The above table shows the mean trait anxiety scores of participants who completed the trait questionnaire after receiving instructions for the computer task. Left-handed males had the highest mean trait anxiety score followed by left-handed females and then right-handed females. Right-handed males had the lowest mean trait score. Left-handers had higher average trait scores than right-handers (43.25 v 39.13) and males had higher mean trait scores than females (42.34 v 40.03).

In order to examine these differences a 2x2 (handedness (left vs. right) by sex (male vs. female)) between subjects ANOVA was carried out on the trait anxiety scores of the STAI. The main effect of handedness was not significant F(1, 39) = 1.965, $p>0.05$. The main effect of sex was also not significant F(1, 39) =0.618, $p>0.05$. The interaction also failed to reach significance F(1, 39) =0.898, $p>0.05$. The participants in this group saw the instructions for the computer task before they completed the state part of the questionnaire.

The main findings from experiment 7 were:

- There was a main effect of handedness on the **overall state anxiety scores** with left-handers reporting themselves to be significantly more anxious at that moment than right-handers. There were no other main effects or interactions.

- There were no significant main effects on the **overall trait anxiety scores**.

- When given the **state anxiety** questionnaire **before** seeing the task instructions (the before group) there were no significant main effects or interactions.

- There were no significant main effects on the **trait anxiety scores** of the participants in the ‘before’ group.

- When given the **state anxiety** questionnaire **after** seeing the task instructions (the after group) there was a significant main effect of handedness with left-handers reporting themselves to be significantly more anxious at that moment than right-handers.

- There were no significant main effects on the **trait anxiety scores** of the participants in the ‘after’ group.

7.5. Discussion

In this experiment it was hypothesised that left-handers would have higher state anxiety scores overall than right-handers. This hypothesis was supported as left-handers reported themselves to be more anxious (in their responses to the state anxiety questionnaire) at that specific moment than right-handers. It is difficult to draw conclusions about previous studies concerning anxiety and handedness that support these findings as most anxiety measurements reported are general anxiety measurements and are usually forms of trait or generalised anxiety. Thus studies such as Hicks et al. (1978), Wienrich et al. (1982) and Beaton and Moseley (1984) cannot be directly compared with state anxiety measurements as they only used trait measurements of anxiety. However, French and Richards (1990) used the state anxiety questionnaire (Speilberger, 1983) but found that there was no relationship between state anxiety scores and handedness, which does not support the current findings.

However, there were a few problems with French and Richards's study and their measurement of state anxiety. In the French & Richard study the state anxiety questionnaire was given alongside the trait questionnaire and a handedness questionnaire. The state questionnaire was not used to measure the mood of the participant in relation to a task or situation and thus this differs from the current study which measures how the participant feels in relation to a known or unknown experimental task that they are about to complete. Therefore, it is possible that the state scores may be lower in French and Richard's sample for this reason. Another problem with French and Richard's study was that they did not have a big enough sample. Thus they combined five different samples, one of which was composed of people attending interview for a place to study psychology at university. The problem with combining the sample is that state measurements of anxiety (according to how they felt at that moment in time) were being measured and therefore it is probable that the group waiting to be interviewed for a place at university would be more anxious than the other 4 groups and this would affect the mean overall state score. In addition, French and Richards reported that there were not enough left- or mixed-handers in each group to analyse the data separately and therefore that is why they had to merge the groups but perhaps it would have been best to have just combined the four groups of students. One final note on French and Richard's study is that when the handedness scores were split in to Annett's (1970) handedness classifications that there were 211 pure-right-handers while there were only 15 pure left-handers. It therefore makes it difficult to draw conclusions about the relationship between handedness and anxiety scores when right-handers heavily populated the sample. Upon examining the mean state anxiety scores of French and Richard's sample consistent left-handers scored lower on state anxiety than right-handers did indicating that right-handers were more anxious at that moment in time. This does not support the findings of my current study where left-handers had a higher mean state anxiety score than right-handers. In the current study (study 1) the number of male and female left- and right-handers are matched as closely as possible. However, the binary categorisation of the sample in to left- and right-handedness was used, as there were not enough available participants in order to divide the group in to further sub-divisions of handedness. However, most participants scored strongly on the Peters (1998) adapted handedness questionnaire which suggests that the sample consisted mainly of strong left- and right-handers.

It was also hypothesised that left-handers would score higher on the trait anxiety questionnaire than right-handers. This hypothesis was not supported. This finding fails to support the findings of Orme (1970), Hicks and Pellegrini (1978) and Dillon (1989) who reported than left-handers were found to be significantly more anxious in general (trait anxiety). However, Hicks and Pellegrini used the Taylor Manifest Anxiety Scale to measure anxiety while Orme used an emotional instability scale that he constructed himself and Dillon used the Student Worry Scale thus in using different instruments to quantify anxiety it is difficult to draw parallels with their findings as each instrument may measure different elements of anxiety. The findings of the current study, however, support the work of Wienrich et al. (1982); Beaton and Moseley (1984); French and Richards (1990) and Beaton and Moseley (1991) who used the trait questionnaire of the STAI and found no relationship between trait anxiety and handedness (however, see earlier in this section for details about Wienrich et al.'s. findings). Left-handers (both males and females) did score higher, on average, on the trait questionnaire than right-handers but these differences were not significant. It was hypothesised that there would be a difference between the state anxiety scores of left- and right-handers in the condition where the state questionnaire was given **before** the instructions to the computer task. This hypothesis was not supported. The left-handed females had the highest state scores here but right-handed males also had relatively high state scores. It was also hypothesised that there would be a difference between the state anxiety scores of left- and right-handers in the condition where the state questionnaire was given **after** the instructions to the computer task. This hypothesis was supported; there was a significant effect of handedness where left-handers reported themselves to be significantly more anxious than right-handers after seeing the instructions for the computer task. With respect to sex differences and anxiety scores it was found that on average males had higher state anxiety scores than females (although this difference was not significant) and there was no difference between male and female mean trait anxiety scores. These results support previous work by Merckelbach et al. (1989) and French and Richards (1990) who also found no sex differences between anxiety scores and fails to support Wienrich et al.'s. (1982) finding that females had a significantly higher trait anxiety score than males.

7.6. Experiment 8: Behavioural activation and behavioural inhibition

7.6.1. Introduction

Converging evidence from a number of fields suggests that the right-hemisphere is more involved in processing negative emotional information (see chapters 4 & 5) and that right-hemisphere activation is associated with temperamental shyness, anxiety, and behavioural inhibition in human infants (Schmidt et al., 1999), and behavioural inhibition in primate’s motor responses to novel objects (Hopkins & Bennett, 1994; Rogers, 1999; Cameron & Rogers, 1999). Thus, research consistently indicates that right hemisphere dominance, or activation, can result in behavioural inhibition. Gray (1982) suggested that we have two independent neural behavioural systems. He states that these two systems are motivational systems and they influence our underlying behaviour. The first is known as the Behavioural Inhibition System (BIS) and the second the Behavioural Approach (or Activation) System (BAS). These two systems are in more simplistic terms related to either anxiety (BIS) or impulsivity (BAS) and it is proposed that the BIS system relates to avoidance behaviour while the BAS relates to approach behaviour (Carver & White, 1994). The BIS is related to negative, inhibitory stimuli and is activated by reaction to new or unpleasant stimuli and signs of frustration. More specifically, the BIS is sensitive to any form of punishment (including non-reward) and reacts to novelty. Carver and White (1994) add that when the BIS is activated that the behaviour of the individual may become inhibited in such a way that it may avoid negative outcomes but effect the individual in moving towards goals. If an individual is susceptible to high BIS sensitivity then the prospect of a task or situation that involves impending punishment, danger of some form or a negative outcome would result in high levels of anxiety in this individual. However, if another person in this situation had low BIS sensitivity then they would not experience such levels of anxiety and would probably not be affected by the outcome and respond with very little distress compared to the person with high BIS sensitivity. The BIS can also be activated by stressful life events (Gable, Reis & Elliot, 2000). Gray (1981) states that the activation of the BIS makes the individual experience negative feelings such as frustration, fear and anxiety. In addition, Stuettgen, Hennig, Reuter and Netter (2005) report that people with high BIS scores may be prone to high levels of anxiety but this does not mean that they will display constant high levels of trait anxiety. Stuettgen et al. add that individuals who are prone to high anxiety levels possibly adopt a series of coping strategies in order to reduce their anxiety levels. They state that these strategies are behavioural but do not give any examples of these. The BAS, however, is activated by positive stimuli and results in approach behaviour. This system is related to appetitive behaviour and is activated by behaviour such as reward, incentive and non-punishment. When the BAS is activated the behaviour experienced is the opposite from the BIS. Behaviour includes moving towards or attaining goals and experiencing positive emotions such as happiness and hope (Gray & McNaughton, 2000).

As the BIS is related to anxiety and the BAS is related to impulsivity, Gray (1981) suggested that differences in the activation of the individual systems can result in personality differences (for example a highly activated BAS system would result in a more impulsive person). In general terms the BIS is related to negative affect while the BAS is related to positive affect and the two systems are completely independent of one another. Therefore individuals can experience a number of combinations of BIS/BAS sensitivity. For example, one individual may experience high BAS sensitivity but low BIS sensitivity while another may experience low BIS and low BAS sensitivity. Therefore if one specific stimulus were shown then a group of people would react in a number of different ways depending on which of the behavioural systems were activated and to what extent. These differences in responses are thought to be particularly important in determining emotional (and behavioural) responses when faced with a threatening situation (Meyer, Olivier and Roth, 2005).

One of the main problems with measuring behavioural activation and behavioural inhibition is the lack of a reliable and standardised available measurement. Instruments currently used to measure behavioural activation and inhibition include the Eysenck Personality Questionnaire which examines extroversion and neuroticism scores. However, one problem with this is that Gray (1981) states that the data taken from the EPQ does not effectively fit the theory of behavioural inhibition or activation. He adds that extravert behaviour is not a variant of impulsivity and that high levels of impulsivity would lead to extraversion rather than represent the same concept. Other common measurements used are the Trait Anxiety Inventory that is commonly used to measure behavioural inhibition (Speilberger, 1983) and the Impulsiveness-Venturesomeness-Empathy Scale (Eysenck and Eysenck, 1996), which is often used to measure behavioural activation/approach. Carver and White (1994) developed a questionnaire to measure behavioural inhibition and activation and this questionnaire is thought to be one of the best attempts at quantifying these behaviours and has been widely used. Carver and White developed a BIS/BAS questionnaire where 4 different scales were examined. One scale was devoted entirely to the behavioural inhibition system while the other 3 scales were divided in to 3 sub-scales of the behavioural activation system. These scales were reward responsiveness; drive and fun seeking. One problem with these 3 sub-scales was that Carver and White did not make it entirely clear how they divided the scales and gave no justification for why only these 3 categories were used. However, they did report that there was a very high reliability factor using these sub-scales. Carver and White reported that individuals scoring highly on the BIS scale were more anxious and nervous than those scoring low on the BIS scale. They also reported that BIS scores have been found to predict self-reported anxiety (on the Manifest Anxiety Scale), this would suggest that an individual scoring highly on the BIS questionnaire would be expected to report a high level of anxiety on a self-report scale (although it is not distinguished whether this refers to state or trait anxiety) while another individual scoring low on the BIS questionnaire would be expected to have low self-report levels of anxiety. Quilty and Oakman (2003), however, state that differences between individuals in the activation of the BIS are thought to underlie trait anxiety while differences between individuals in the activation of the BAS are thought to underlie trait-impulsivity.

7.6.2. Rationale and hypotheses for experiment 8

In relation to the current study, as behavioural inhibition is a key characteristic of increased anxiety (Gray, 1981) it is possible that increased anxiety in the left-handers caused them to delay their initial move (either to begin problem solving or to approach a situation or object). Therefore it was decided to investigate behavioural inhibition and behavioural activation in left- and right-handers. Behavioural inhibition is often cited as being related to anxiety and novelty and therefore this could be related to the previous findings found in the Tower of Hanoi study in Chapter 4 (sections 4.3. – 4.7.). Additionally, as mentioned earlier in this chapter, the approach behaviour exhibited by left and right-handers could be attributed to personality differences between the two groups (see sections 7.2 to 7.4. in this chapter). Previous research regarding handedness and anxiety has reported that left-handers have been found to be significantly more anxious than right-handers, thus, with respect to the BIS/BAS questionnaire (Carver & White, 1994) it would be expected that left-handers would score higher on the BIS questionnaire than right-handers as the BIS is related to negative affect and anxiety. On the contrary, as the BAS is related to impulsivity then it could be proposed that right-handers would be more impulsive than left-handers on each of the 3 BAS dimensions (although in an earlier experiment – see chapter 4, section 4.9. left-handers reported themselves to be more impulsive than right-handers). However, a previous study that examined impulsivity using an impulsivity-matching task (see chapter 4, sections 4.11. & 4.12.)

reported that right-handers were more impulsive in their responses than left-handers to a set of novel stimuli. Little research has been carried out on BIS/BAS and handedness so predictions are not based on direct previous findings.

Experiment 8 involves participants completing Carver and White's (1994) self-report BIS/BAS questionnaire. This is carried out alongside the 'Fastest Finger First' task reported in Chapter 6 (section 6.7.). As left-handers are right hemisphere dominant and this is linked to the inhibitory system of the brain then it is hypothesised that the behavioural inhibition scores of left-handers will be higher than the behavioural inhibition scores of right-handers. As right-handers are left hemisphere dominant and this is linked to the behavioural activation system, it is hypothesised that for each sub-section of the BAS scale (a, b, c) that right-handers will score higher than left-handers.

7.7. Method

7.7.1. Participants

75 participants took part in this study. 37 were male and 38 were female. 38 participants were left-handed (19 males and 19 females) and 37 participants were right-handed (18 males and 19 females). All participants had normal colour vision and normal or corrected-to-normal visual acuity.

7.7.2. Materials

The adapted version of Peter's (1998) handedness questionnaire was used (see appendix 2). The BIS/BAS questionnaire (Carver & White, 1994) consisted of a list of 24 statements that the participant was asked whether they agreed or disagreed with. For each statement, the participant had to indicate how much they agreed with each statement using very true for me; somewhat true for me; somewhat false for me or very false for me. Participants were instructed to respond to all items and not leave any blank. They were also instructed that they should only respond to each statement once and to treat each statement as if it were the only item. For each statement a box was given with the four choices in boxes and the participant was asked to mark the box with their response. The scoring system measured the participants' Behavioural Activation levels and behavioural inhibition levels. All questions were scored giving each 'very true for me' answer 1 point, each 'somewhat true for me' answer 2 points; 'somewhat false for me' 3 points and 'very false for me' answer 4 points. Questions 2 and 22 were scored using the inverse of the scoring system (see appendix 25 for a copy of this questionnaire).

7.7.3. Procedure

Participants were asked to complete the BIS/BAS questionnaire in the same study as the 'Fastest Finger First' experiment (see Chapter 6 for details of this). They were asked to read the instructions carefully and answer as honestly as they could. Once they had completed the BIS/BAS questionnaire they were asked to read the instructions for the 'Fastest Finger First' task and complete it when they were ready. The 'Fastest Finger First' task was described along with the other planning tasks in Chapter 6 and the BIS/BAS results are described here as they fit in with the anxiety and inhibitory explanations that were proposed in Chapter 4.

7.8. Results

BIS/BAS Questionnaire

There were 4 different measurements taken from the questionnaire.

BAS drive, BAS fun seeking, BAS reward responsiveness (all behavioural approach system) and BIS (behavioural inhibition system).

Table 7.7: Mean male and female BIS/BAS questionnaire scores (with standard deviations in parentheses)

	BAS Drive	**BAS Fun seeking**	**BAS Reward responsiveness**	**BIS**
Male	10.1 (*2.2*)	11.6 (*1.8*)	16.1 (*1.8*)	20.9(*3.7*
Female	10.1 (*2.2*)	10.8 (*1.8*)	16.3 (*2.2*	23.5 (*3.5*)
Total	10.1 (*2.2*)	11.2 (*1.8*)	16.2 (*2.0*)	22.2(*3.8*)

Table 7.7 shows that males and females scored exactly the same on average on the BAS drive scale. Males scored slightly higher on the BAS fun seeking scale but

lower, on average, on the reward responsiveness scale. On the BIS scale females scored higher than males.

Table 7.8: Mean left and right-handers' BIS/BAS questionnaire scores (with standard deviations in parentheses)

	BAS Drive	**BAS Fun seeking**	**BAS Reward responsiveness**	**BIS**
Left	10.0 (*2.2*)	11.1 (*1.6*)	16.4 (*1.9)*	22.8 (*4.1)*
Right	10.2 (*2.1*)	11.2 (*2.1)*	16.0 (*2.1*)	21.5 (*3.3)*
Total	10.1 (*2.2)*	11.2 (*1.8*)	16.2 (*2.0)*	22.2 (*3.8*)

Table 7.8 shows that right-handers scored, on average, slightly higher than left-handers on the BAS drive scale. Right-handers scored slightly higher on the BAS fun seeking scale but lower, on average, on the reward responsiveness scale. On the BIS scale left-handers scored higher than right-handers.

Table 7.9: Mean sex and handedness questionnaire scores (with standard deviations in parentheses)

	BAS Drive	**BAS Fun seeking**	**BAS Reward responsiveness**	**BIS**
Male right	10.0 *(2.1)*	11.6 *(2.0)*	16.0 *(1.8)*	20.1 *(1.91)*
Female right	10.4 *(2.2)*	11.0 *(2.2)*	16.0 *(2.4)*	22.8 *(3.87)*
Male left	10.2 *(2.8)*	11.6 *(1.6)*	16.2 *(1.9)*	21.6 *(4.69)*
Female left	9.8 *(2.2)*	10.6 *(1.3)*	16.7 *(1.9)*	24.1 *(2.94)*

Table 7.9 shows that on the BAS drive scale all scores were, on average, similar. Female right-handers scored the highest on this scale and female left-handers scored the lowest but there was only a difference of 0.53 between the highest and lowest scores. Male left-handers scored the highest, on average, on the BAS fun

seeking scale; they were closely followed by male right-handers (only 0.07 behind) and them female right-handers. Female left-handers scored the lowest on the BAS fun seeking scale. All scores were similar on the BAS reward responsiveness scale, female left-handers scored the highest and male and female right-handers scored the lowest. However, there was only a 0.68 difference between the highest and the lowest score. On the BIS scale, female left-handers scored the highest (they scored on average 24.11 out of a possible 28). Female right-handers scored the next highest on the BIS scale, followed by male left-handers and then male right-handers.

BAS Drive

A 2 x 2 (handedness (left Vs. right) by sex (male Vs female)) ANOVA was carried out on BAS drive scores. There were no main effects found. F<1.

BAS Fun Seeking

A 2 x 2 (handedness (left Vs. right) by sex (male Vs female)) ANOVA was carried out on BAS fun seeking scores. There was a significant main effect of sex $\underline{F}(1, 71) = 3.981$, $\underline{p}=0.05$ with males scoring higher than females (mean 11.59 (1.79) vs. 10.76 (1.78) respectively). There was no main effect of handedness $\underline{F}(1, 71) = 0.123$, $\underline{p}>0.05$ and the interaction between sex and handedness also failed to reach significance $\underline{F}(1, 71)$, 0.285, $\underline{p}>0.05$.

BAS Reward Responsiveness

A 2 x 2 (handedness (left Vs. right) by sex (male Vs female)) ANOVA was carried out on BAS reward responsiveness scores. There were no main effects found. $\underline{F}<1$.

BIS

A 2 x 2 (handedness (left Vs. right) by sex (male Vs female)) ANOVA was carried out on BIS scores. There was a significant main effect of sex $\underline{F}(1, 71) = 10.20$, $\underline{p}<0.01$ (one-tailed) with females scoring higher than males (mean 23.45 (3.45) vs. 20.86 (3.65) respectively). There a significant main effect of handedness $\underline{F}(1, 71) = 2.918$, $\underline{p}<0.05$ (one-tailed) with left-handers having higher BIS scores than right-handers. The interaction between sex and handedness failed to reach significance $\underline{F}(1, 71) = 0.009$, $\underline{p}>0.05$.

The main findings from experiment 8 were:

- There were no main effects or interactions on BAS drive scores.
- There were no main effects or interactions on BAS reward scores.
- Males scored significantly higher on BAS fun questions than females but there were no other main effects or interactions.
- There was a significant main effect of sex and handedness on BIS scores.

7.9. Discussion

In this study three different measurements of behavioural activation and a single measure of behavioural inhibition were taken using Carver and White's (1994) BIS/BAS Questionnaire. Males and females scored almost identically on the BAS Drive Scale and the BAS Reward Responsiveness Scale but males scored higher on the BAS fun seeking scale than females. With regards to behavioural inhibition scores females scored higher than males. Left and right-handers scored almost identical scores on each of the BAS measurements but left-handers scored higher on the BIS questions than right-handers. It was hypothesised that right-handers would score higher on the BAS questions than left-handers. This hypothesis was not supported, as almost all BAS scores were identical, on average, for left- and right-handers and there was no significant main effect of handedness on any of these scores. It was also hypothesised that left-handers would score higher on the BIS questionnaire than right-handers. It was found that on average left-handers did score significantly higher on the BIS scores than right-handers (one-tailed p=0.046). It is difficult to relate this finding to previous research as, to my knowledge, there is very little available literature concerning BIS/BAS and handedness. However, it was expected that left-handers would score higher on the BIS questionnaire as it is related to inhibitory behaviour and is also said to reflect anxiety. A number of previous studies (see section 7.2.) have reported that left-handers are more anxious than right-handers then it would be expected that left-handers would also therefore display a higher BIS score.

Carver and White (1994) reported that the behavioural inhibition system reacts to new or novel objects and situations and the presence of such stimuli causes the individual to become inhibited in their behaviour in some way. One prediction in the current study (see next section for details of this) is that there may be an effect of novelty on the performance of left- and right-handers and it would be expected that left-handers would be more anxious about a novel situation than right-handers (this relates back to the dominance of the right hemisphere and the link to shyness, anxiety and behavioural inhibition in human infants (e.g. Schmidt et al, 1999) and to behavioural inhibition to novel objects in various primates (e.g. Hopkins & Bennett, 1994; Cameron & Rogers, 1999). If the aspect of novelty is combined with the prospect of a task to complete in which the participant does not know the outcome then high levels of anxiety would be displayed by someone with high BIS sensitivity (e.g. Stuettgen et al., 2005).

In the current study each participant was informed that they were going to take part in a computerised task which was similar to the ‘Fastest finger first’ task on ‘Who wants to be a millionaire’ (see chapter 6, section 6.7. for details of this task) and this task was novel to all participants and was also timed. The BIS questionnaire refers to general situations (trait) but a state version might also be useful to investigate participant’s immediate feelings about a situation. The BAS is related to impulsivity and previous findings (see chapter 4) reported that there was no difference between left- and right-hander’s self-report impulsivity scores (Although on the impulsivity matching task right-handers responded significantly faster than left-handers to a series of stimuli). However, as previously mentioned, there was no difference between left- and right-hander’s responses to the BAS questionnaires thus it is difficult to draw conclusions about impulsivity and handedness.

It was also hypothesised that females would score higher on the BIS questionnaire than males as females are often reported to have higher anxiety levels than males (e.g. Wienrich et al, 1982). In this study there was a significant effect of sex on BIS scores with females scoring significantly higher than males and therefore the hypothesis was supported. It was hypothesised that there would be no difference between male and female BAS scores. However, there was a main effect of sex on Bas fun seeking scores with males scoring significantly higher than females. There was no effect of sex however on BAS reward responsiveness or BAS drive.

As research concerning the behavioural inhibition and activation systems is very limited, particularly with respect to handedness, it is difficult to discuss these findings with respect to previous studies. However, as the BIS is associated with anxiety or inhibitory behaviour and the BAS with impulsivity then conclusions can be drawn using these concepts. It can be concluded that again there was a difference between left- and right-hander's inhibition scores with left-handers displaying higher inhibition scores (BIS) than right-handers. This adds to the growing body of evidence that currently exists which reports left-handers as being a more anxious or inhibited population, in general, than right-handers. This is also backed up in the current series of experiments through two different studies involving state anxiety scores (see sections 7.3. & 7.10. of this chapter) where left-handers report themselves in the test/experimental situation to feel more anxious than right-handers. However, this is not the case for trait anxiety. Females are often reported to be more anxious than males (again see Wienrich et al., 1982) and this again was found using the BIS questionnaire. Very little literature also exists concerning impulsivity and handedness (see chapter 4, section 4.9.) however it would be expected that right-handers would be more impulsive than left-handers and this in terms of the BAS questions of the questionnaire was not found to be the case. A final aspect that needs to be explored further is the concept of novelty in relation to anxiety. The following study examines whether novelty affects anxiety levels in left- and right-handers.

Future studies will examine the correlation between BIS scores and state/trait anxiety scores in relation to handedness where, based on current literature and findings, it would be expected that generally those with high BIS scores would also score highly on state/trait anxiety and with respect to handedness left-handers would score higher on BIS questionnaire and on anxiety questionnaires.

7.10. Experiment 9: Tower of Hanoi (novelty and complexity) and stress and anxiety.

7.10.1. Introduction

The first task that participants were asked to complete was Peter's revised handedness questionnaire (1998) and participants were asked to answer the 28 questions and a handedness score was calculated from their responses.

A detailed overview of the Tower of Hanoi was outlined in Chapter 4 (see section 4.3) and therefore this will not be covered again in this section. However, more specifically this brief introduction will outline the current experiment and focus upon the issues of task novelty, task anxiety and task complexity.

7.10.2. Novelty

With respect to anxiety and novelty of a task Suddon and Link (1959) carried out a study using left- and right-handed participants to operate a machine (the Toronto Complex Coordinator). Left-handers in this study were allowed 5 minutes practice on the machine while right-handers were given no practice. Suddon and Link found that the left-handers' performances were better than those of right-handers (in that the made fewer errors). Suddon and Link proposed that the left-handers' experience of previously operating the machine might account for their superior performance on it. However, they conclude by proposing that left-handers might experience less anxiety in completing this task as the machine is designed for right-handed use and therefore the task is 'unnatural' to the left-hander and thus this will lead to the expectation that the left-hander should not be able to operate the machine and therefore any success in performance will be acknowledged whereas right-handers would be expected to be able to operate the machine and thus there would be added pressure for them to be able to do so.

This logic contradicts several other studies that report that if a task is new or unnatural to a left-hander then this will increase their anxiety levels (e.g. Cameron & Rogers, 1999). Most of these studies involve non-human participants. As previously reported, Cameron and Rogers (1999) found that there was a difference between left- and right-handed marmosets in their response behaviour towards a novel object in that left-handers took significantly longer to approach and touch the novel object. Roger's (1999) replicated this finding and reported a difference in approach behaviour to a novel object between left-handed and right-handed marmosets. These findings extend earlier work by Hopkins and Bennett (1994) who found that left-handed chimpanzees were slower to approach novel objects than right-handed chimpanzees. However, Watson and Ward (1996) who investigated temperament and problem solving in the small-eared bush baby found contradictory results. They found that left-handed bush babies were less inhibited in their approach to novel objects than right-handed subjects.

Thus, it appears that the introduction of a novel object may influence the delay in the response of left-handers compared to right-handers. This finding was also supported by Rogers (1999) who found a difference in approach behaviour to a novel object between left-handed and right-handed marmosets and by Hopkins and Bennett (1994) who found that left-handed chimpanzees were slower to respond to novel objects than right-handed chimpanzees. Rogers (1999) suggested that these findings could be accounted for due to the differences in hemispheric specialisation for processing novel stimuli and controlling emotional responses. She proposed that the left hemisphere controls exploratory behaviour while the right hemisphere is associated with inhibitory or avoidance behaviour and thus this would suggest that right-handers would be influenced by the dominant left hemisphere and would be more likely to demonstrate exploratory behaviour while left-handers would be more likely to be controlled by the right hemisphere and demonstrate avoidance behaviour. Davidson (1992) also states that approach or exploration behaviour is related to the left hemisphere while avoidance behaviour is linked with activation of the right hemisphere. Although Rogers' (1999) findings were on marmoset monkeys she stated that this finding could possibly also be attributed to humans.

However, although this work supports the proposal that the right hemisphere is associated with fear and avoidance behaviour and is linked to the inhibitory system, Goldberg, Podell and Lovell (1994) have reported conflicting findings. Goldberg et al. found that the right hemisphere appears to be involved in preference for novelty. They report that the right hemisphere is more spontaneous and unreflective and indicate that it does not effectively organise information but instead uses a type of trial and error system. Goldberg et al., however, reported that the left hemisphere is concerned with a preference for familiarity and is more reflective and organised when processing information. This contradicts previous findings that have indicated that they delay in response to novel objects by left-handers might have been caused by the inhibited, emotional dominant right hemisphere. If the findings of Goldberg et al. are supported then it would be expected that when exposed to a novel object or problem then right-handers would be more likely to delay their response while they thought logically about the problem or situation. Left-handers in this scenario would be expected to be spontaneous and not think about the problem or situation and show no delay before approaching this situation. The findings from the Tower of Hanoi experiment in experiment 4 contradict the findings of Goldberg et al. (1994) in that the opposite behaviour pattern was displayed. Right-handers were found to begin the task significantly quicker and also displayed more of a trial and error system to the solving (in that they took more moves to solve the problem than left-handers). Left-handers took longer to start the problem and displayed a more logical approach in their solving strategies thus failing to support Goldberg et al.'s. findings.

Goldberg (2001) more recently reported that left-handers appear to be more responsive to novelty than right-handers. This work contradicts the previous non-human findings of Cameron and Rogers (1999) and Hopkins and Bennett (1996) and

Rogers (1999) in that the left-handed primates in each study reacted to the novel environments and objects by avoiding them or taking longer to approach them rather than approach them, as Goldberg would suggest. This point made by Goldberg is particularly important in relation to the findings of Hopkins and Bennett and Cameron and Rogers as he states that monkeys are more attracted to novelty than humans. Goldberg reported in a Cognitive Bias study that left-handed males preferred different shapes rather than similar shapes and concluded that this group were novelty seekers rather than preferring familiarity. However, the type of novelty that Goldberg reports is a different kind of novelty from the type that is examined in the current studies. Previous studies such as Cameron and Rogers (1999) examined novel objects and situations rather than novel or familiar shapes. This could explain why Goldberg et al. concluded that left-handed males are novelty seekers.

Finally, Goldberg (2001) states that the left hemisphere is associated with cognitive routines and the right hemisphere is associated with cognitive novelty. Therefore, those who are left hemisphere dominant would be expected to display more cautious behaviour with respect to novelty whereas those who are right hemisphere dominant would be expected to be less cautious and more at ease in novel situations if Goldberg's work is supported. Again this contradicts the findings of previous primate studies concerning handedness and novelty.

7.10.3. Test Anxiety

One final factor that should be considered when examining differences in anxiety between left- and right-handers, that links to state anxiety, is test anxiety. Test anxiety, as defined by Friedman and Bendas-Jacob (1997) is "*A specific category of anxiety observed in evaluative situations. It is an affect or feeling of apprehension and discomfort accompanied by cognitive difficulties*" (p1035). Hembree (1988) states that high levels of test anxiety are correlated with deficits in cognitive performance. However, Hembree adds that deficits on performance due to task anxiety can be deduced by the complexity of the task. That is, the more complex the task the more anxious a person who experiences test anxiety may become.

Few studies have been carried out on test anxiety and handedness, however, Mueller, Grove and Thompson (1991) examined differences in test anxiety between left- and right-handers. They found that that there were no differences for men or for women for the worry or the emotionality part of test anxiety and they concluded that high-test anxiety did not affect left-handers any more than it affected right-handers.

Friedman and Bendas-Jacob (1997) developed the Friedben test anxiety scale (FTA). The scale consists of 23 statements and within this there are 3 sub-sections that measure social derogation; cognitive obstruction and tenseness. Friedman and Bendas-Jacob state that common behaviours associated with test anxiety include anticipated fear or danger about something that is so far unknown to the individual; a variety of physiological responses such as arousal or distress and unclear cognitive thinking. Test anxiety has been described as containing two main components, worry and emotionality. The individual relates the worry component to negative thoughts and possible failure while the emotionality component relates to the physiological side such as the feelings of anxiety or tension about the test situation.

These findings could be related to previous state anxiety findings, however, in order to gain more insight in to the concept of handedness and test anxiety further studies would have to be carried out. At present there are very few conclusions that can be drawn on this topic but further work could be carried out, for example, during a series of examinations using the Friedben test.

7.10.4. Task complexity

One factor that has to be taken in to account when considering anxiety levels and problem solving is that of task complexity. As Hembree (1988) stated, it is more likely that higher levels of anxiety will be produced when the task is more complex. However, Druckman and Swets (1988) stated that simple tasks require a high state of arousal by participants in order for them to remain focussed on the task that they have to complete whereas more complex tasks require a lower level of arousal. They add that as task complexity increases then the level of arousal should decrease.

Fink and Neubauer (2004) suggest that the easier a task was that introverts were more likely to display a lower cortical activation (suggesting that they were not as stressed) as compared with extraverts. However, in more complex test conditions there was more cortical activation in introverts as compared with extraverts. This work is based on Eysenck’s arousal theory, which suggests that extraverts are generally less cortically aroused than introverts. However, this theory has been challenged and it has been suggested (e.g. Gale, 1973) that arousal levels might be altered accordingly by the experimental test conditions and these will vary across different experiments and depending on the individual.

A suggestion, consistent with the existing literature, is that left-handers take longer to make a motor response in a novel situation due to increased caution and behavioural inhibition (Rogers, 1999; Hopkins & Bennett, 1994).

7.10.5. Rationale and hypotheses for experiment 9

An implication of the findings of the first Tower of Hanoi study carried out in Chapter 4 was that a dominant right hemisphere might elicit negative emotions, such as increased anxiety, in participants who are confronted with novelty. Thus, left-handers may show increased levels of state anxiety, but not trait anxiety, when confronted with a novel task. It is possible that inconsistent results in the literature, with regard to anxiety and laterality, may have been due to previous studies failing to discriminate between trait and state anxiety. The findings from experiment 7 suggest that left-handers may only exhibit greater anxiety in particular states and situations and therefore this has to be investigated further. In the current experiment task novelty and task complexity will be investigated. Many of the tasks that have been carried out during this thesis are novel tasks, however, if differences have been reported using these tasks then it cannot be certain that the novelty of the task is having a direct effect. Therefore in order to directly examine task novelty an identical task will be carried out twice in order to see if there is a difference in the approach behaviour of participants across the tasks. Additionally, as the task might become much more simple the second time then an additional condition will be added in order to examine not only the issue of task novelty (by doing the same task twice although it is a different version) but also task complexity. The current study will examine participants' state anxiety levels both in relation to the novelty of the task and the complexity in order to see if there is a difference firstly between left- and right-handers and also to see if the novelty or the complexity of the task increases or decreases state anxiety levels.

Experiment 9 looks at problem solving performance on the Tower of Hanoi (along with task novelty and complexity) and self-report anxiety measurements. It is hypothesised that left-handers will take longer to move the first disk on the first trial (the novel trial) of the Tower of Hanoi than right-handers. However, it is predicted that there will be no difference in the time taken to move the first disk of the second trial of the Tower of Hanoi between left- and right-handers. It is also predicted that left-handers will have a higher state anxiety score than right-handers before completing the first Tower of Hanoi trial but there will be no difference between the state scores of left- and right-handers before completing the second trial of the Tower of Hanoi. Additionally, left-handers' state anxiety scores will be higher before completing the first Tower of Hanoi than before completing the second Tower of Hanoi but there will be no difference between right-handers' state scores before completing the first and second trial of the Tower of Hanoi. Finally, it is predicted that there will be no difference between the trait anxiety scores of left- and right-handers.

To conclude, the findings in chapter 4 supported the work of Cameron and Rogers (1999) and Hopkins and Bennett (1994) that demonstrated that left-handers showed some form of inhibitory behaviour in response to a novel task. This finding adds to the existing evidence that suggests that left-handedness is associated with increased anxiety and avoidance behaviour in novel situations. An important implication of these findings is that differences in cognitive processing and motor behaviour, between left and right-handers, may be partly due to differences, possibly in anxiety, expressed by novel performance tasks. These factors are examined in the current experiment.

7.10.6. Current study

There are two conditions in the Tower of Hanoi experiment. The first condition consists of presenting the participant with a four-disk Tower of Hanoi the first time they do the task and the second time they do the task asking them to solve an identical four-disk Tower of Hanoi again. In the second condition the participant will be asked to solve the three-disk Tower of Hanoi as part of the first trial and then for the second trial they will be asked to solve the four-disk Tower of Hanoi. Participants are randomly assigned within their sex and handedness groups into these conditions. There are three dependent variables for each trial of the Tower of Hanoi study. The first is the time taken (in seconds) to make the first move (or touch the first disk). The second dependent variable is the number of moves taken to solve the Tower of Hanoi and the third is the total time taken (in seconds) to solve the Tower of Hanoi. This information was recorded for both trials of each participant.

It should be noted that those in the condition of the 3-disk and then the 4-disk are not counterbalanced to do the 4-disk and the 3-disk for one main reason. Given that half of the participants do the 4 disk first (50 people) in the 4-disk, 4-disk condition then half of the second condition (3-disk, 4-disk) would also have to do the 4 disk first (25 people) and thus 75 people out of the 100 participants would do the 4 disk TOH first compared to 25 out of 100 peopled doing the 3-disk first. Thus in order to examine the issue on novelty and complexity this is easily done if half of the sample complete the 4-disk version first and the other half of the sample the 3-disk version and thus direct comparisons can be made. A third condition where the 3-disk version is completed twice would have to be added in order to allow the mixed condition to be able to be counterbalanced. The main problem with this is the lack of available and consenting left-handed participants and also the time constraints that are spent recruiting this group.

State Trait Anxiety Inventory

Participants will complete the twenty questions of the State questionnaire twice and the twenty questions of the Trait questionnaire once. Each question is assigned a score either ranging from 1-4 or 4-1 (see materials and apparatus for details and appendices 23 and 24 for a copy of the questions). Thus the dependent variables are the total State scores and the total Trait score. The scores are calculated based on the participant’s responses to the questions (in this study two state scores are calculated, one before the first Tower of Hanoi trial and one before the second Tower of Hanoi trial).

7. 11. Method

7.11.1. Participants

100 participants took part in the study. 50 were male and 50 were female. Of these 100 participants, 25 were left-handed males, 25 were right-handed males, 25 were left-handed females and 25 were right-handed females. Participants were all staff and students of the University of Abertay and Dundee College. All participants had normal colour vision and normal or corrected-to-normal visual acuity. The participants volunteered to take part in the study and no payment was made to them. There were two conditions as part of the Tower of Hanoi section of the experiment. The first condition was the 3-disk Tower of Hanoi followed by the 4-disk Tower of Hanoi as the second task. The second condition was the 4-disk Tower of Hanoi followed by the same 4-disk Tower of Hanoi as the second task. There were 54 participants in the 4-4-disk Tower of Hanoi condition (28 left-handers and 26 right-handers) and 46 participants in the 3-4-disk condition (24 left-handers and 22 right-handers).

7.11.2. Materials and apparatus

The Tower of Hanoi Task consisted of three pegs and up to four coloured disks stacked on one of the pegs (The largest disk was purple, the second largest disk was blue, the next was green and the smallest disk was yellow (see appendices 26a & 26b for details of the 4-disk instructions and appendices 6a & 6b for details of the 3-disk Tower of Hanoi). Counterbalancing was carried out so that half of all left-handed and right-handed participants began the task with the disks stacked on the left peg and worked to move all of the disks to the last empty peg on the right. The other half of the left- and right-handers began with the disks stacked on the peg on the right side and aimed to stack them all on the empty peg on the left. The disks were stacked on the peg in order of size with the largest one on the bottom and the smallest one on the top. The two empty pegs were there to be used to move the rings from the full peg to the last empty peg. A stopwatch was also required. The stopwatch had a split-time function, which allowed the initial first move time to be stored in the watch alongside the total time. A Sony video camera was also used to record each session. A cardboard cover was used to conceal the Tower of Hanoi. A Tower of Hanoi scoring sheet was also used (see appendix 27) to record the time it took the participant to make the first move (on the first and second trials), to record the total time if took to complete the Tower of Hanoi on the first and second trial, to record how many moves it took to solve the Tower of Hanoi on the first and second trials and finally to record any rules that were broken by the participants during the trials. A short form which questioned whether participants had solved the Tower of Hanoi before and whether they were aware of the Tower of Hanoi before was also given in order to ensure that the task was novel to all participants who were to be included in the data analysis. Instruction sheets for the Tower of Hanoi were also given to the participants (see appendices 26a and 26b). The instructions outlined the rules of the Tower of Hanoi and also depicted the initial state and the goal state for the participants to see. Participants were instructed that they were going to see three pegs and on one of the pegs there would be a number of disks (either three or four depending upon the condition) stacked on it (there were separate instructions for the three-disk and the four-disk trial – see appendices 6a and 6b for the three-disk Tower of Hanoi instructions). They were instructed that they had to get all of the disks from the initial peg onto the far away peg in the same order that they were stacked in at the goal state (smallest to largest) but that there were a number of rules attached when they were doing so. Firstly, only one disk could be moved at a time and secondly, a bigger disk could never be placed upon a smaller disk. The participants in condition one (who did the four-disk Tower of Hanoi twice) were given identical instructions the second time they did the task except that it was emphasised that the task was **exactly** the same as the first time that they solved it and **exactly** the same rules applied. Those who were in the second condition were given the three-disk instructions first time and then the four-disk instructions the second time. For details of the STAI (Speilberger, 1983) see section 7.3.). The revised version of Peter's (1998) handedness questionnaire was also given to participants (See appendix 2).

7.11.3. Procedure

There were two conditions in the experiment. Half of the participants were assigned to the first condition and the other half to the second condition. In the first condition participants completed the 3-disk Tower of Hanoi first followed by the 4-disk Tower of Hanoi. The second condition consisted of participants completing the 4-disk Tower of Hanoi first and then completing exactly the same task again later on in the experiment. All other parts of the experiment remained constant throughout the two conditions. Participants were firstly given the revised version of Peter's (1998) handedness questionnaire. They had to fill in details of their name, course, matriculation number, sex and decade of birth on the front of the questionnaire and inside they were instructed to assume that their hands were empty and imagine which hand they would use to perform a number of actions. When the handedness questionnaire was completed participants were then given a copy of the instructions for the problem-solving task that they would be instructed to complete (either the 3-disk or 4-disk Tower of Hanoi).

After reading the Tower of Hanoi instructions participants were asked to fill in the state questionnaire of the STAI. They were instructed to answer the questions according to how they felt right at that time. Once this was completed participants were then instructed to solve the Tower of Hanoi (3- or 4-disk depending on the condition that they were assigned to). The solving of the Tower of Hanoi was video recorded in order to check the reliability of the timings at a later date. The Tower of Hanoi was concealed with a large cardboard cover and this was removed when the participant was ready to begin the task. When the participant indicated that they understood the rules of the Tower of Hanoi the video camera was started and the experimenter instructed them to begin (upon removal of the screen and simultaneous starting of the stopwatch). The stopwatch had a split-time function, which allowed two times to be recorded on it at the same time. When the participant made contact with the first disk the experimenter pressed a button on the stopwatch to record this. The experimenter also kept a note of the number of moves the participant took to solve the Tower of Hanoi and also how many rules they broke throughout the solving process. When the participant had successfully solved the Tower of Hanoi the stopwatch was stopped and the total time taken to complete the task was recorded. The trait questionnaire of the STAI was then completed. For this participants were instructed to answer the questions according to how they felt in general.

A second set of Tower of Hanoi instructions was then given to participants. These instructions differed depending on the condition that each participant was in. Participants who were in the condition where they did the 4-disk Tower of Hanoi twice were given an identical set of instructions to the ones they received the first time except this time it was emphasised that the task was **exactly** the same as they did the first time and that the rules and the side that the disks were stacked on remained identical to the first trial. Those in the condition where they completed the 3-disk Tower of Hanoi first were now given a set of 4-disk Tower of Hanoi instructions that outlined the rules (which were identical to the 3-disk task) and showed a picture of the initial and goal state. When participants had read the instructions they were issued with another state anxiety questionnaire, which again asked them to complete twenty questions according to how they felt right at that moment. When this was completed participants were then asked if they wanted to remind themselves of the rules of the Tower of Hanoi again and when they were familiar with them they were then asked to complete the second trial of the Tower of Hanoi. The disks on the second Tower of Hanoi were placed at the same side as they had been when each participant did their first Tower of Hanoi trial in order to keep the conditions between each individual’s performance as consistent as possible over the two trials (even if the trials consisted of the 3-disk trial and then the 4-disk trial). The side of the disks was counterbalanced across all participants so that half of the left-handed males started from the right when doing the three-disk Tower of Hanoi and the other half of the left-handed males who started on the three-disk Tower of Hanoi began with the disks stacked on the left peg. This was the same for the other sex and handedness groups across the 3-and 4--disk trials. The second trial of the Tower of Hanoi was again video recorded and this began when the screen was removed from the Tower of Hanoi and the stopwatch was started. The time taken to make contact with the first disk was recorded on the split-time stopwatch and the experimenter counted the moves that the participant took to solve the Tower of Hanoi (this was able to be checked using the video footage). When the participant successfully solved the Tower of Hanoi the time taken to complete it was also recorded along with the number of rules that were broken during the trial. The participant was then asked to fill in a short form which asked them if they had ever solved the Tower of Hanoi before or if they were aware of the Tower of Hanoi before now. This was done in order to ensure that the task remained novel to all participants throughout the experiment and anyone who had solved the Tower of Hanoi before was excluded from the data analysis. The participant was then informed that that was the end of the experiment. Participants were thanked for taking part in the experiment and were offered an explanation of the purpose and aims of the experiment (which most participants accepted). Participants were ensured that their data was confidential and that it would remain so.

7.12. Results – Tower of Hanoi (novelty and complexity) and anxiety.

Condition 1: 3-disk Tower of Hanoi (TOH) followed by 4-disk Tower of Hanoi

Analysis was carried out on the first condition on the 3-disk and then the 4-disk of Tower of Hanoi in the same testing session. Each group completed the 3-disk and then 4-disk version in the same session thus novelty and complexity are examined here.

a) First move scores on the 3-disk (condition1) TOH

Table 7.10: Mean time taken (in seconds) to move the first disk on the 3-disk Tower of Hanoi (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	2.5 *(1.0)*	3.1 *(3.3)*	2.8 *(2.4)*
Female	6.3 *(4.3)*	4.2 *(4.2)*	5.3 *(4.3)*
Total	4.7 *(3.9)*	3.8 *(3.8)*	

Table 7.10 shows that on average left-handed males started to move the disks of the Tower of Hanoi the quickest followed by right-handed males. Right-handed females took an average of 4.2 seconds to move the first disk and the slowest group was left-handed females. Males began moving the first disk quicker than females and right-handers moved the first disk quicker than left-handers.

A 2 x 2 between subjects ANOVA (sex x handedness) was carried out on the time taken to move the first disk on the 3-disk Tower of Hanoi. There was a significant main effect of sex F(1, 42) = 5.032, $p<0.05$ with females taking significantly longer to move the first disk than males. There was no main effect of handedness F(1, 42) = 0.422, $p>0.05$ and the interaction between sex and handedness also failed to reach significance F(1, 42) = 1.657, $p>0.05$.

Table 7.11: Mean time taken (in seconds) to move the first disk on the 4-disk Tower of Hanoi as a secondary task (2nd TOH of the session) (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	2.7 *(2.9)*	1.8 *(0.6)*	2.3 *(2.1)*
Female	3.5 *(3.3)*	2.4 *(2.2)*	3.0 *(2.8)*
Total	3.2 *(3.1)*	2.1 *(1.4)*	

The above table shows that on the second trial of the Tower of Hanoi when initiating the 4-disk problem right-handed males took the least time to move the first disk on the second trial this was followed by right-handed females. Male left-handers took slightly longer and the slowest group to start moving the first disk was left-handed females.

A 2 x 2 (sex x handedness) between subjects ANOVA was carried out on the time taken to move the first disk on the second trial of the Tower of Hanoi (4-disk) of the 3-4-disk condition. There were no significant main effects found for sex F(1, 42) = 0.787, $p>0.05$, handedness F(1, 42) = 1.727, $p>0.05$ or the interaction between sex and handedness F(1, 42) = 0.027, $p>0.05$.

Comparison across the 2 trials

In order to examine whether there was a difference in the time taken to move the first disk of the ToH when completing the 3-disk version and then the 4-disk version a 2 (between) X 2 (between) X 2 (within) mixed model ANOVA was carried out where the between subjects factors were sex (male and female) and handedness (left and right) and the within subjects factor was the trial of the ToH (1^{st} v 2^{nd}). There was a significant main effect of trial F(1, 42) = 7.758, $p< 0.01$ with participants taking significantly longer to move the first disk on the first trial than the second trial (4.05 vs. 2.6 seconds), the main effect of sex approached significance F(1, 42) = 4.006, $p=0.052$ (females took longer to move the first disk than males) and the main effect of handedness failed to reach significance F(1, 42) = 1.218, p>0.05. There were no significant interactions.

b) Number of moves taken to solve the Tower of Hanoi

Table 7.12: Mean number of moves taken to solve the 3-disk Tower of Hanoi (1st trial) (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	10.5 *(4.0)*	13.0 *(4.4)*	11.8 *(4.3)*
Female	13.7 *(10.4)*	12.0 *(4.5)*	12.9 *(8.1)*
Total	12.7 *(7.2)*	12.5 *(4.4)*	

Table 7.12 shows than on average left-handed females took most moves to solve the 3-disk Tower of Hanoi followed by right-handed males, right-handed females took an average of 12 moves and left-handed males solved the 3-disk Tower of Hanoi in the fewest number of moves. Males on average solved the 3-disk Tower of Hanoi in fewer moves than males and right-handers solved the 3-disk Tower of Hanoi in less moves than left-handers.

A 2 x 2 (sex x handedness) between subjects ANOVA was carried out on the number of moves taken to solve the 3-disk Tower of Hanoi. There were no significant main effects for sex F(1, 42) = 0.562, p>0.05 or handedness F(1, 42) = 0.000, p>0.05 and the interaction between sex and handedness failed to reach significance F(1, 42) = 1.537, p>0.05.

Table 7.13: Mean number of moves taken to solve the 4-disk Tower of Hanoi (2nd trial) (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	54.7 *(88.6)*	30.5 *(14.7)*	42.6 *(63.0)*
Female	26.5 *(10.0)*	34.8 *(17.1)*	30.3 *(14.1)*
Total	38.2 *(57.7)*	32.8 *(15.8)*	

Table 7.13 shows than on average left-handed males took most moves to solve the 3-disk Tower of Hanoi (but they had a very high standard deviation) followed by right-

handed females), right-handed males took an average of 30.5 moves and left-handed females solved the 4-disk Tower of Hanoi in the fewest number of moves. Females on average solved the 4-disk Tower of Hanoi in fewer moves than males and right-handers solved the 4-disk Tower of Hanoi in less moves than left-handers.

A 2 x 2 (sex x handedness) between subjects ANOVA was carried out on the number of moves taken to solve the 4-disk Tower of Hanoi. There were no significant main effects for sex F(1, 42) = 0.876, p>0.05 or handedness F(1, 42) = 0.392, p>0.05 and the interaction between sex and handedness failed to reach significance F(1, 42) = 1.620, p>0.05.

A comparison of the number of moves across trials could not be carried out in this condition due to the different number of disks used in each trial and therefore no direct conclusions can be drawn.

c) Mean time taken to complete the ToH (3-4-disk condition)

Table 7.14: Mean time taken (in seconds) to solve the 3-disk Tower of Hanoi (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	33.0 *(19.2)*	40.6 *(22.0)*	36.8 *(20.5)*
Female	47.7 *(34.5)*	53.2 *(41.8)*	50.2 *(37.3)*
Total	41.6 *(29.6)*	47.5 *(34.1)*	

The above table shows that on average male left-handers solved the 3-disk Tower of Hanoi in the shortest time followed by right-handed males then left-handed females and right-handed females who took the longest to solve the Tower of Hanoi. Males solved the Tower of Hanoi quicker on average than females and left-handers solved it quicker than right-handers.

A 2 x 2 (sex x handedness) between subjects ANOVA was carried out on the time taken to solve the 3-disk Tower of Hanoi. There were no significant main effects for sex F(1, 42) = 2.261, p>0.05 or handedness F(1, 42) = 0.428, p>0.05 and the interaction between sex and handedness failed to reach significance F(1, 42) = 0.027, p>0.05.

Table 7.15: Mean time taken (in seconds) to solve the 4-disk Tower of Hanoi (2nd trial) (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	73.1 *(61.4)*	133.6 *(157.6)*	103.3 *(120.5)*
Female	98.5 *(83.4)*	117.0 *(54.5)*	107.0 *(70.8)*
Total	87.9 *(74.7)*	124.6 *(110.8)*	

The above table shows that on average male left-handers solved the 4-disk Tower of Hanoi in the shortest time followed by left-handed females then right-handed females and right-handed males took the longest to solve the Tower of Hanoi on average. Males solved the Tower of Hanoi slightly quicker on average than females and left-handers solved it quicker than right-handers. Once again there was a much higher standard deviation among the right-handed male group and this therefore could affect the results of this specific group.

Again a 2 x 2 (sex x handedness) between subjects ANOVA was carried out on the time taken to solve the 4-disk Tower of Hanoi (trial 2). There were no significant main effects for sex $\underline{F}(1, 42) = 0.024$, $\underline{p}>0.05$ or handedness $\underline{F}(1, 42) = 1.941$, $\underline{p}>0.05$ and the interaction between sex and handedness failed to reach significance $\underline{F}(1, 42) = 0.546$, $\underline{p}>0.05$.

Time minus initiation (or ‘first move’) time was not calculated as there were no significant findings either for first move time or completion time.

Condition 2: 4-disk TOH followed by 4-disk TOH

Participants in this condition completed the 4-disk Tower of Hanoi as their first trial and then completed the same 4-disk Tower of Hanoi as their second trial. Both Towers were identical and the reason for this was that the issue of novelty was being investigated.

a) First move scores on the 4-disk TOH (first trial of condition 2)

Table 7.16: Mean time taken (in seconds) to move the first disk on the 4-disk Tower of Hanoi (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	2.9 *(1.9)*	3.9 *(3.4)*	3.4 *(2.8)*
Female	4.6 *(3.1)*	8.2 *(10.0)*	6.2 *(7.3)*
Total	3.8 *(2.7)*	6.0 *(7.7)*	

Table 7.16 shows that on average left-handed males started to move the disks of the Tower of Hanoi the quickest followed by right-handed males. Left-handed females took an average of 4.6 seconds to move the disks and the slowest group was right-handed females. Males began moving the first disk quicker than females and left-handers moved the first disk quicker than right-handers. This is the opposite pattern from the 3-4-disk condition.

A 2 x 2 between subjects ANOVA (sex x handedness) was carried out on the time taken to move the first disk on the 4-disk Tower of Hanoi (first trial). There was a significant main effect of sex F(1, 50) = 3.994, p=0.05 with females taking significantly longer to move the first disk than males. There was no main effect of handedness F(1, 50) = 2.312, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 50) = 0.761, p>0.05.

Table 7.17: Mean time taken (in seconds) to move the first disk on the 4-disk Tower of Hanoi as a secondary task (2nd TOH of the session) (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	1.9 *(1.3)*	2.2 *(1.3)*	2.1 *(1.3)*
Female	2.4 *(1.4)*	1.7 *(0.6)*	2.1 *(1.2)*
Total	2.2 *(1.4)*	2.0 *(1.0)*	

The above table shows that on the second trial of the Tower of Hanoi when initiating the 4-disk problem right-handed females took the least time to move the first disk on the second trial this was followed by left-handed males. Male right-handers took slightly longer and the slowest group to start moving the first disk on the second trial was left-handed females.

A 2 x 2 (sex x handedness) between subjects ANOVA was carried out on the time taken to move the first disk on the second trial of the Tower of Hanoi (4-disk) of the 4-disk first condition. There were no significant main effects found for sex F(1, 50) = 0.002, p>0.05, handedness F(1, 50) = 0.393, p>0.05 or the interaction between sex and handedness F(1, 50) = 2.244, p>0.05.

Comparison of 4-disk first moves first trial and 4-disk first move on 2nd trial

In order to examine whether there was a difference in the time taken to move the first disk of the ToH when completing the 4-disk version (1st trial) and then the 4-disk version (2nd trial) (and thus examining the issue of task novelty) a 2 (between) X 2 (between) X 2 (within) mixed model ANOVA was carried out where the between subjects factors were sex (male and female) and handedness (left and right) and the within subjects factor was the trial of the ToH (1st v 2nd). There was a significant main effect of trial F(1, 50) = 15.359, p< 0.001 with participants taking significantly longer to move the first disk on the first trial than the second trial (mean score 4.9 vs. 2.1 seconds), the main effect of sex approached significance F(1, 50) = 3.315, p=0.075 (females taking longer to move the first disk than males) and the main effect of handedness failed to reach significance F(1, 50) = 1.601, p>0.05. There was a significant two-way interaction between trial and sex F(1, 50) = 4.465, p<0.05 (see appendix 28 for details of further analysis of this interaction) and the two-way interaction between trial and handedness approached significance F(1, 50) = 3.047, p=0.087. The three-way interaction between trial, sex and handedness failed to reach significance F(1, 50) = 1.599, p>0.05.

b) Number of moves

Table 7.18: Mean number of moves taken to solve the 4-disk Tower of Hanoi (first trial) (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	22.4 *(6.3)*	30.5 *(12.6)*	26.4 *(10.6)*
Female	29.4 *(11.4)*	23.2 *(7.3)*	26.5 *(10.0)*
Total	26.1 *(9.9)*	26.8 *(10.7)*	

Table 7.18 shows than on average right-handed males took most moves to solve the 4-disk Tower of Hanoi (but they have the highest level of variability) followed by left-handed females, right-handed females took an average of 23.2 moves and left-handed males solved the 4-disk Tower of Hanoi in the fewest number of moves. (This is the same order as the 3-disk TOH from condition 1). Females and males on average solved the 4-disk Tower of Hanoi in almost an identical number of moves and left-handers solved the 4-disk Tower of Hanoi in slightly less moves than right-handers.

A 2 x 2 (sex x handedness) between subjects ANOVA was carried out on the number of moves taken to solve the first trial of the 4-disk Tower of Hanoi. There were no significant main effects for sex F(1, 50) = 0.002, p>0.05 or handedness F(1, 50) = 0.127, p>0.05 however, the interaction between sex and handedness was significant F(1, 50) = 7.060, p<0.05. (See appendix 28 for details of this). Therefore, the significant interaction seems to have been influenced by the performance of left-handed males and right-handed females who took the fewest moves, on average, to solve the 4-diskTower of Hanoi first time. Also, left-handed females and right-handed males took the most moves to solve the Tower of Hanoi and this also contributed to the significant interaction.

Table 7.19: Mean number of moves taken to solve the 4-disk Tower of Hanoi (second trial) (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	25.2 *(10.5)*	22.6 *(10.9)*	23.9 *(10.6)*
Female	26.0 *(12.9)*	29.8 *(10.2)*	27.8 *(11.7)*
Total	25.7 *(11.6)*	26.2 *(11.0)*	

Table 7.19 shows than on average right-handed females took the most moves to solve the 4-disk Tower of Hanoi followed by left-handed females, left-handed males took an average of 25.24 moves and right-handed males solved the 4-disk Tower of Hanoi in the fewest number of moves. Males on average solved the 4-disk Tower of Hanoi in fewer moves than females and left-handers solved the 4-disk Tower of Hanoi in less moves than right-handers.

A 2 x 2 (sex x handedness) between subjects ANOVA was carried out on the number of moves taken to solve the 4-disk Tower of Hanoi. There were no significant main effects for sex F(1, 50) = 01.661, p>0.05 or handedness F(1, 50) = 0.035, p>0.05 and the interaction between sex and handedness failed to reach significance F(1, 50) = 1.087, p>0.05.

Comparisons were carried out between the number of moves taken to complete the first trial and the number of moves taken to complete the second trial of the 4-4-disk condition of the ToH. However, there were no significant main effects and the only significant interaction was a three-way sex X handedness X trial interaction. See appendix 28 for this full analysis.

c) Completion time

Table 7.20: Mean time taken (in seconds) to solve the 4-disk Tower of Hanoi (first trial) (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	80.1 *(59.9)*	92.4 *(40.1)*	86.2 *(50.1)*
Female	115.7 *(66.5)*	116.6 *(69.4)*	116.1 *(66.6)*
Total	99.2 *(64.8)*	104.5 *(56.9)*	

The above table shows that on average male left-handers solved the 4-disk Tower of Hanoi in the shortest time followed by right-handed males then left-handed females and right-handed females who took the longest to solve the Tower of Hanoi. Males solved the Tower of Hanoi quicker on average than females and left-handers solved it quicker than right-handers.

A 2 x 2 (sex x handedness) between subjects ANOVA was carried out on the time taken to solve the 4-disk Tower of Hanoi (first trial). There were no significant main effects for sex F(1, 50) = 3.311, p>0.05 (although this approached significance p=0.075) or handedness F(1, 50) = 0.160, p>0.05 and the interaction between sex and handedness failed to reach significance F(1, 50) = 0.118, p>0.05.

Table 7.21: Mean time taken (in seconds) to solve the 4-disk Tower of Hanoi (second trial) (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	57.5 *(47.4)*	48.7 *(28.8)*	53.1 *(38.7)*
Female	65.9 *(44.6)*	84.9 *(47.8)*	74.7 *(46.3)*
Total	62.0 *(45.3)*	66.8 *(42.8)*	

The above table shows that on average male right-handers solved the 4-disk Tower of Hanoi in the shortest time followed by left-handed males then left-handed females and right-handed females took the longest to solve the Tower of Hanoi on average. Males solved the Tower of Hanoi quicker on average than females and left-handers solved it quicker than right-handers.

A 2 x 2 (sex x handedness) between subjects ANOVA was carried out on the time taken to solve the 4-disk Tower of Hanoi (trial 2). There were no significant main effects for sex F(1, 50) = 3.628, p>0.05 (although this approached significance p=0.063) or handedness F(1, 50) = 0.191, p>0.05 and the interaction between sex and handedness failed to reach significance F(1, 50) = 1.416, p>0.05.

Comparison of completion time of trial 1 and trial 2 in the 4-4-disk condition

A 2 X 2 X 2 mixed model ANOVA was conducted to examine any differences between trials on the time taken to complete the 4-disk Tower of Hanoi in trial 1 vs. trial 2. This revealed that there was a significant effect of Trial (whether it was trial 1 or trial 2) on the time taken to complete the 4-disk Tower of Hanoi F(1, 50) = 17.487, p<0.001 showing that the time taken to complete the 4-disk ToH was significantly longer in the first trial than in the second trial (almost twice as long). There was a significant main effect of sex F(1, 50), 5.424, p<0.05 with males completing the ToH significantly faster than females. However, the main effect of handedness failed to reach significance F(1, 50) = 0.272, p>0.05. There were no significant two-way interactions (trial X sex; trial X handedness & sex X handedness all p>0.05) and the 3-way interaction between trial, sex and handedness failed to reach significance F(1, 50) = 1.231, p>0.05.

Comparisons between condition 1 and condition 2

Comparisons were then made across conditions (3-4-disk vs. 4-4-disk) on the time taken to move the first disk on the Tower of Hanoi. However, the only significant difference that was found was that females took significantly longer to move the first disk than males regardless of the condition. A full analysis of all comparisons can be found in appendix 28.

Comparisons could only be made across the conditions for the second trial on the other measurements taken on the Tower of Hanoi as the time taken to solve the Tower of Hanoi and the number of moves cannot be directly compared on the 3-disk version and the 4-disk version. Thus the 4-disk version when one group did it for the first time was compared against the scores of the group that did it for a second time to see if there is any effect of the novelty of the task on how efficiently it is solved.

Thus comparisons were made across the second trial versions of the 4-disk Tower of Hanoi (condition 1 vs. condition 2) on the number of moves taken to solve the task. However, there were no significant main effects or interactions. This analysis can be found in full in appendix 28.

Finally, comparisons were made across the second trials of each condition on the time taken to solve the 4-disk Tower of Hanoi. The only significant result was that there was a main effect of condition on the time taken to solve the task with those who did the 4-disk Tower of Hanoi for a second time solving it significantly faster than those solving it for the first time. There were no other significant main effects or interactions. A full set of results for the time taken to solve the task can be found in appendix 28).

Self-report anxiety (state and trait scores)

Condition 1: 3-disk TOH followed by 4-disk TOH

State anxiety scores

Participants were asked to complete two state anxiety questionnaires during the course of the study, one questionnaire was administered after they received and read the instructions for the 3-disk Tower of Hanoi and the other state questionnaire was administered after participants had received and read the instructions for the 4-disk

Tower of Hanoi. Both questionnaires were completed before the participant physically solved each Tower of Hanoi.

Table 7.22: Participant's mean state score before completing the 3-disk Tower of Hanoi (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	38.8 *(3.2)*	35.5 *(8.7)*	37.2 *(6.6)*
Female	39.8 *(6.7)*	32.2 *(8.4)*	36.2 *(8.3)*
Total	39.4 *(5.4)*	33.7 *(8.5)*	

The above table shows that left-handed females have the highest mean state anxiety score before completing the 3-disk version of the Tower of Hanoi. The next highest group was the left-handed males. Right-handed males scored an average of 35.5 and the group with the lowest state anxiety score was the right-handed females. Males scored slightly higher than females on average and left-handers scored higher than right-handers.

A 2 x 2 (sex x handedness) between subjects ANOVA was carried out on the state anxiety score before completion of the 3-disk Tower of Hanoi. There was a significant main effect of handedness $\underline{F}(1, 42) = 6.65$, $\underline{p}<0.05$ with left-handers scoring significantly higher on state anxiety than right-handers before completing the 3-disk ToH. There was no significant effect of sex $\underline{F}(1, 42) = 0.307$, $\underline{p}>0.05$ and the interaction between sex and handedness failed to reach significance $\underline{F}(1, 42) = 1.041$, $\underline{p}>0.05$.

Table 7.23: Participant's mean state score before completing the 4-disk Tower of Hanoi – second condition of the 3-4-disk condition (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	36.9 *(5.0)*	33.8 *(9.3)*	35.4 *(7.5)*
Female	35.6 *(6.3)*	32.9 *(11.3)*	34.4 *(8.9)*
Total	36.2 *(5.7)*	33.3 *(10.2)*	

The above table shows that left-handed males have the highest mean state anxiety score before completing the 4-disk version of the Tower of Hanoi (second task after completing the 3-disk task previously). The next highest group was the left-handed females. Right-handed males scored an average of 33.8 and the group with the lowest state anxiety score was the right-handed females. Males scored slightly higher than females on average and left-handers scored higher than right-handers.

A 2 x 2 (sex x handedness) between subjects ANOVA was carried out on the state anxiety score before completion of the 4-disk Tower of Hanoi (trial 2 after completing the 3-disk TOH previously). There were no significant main effects found for handedness F(1, 42) = 1.368, p<0.05 or sex F(1, 42) = 0.185, p>0.05 and the interaction between sex and handedness failed to reach significance F(1, 42) = 0.006, p>0.05.

Comparison of state scores between trials of the 3-disk – 4-disk ToH condition

The state scores from trial 1 (3-disk Tower of Hanoi) were examined, with respect to sex and handedness, against the state scores from trial 2 (4-disk Tower of Hanoi) using a 2 X 2 X 2 mixed model ANOVA (with the trial number being the within subject factor –trial 1 and trial 2 and sex and handedness being the between subjects factors (male and female and left- and right). There was a significant main effect of trial F(1, 42) = 4.894, p<0.05 with the state scores in the first trial being significantly higher than the state scores in the second trial. There was no significant main effect of sex F(1, 42) = 0.267, p>0.05 and the main effect of handedness approached significance F(1, 42) = 3.714, p=0.06 with left-handers scoring higher overall on the state questionnaire than right-handers. The two-way interaction between trial and sex failed to reach significance F(1, 42) = 0.004, p>0.05. The two-way interaction between trial and handedness also failed to reach significance F(1, 42) = 2.596, p>0.05 as did the two-way interaction between sex and handedness F(1, 42) = 0.206, p>0.05. The three-way interaction between trial, sex and handedness was not significant F(1, 42) = 2.204, p>0.05.

Trait anxiety scores

Table 7.24: Mean trait scores of participants that completed the 3-disk Tower of Hanoi first (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	42.1 *(8.0)*	37.8 *(9.3)*	40.0 *(8.8)*
Female	42.4 *(8.8)*	38.5 *(9.7)*	40.6 *(9.3)*
Total	42.3 *(8.3)*	38.2 *(9.3)*	

The above table shows that left-handed males and left-handed females have similar mean trait scores followed by right-handed females and then right-handed males who have the lowest trait scores on average although all scores are similar. Males and females scored similar trait scores and left-handers scored higher on average then right-handers

A 2 x 2 (sex x handedness) between subjects ANOVA was carried out on the trait scores of participants who completed the 3-disk Tower of Hanoi first. There were no significant main effects for sex $\underline{F}(1, 42) = 0.032$, $\underline{p}>0.05$ or handedness $\underline{F}(1, 42) = 2.311$, $\underline{p}>0.05$ and the interaction between sex and handedness failed to reach significance $\underline{F}(1, 42) = 0.007$, $\underline{p}>0.05$.

Condition 2: 4-disk TOH (first trial) followed by 4-disk TOH (second trial) - Self report anxiety

State anxiety scores

Participants were also asked to complete two state anxiety questionnaires during the 4-4-disk ToH condition. Again, the first questionnaire was administered after participants had received and read the instructions for the 4-disk Tower of Hanoi (first trial) and the other questionnaire was administered after participants had received and read the instructions for the 4-disk Tower of Hanoi (second trial). Both questionnaires were completed before the participant physically solved each Tower of Hanoi.

Table 7.25: Participants' mean state score before completing the 4-disk Tower of Hanoi (first trial) (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	27.7 *(6.0)*	32.8 *(10.5)*	30.2 *(8.8)*
Female	33.3 *(8.4)*	33.0 *(9.8)*	33.1 *(8.9)*
Total	30.7 *(7.8)*	32.9 *(10.0)*	

The above table shows that left-handed females have the highest mean state anxiety score before completing the 4-disk version of the Tower of Hanoi (first trial) closely followed by right-handed females. The next highest group was the right-handed males who had a mean score of 32.8 and the group with the lowest state anxiety score was the left-handed females. Females scored slightly higher than males on average and right-handers scored higher than left-handers.

A 2 x 2 (sex x handedness) between subjects ANOVA was carried out on the state anxiety score before completion of the first 4-disk Tower of Hanoi. There was no significant main effect of handedness $\underline{F}(1, 50) = 0.997$, $\underline{p}>0.05$ or sex $\underline{F}(1, 50) = 1.453$, $\underline{p}>0.05$ and the interaction between sex and handedness failed to reach significance $\underline{F}(1, 50) = 1.231$, $\underline{p}>0.05$.

Table 7.26: Participants' mean state score before completing the 4-disk Tower of Hanoi – second condition (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	26.5 *(5.0)*	30.8 *(9.4)*	28.7 *(7.7)*
Female	32.5 *(9.0)*	31.8 *(9.6)*	32.2 *(9.1)*
Total	29.7 *(7.9)*	31.3 *(9.3)*	

The above table shows that left-handed females have the highest mean state anxiety score before completing the 4-disk version of the Tower of Hanoi (for the second time). The next highest group was the right-handed females. Right-handed males scored an average of 30.8 and the group with the lowest state anxiety score was the left-handed males. Females scored slightly higher than males on average and right-handers scored higher than left-handers.

A 2 x 2 (sex x handedness) between subjects ANOVA was carried out on the state anxiety score before completion of the 4-disk Tower of Hanoi (trial 2 after completing the 4-disk TOH previously). There were no significant main effects found for handedness F(1, 50) = 0.636, p>0.05 or sex F(1, 50) = 2.326, p>0.05 and the interaction between sex and handedness failed to reach significance F(1, 50) = 1.196, p>0.05.

Comparison of state scores between trials of the 4-disk – 4-disk ToH condition

The state scores from trial 1 (4-disk Tower of Hanoi first time) were examined, with respect to sex and handedness, against the state scores from trial 2 (4-disk Tower of Hanoi second time) using a 2 X 2 X 2 mixed model ANOVA (with trial number being the within subject factor – trial 1 and trial 2 and sex and handedness being the between subjects factors (male and female and left- and right). The main effect of trial approached significance F(1, 50) = 3.794, p=0.057 with the state scores in the first trial being higher than the state scores in the second trial. There was no significant main effect of sex F(1, 50) = 2.005, p>0.05 and the main effect of handedness also failed to reach significance F(1, 50) = 0.875, p>0.05. The two-way interaction between trial and sex failed to reach significance F(1, 50) = 0.240, p>0.05. The two-way interaction between trial and handedness also failed to reach significance F(1, 50) = 0.185, p>0.05 as did the two-way interaction between sex and handedness F(1, 50) = 1.312, p>0.05. The three-way interaction between trial, sex and handedness also failed to reach significance F(1, 50) = 0.011, p>0.05.

Trait anxiety scores

Table 7.27: Mean trait scores of participants who completed the 4-disk Tower of Hanoi first (with standard deviations in parentheses).

	Left	**Right**	**Total**
Male	34.1 *(7.4)*	40.3 *(10.1)*	37.2 *(9.2)*
Female	40.7 *(7.8)*	38.9 *(11.1)*	40.0 *(9.3)*
Total	37.6 *(8.2)*	39.6 *(10.4)*	

The above table shows that left-handed females and right-handed males have similar mean trait scores followed by right-handed females and then left-handed males who have the lowest trait scores on average. Males had lower trait scores than females and right-handers scored higher on average than left-handers.

A 2 x 2 (sex x handedness) between subjects ANOVA was carried out on the trait scores of participants that completed the 4-disk Tower of Hanoi twice. There were no significant main effects of sex F(1, 50) = 1.110, p>0.05 or handedness F(1, 50) = 0.780, p>0.05 and the interaction between sex and handedness failed to reach significance F(1, 50) = 2.582, p>0.05.

Comparison of state scores and trait scores between the 3-disk TOH condition and the 4-disk TOH -Self report anxiety.

First state scores

As previously mentioned participants were asked to complete two state anxiety questionnaires during the course of the study, the first questionnaire was administered after participants had received and read the instructions for the 3- or 4-disk Tower of Hanoi (first trial) and the other questionnaire was administered after participants had received and read the instructions for the 4-disk Tower of Hanoi (second trial) (depending on condition). Both questionnaires were completed before the participant physically solved each Tower of Hanoi. It was found that there was a significant main effect of condition on the state scores before the first trial of each Tower of Hanoi with state scores being significantly higher before competing the 3-disk ToH than before completing the 4-disk ToH . Also, there was a significant two-way interaction between hand preference and condition and further analysis revealed that left-handers who completed the 4-disk Tower of Hanoi as their first trial had a lower mean state score than the right-handers, however, left-hander's mean state scores were much higher than right-handers mean state scores before they completed the 3-disk Tower of Hanoi. This full analysis can be found in appendix 28.

Second state scores (state 2)

In order to examine the differences for the second state anxiety scores a 2 x 2 x 2 between subjects ANOVA (sex x handedness x condition) was carried out on the self-reported second state scores (either before one group did the 4-disk TOH for the first time after previously completing the 3-disk TOH and the other group did the 4-disk TOH for the second time). The main effect of sex was not significant F(1, 92) =, 0.523, p>0.05. The main effect of handedness was not significant F(1, 92) = 0.098,

$p > 0.05$. However, the main effect of condition was significant $F(1, 92) = 6.647$, $p < 0.05$ with state anxiety scores significantly higher when participants completed the 4-disk Tower of Hanoi for the first time than when they completed it for a second time. The two-way interaction between sex and handedness failed to reach significance $F(1, 92) = 0.475$, $p > 0.05$ as did the two-way interaction between sex and condition $F(1, 92) = 1.827$, $p > 0.05$ and the two-way interaction between hand preference and condition $F(1, 92) = 1.952$, $p > 0.05$. The three-way interaction between sex, handedness and condition failed to reach significance $F(1, 92) = 0.638$, $p > 0.05$.

Trait scores

(The trait questionnaire was carried out after both ToH's in the session had been completed). There were no main effects found when comparing the trait scores from condition 1 with the trait scores from condition 2. This full analysis can be found in appendix 28

The main findings from experiment 9 were:

- In the 3- then 4-disk condition left-handers reported themselves to be significantly more anxious on the state anxiety questionnaire than right-handers before completing the 3-disk Tower of Hanoi. There was no difference between left- and right-handers' state anxiety scores on the trial of this condition (the 4-disk Tower of Hanoi). There were no sex effects.

- In the 3-4-disk condition state anxiety scores were significantly higher during the first trial (3-disk) than during the second trial (4-disk), irrespective of sex and handedness.

- In the 4- then 4-disk condition there were no significant effects of sex or handedness on state scores before the first trial or the second trial. Left-handers did score higher before the first trial but not significantly so.
- There were no effects of sex or handedness on the trait anxiety scores irrespective of condition.

- In the 3-4-disk condition there was a significant effect of sex on the time taken to make the first move on the 3-disk Tower of Hanoi with females taking significantly longer than males. There was no effect of handedness but left-handers took longer than right-handers on average. There were no main effects on the second trial (4-disk). Participants took significantly longer to move the first disk on the first trial than they did on the second trial.

- In the 4-4-disk condition there were no significant main effects of sex or handedness on the time taken to move the first disk. Participants took significantly longer to move the first disk on the first trial than they did on the second trial.

- There were no main effects of sex or handedness on the number of moves taken to complete the Tower of Hanoi. This was the case for both trials of the 3-4-disk condition and both trials of the 4-4-disk condition. There was a significant sex X handedness interaction on the first trial of the 4-4-disk condition caused by left-handed males and right-handed females taking fewer moves.

- In the 3-4-disk condition there were no main effects of sex or handedness on the time taken to complete the Tower of Hanoi. However, in the 4-4-disk condition the main effect of sex approached significance in both trials with males completing the task faster than females. The main effect of handedness was not significant, however, left-handers were faster than right-handers during both trials.

- Females took significantly longer than males to move the first disk regardless of condition.

- When comparing the completion times of those doing the 4-disk Tower of Hanoi for the first time (after completing the 3-disk) with those who completed the 4-disk Tower of Hanoi for a second time (having just completed exactly the same task) those doing the 4-disk Tower for the second time completed it significantly faster than those doing it for the first time.

7.13. Discussion

The main aim of this study was to try to address some of the unanswered questions that existed from the previous studies and cover a variety of key concepts that could possibly have contributed to the effects that were reported in preceding chapters. These concepts included task complexity and task novelty. However, since there is not a lot of previous literature that relates to the current study, particularly as many of the findings were inconclusive, then this discussion will be speculative in places. An overview of the main findings will be outlined and discussed.

It was hypothesised that left-handers would take longer to move the first disk on the first trial of the Tower of Hanoi (either the 3-disk or 4-disk version depending on the condition that they were in) than right-handers. There was no significant effect of handedness on the time taken to move the first disk on the 3-disk Tower of Hanoi and this therefore did not support the hypothesis made. However, left-handers did take around one second longer, on average, to move the first disk than right-handers and thus although the difference was not significant the delay in moving the first disk was in the same direction as the findings in Chapter 4 (with left-handers taking longer). Left-handed females also took the longest to move the first disk but left-handed males moved the first disk, on average, in the shortest time. There was a significant effect of sex on the time taken to move the first disk on the 3-disk Tower of Hanoi with females taking significantly longer to move the first disk than males on average. The findings in Chapter 4 did not show a significant effect of sex on the time taken to move the first disk, however, females took marginally longer to move the first disk than males. On the 4-disk Tower of Hanoi in the current study (first trial) right-handers took longer to move the first disk than left-handers. Females again took longer to move the fist disk than males. However, the effect of handedness was not significant. This finding was in the opposite direction of what was predicted with right-handers taking longer to move the first disk than left-handers. There was, however, a significant effect of sex on time taken to move the first disk with females moving the first disk significantly slower than males.

Although left-handers did take longer to touch the first disk on the 3-disk Tower of Hanoi than right-handers this difference was not significant. This does not replicate the findings reported by Wright, Hardie and Rodway (2004) (and thus Chapter 4), however, there could be a number of reasons why this was the case. One reason for this might have been the power of the sample. In the study in Chapter 4, 80 participants completed the 3-disk Tower of Hanoi but in the current study only 40 participants took part in this condition as another 40 participants had to be recruited to take part in the 4-disk Tower of Hanoi condition. A larger number of participants in each condition might have revealed a more robust effect but as it was very difficult to recruit sufficient numbers of left-handers in the allocated time then analysis had to be carried out with the current numbers. A future study could address this problem and recruit larger numbers of left-handers over a longer period of time.

As previous literature does not investigate the time taken to make the first move on the Tower of Hanoi then it makes it more difficult to speculate why there is a different pattern between groups. In Chapter 4 possible reasons given for this delay included planning the solution before solving the problem, differences in emotional processing between the groups and increased levels of anxiety where participants might pause before starting to solve the problem possibly to compose themselves. These possible explanations were proposed with respect to left- and right-handers. With respect to the 4-disk Tower of Hanoi right-handers took almost twice as long to begin the task than left-handers. There is no clear explanation based on previous literature why this result was found. The 4-disk Tower of Hanoi is a much more complicated task than the 3 disk version with an optimal solution of 15 moves. However, as the right-handed participants took longer to begin the 4-disk task it might have been that they were more anxious about the task or that they were trying to plan their first few moves (since the whole solution could not be planned before beginning perhaps due to the capacity of short term memory). However, upon examining the number of moves taken to solve the task it was found that left-handers took slightly fewer moves than right-handers and thus this suggests that planning was not taking place. Again as reported in Chapter 4 and in Chapter 6 planning a solution before beginning the Tower of Hanoi is reported to improve performance and poor performances on this task is often interpreted as having made an inefficient plan (Phillips, Wynn, Gilhooly, Della Sala & Logie, 1999). Goel et al. (2001) stated that in order to solve the task efficiently the participant had to look a few moves ahead and plan the first few moves before making any contact with the task. However, participants cannot just make individual moves especially on a task such as the 4-disk version as a series of sub-goals need to be made in order to move one disk in many cases (for example, moving the purple disk to another peg which sits under three other disks in its starting position) (Welsh, 1991).

Therefore, based on the time taken to start the 4-disk Tower of Hanoi right-handers took longer but based on the number of moves taken to solve the task and the average time taken to complete it left-handers solved it more efficiently. This suggests that the time taken by the right-handers before beginning was not spent planning. In terms of the 3-disk Tower of Hanoi, left-handers took slightly longer to start the task but took slightly more moves, on average, to solve it but completed it in less time. The fact that left-handers took slightly more moves than right-handers suggests that the time before starting the task was not spent planning. However, left-handers did solve the task, on average in 4 seconds less than right-handers and therefore although they did not use an optimal solution to solve the task this finding suggests that left-handers were quicker at moving the disks and perhaps demonstrating on-line planning (making a plan as they went along) rather than before they started. Therefore, it appears that the pause demonstrated by both left- and right-handers could not simply be attributed to planning.

Another reason given for a potential delay in responding to a novel problem was that there might be differences in anxiety levels which affect the response styles of left- and right-handers. State and trait measurements of anxiety were measured using the STAI (Speilberger, 1983). It was hypothesised that left-handers would have a higher state anxiety score than right-handers before completing the first Tower of Hanoi trial. Three different initial state scores were examined. Firstly, before completing the 3-disk Tower of Hanoi, secondly, before completing the first trial of the 4-disk Tower of Hanoi, and thirdly, all scores were combined to give an overall initial state score before participants completed the Tower of Hanoi for the first time. In the 3-disk condition the hypothesis was supported, as there was a significant main effect of handedness on state anxiety scores with left-handers reporting themselves to be significantly more anxious than right-handers. There was no effect of sex. In the condition where participants completed the 4-disk Tower of Hanoi first there were no significant main effects of sex or handedness on state anxiety scores. Right-handers reported themselves to be slightly more anxious than left-handers and females reported themselves to be more anxious than males. Finally, when all scores were combined there were no main effects of sex or handedness on initial state anxiety scores. Relatively few studies exist that examine state anxiety and handedness and ones that have been reported do not test state anxiety in conjunction with an experimental task so it is difficult to draw conclusions (e.g. French & Richards, 1990). As previously reported in this section left-handers took longer to make their first move on the 3-disk Tower of Hanoi than right-handers did but this pattern did not occur on the 4-disk Tower of Hanoi. One reason for this might be that the 4-disk version is much more complex than the 3-disk Tower and thus both left- and right-handers are equally stressed about achieving the solution. However, right-handers took almost 3 seconds longer to begin the 4-disk Tower of Hanoi but the state anxiety scores of the left- and right-handers were similar thus these current results suggest that the delay taken by right-handers to respond to the 4-disk task cannot simply be explained through higher levels of anxiety. The 3-disk Tower of Hanoi is a relatively simple problem and therefore it would be expected that participants would begin this quickly and not feel anxious about the ability to solve it. However, as previously stated it might be the case that left-handers feel pressurised by the potential failure of not being able to solve a simple problem and this might affect their anxiety levels and thus cause a delay before they move the first disk. The finding that left-handers reported themselves to be significantly more anxious than right-handers before they solve the 3-disk Tower of Hanoi supports this possibility.

It was also hypothesised that there would be no difference between the state scores of left- and right-handers before completing the second trial of the Tower of Hanoi. This hypothesis was supported, as there were no main effects of sex or handedness on the state anxiety scores before completing the Tower of Hanoi for a second time. This adds to the support that the novelty of a task affects left-handers more than the complexity of a task. If complexity affected this group then it would have been expected that state scores would have been higher when the complexity of the task increased. Also, this task was not entirely novel to the group as they had already completed the 3-disk Tower of Hanoi and thus this may have also reduced anxiety levels.

A comparison of each handedness group’s performance within their condition was carried out. It was hypothesised that left-hander’s state anxiety scores would be higher before completing the first Tower of Hanoi task than before completing the second Tower of Hanoi task (again this was examined across both conditions) and also that there would be no difference between right-handers’ state scores before completing the first and second trials of the Tower of Hanoi. It was found that in the condition where the 3-disk Tower of Hanoi was completed first and followed by the 4-disk Tower of Hanoi that left-handers reported themselves to be significantly more anxious before the 3-disk task than the 4-disk task. There was no significant difference between the state scores of right-handers however in this condition. When performance was examined in the condition where the 4-disk Tower of Hanoi was completed twice there was no significant difference between first and second state scores in left-handers but there was a significant difference between right-hander’s state scores with them reporting themselves to feel more stressed before completing the first Tower of Hanoi than the second Tower of Hanoi. Thus the hypothesis is supported in the 3-disk-4-disk condition but not in the 4-disk-4-disk condition. Again the reason for this can be attributed to the increased stress levels displayed by left-handers towards simple tasks in novel situations. As the 4-disk Tower is much more complex this increased level of stress does not seem to be displayed or perhaps the task is so complex that on a second trial an equal level of stress is maintained. Mataix-Cols and Bartrés-Faz, (2002) state that learning is not evident until around the fifth trial and thus if a participant had difficulty solving the 4-disk task the first time and then was asked to solve it again then this might maintain their anxiety levels especially if they achieved their original solution by a trial and error approach. This however does not explain why right-handers reported themselves to be significantly more anxious before taking part in the first 4-disk Tower of Hanoi than when they completed the second 4-disk Tower of Hanoi. An explanation of this finding could be that the complexity of the task effects the behaviour of right-handers more than the novelty of the task and as previously mentioned this issue is currently being investigated.

It was also hypothesised that there would be no difference between the trait anxiety scores of left- and right-handers in the study. This hypothesis was supported and there was no difference between the trait anxiety scores of left- and right-handers or between males and females. This finding supports a number of previous studies which found no difference between trait anxiety in left- and right-handers (e.g. Beaton & Moseley, 1984; French & Richards, 1990). However, this finding fails to support findings by Orme (1970), Hicks and Pellegrini (1978) and Dillon (1989). On the other hand, once again it can be argued that the method of measuring anxiety can alter these findings and this has to be taken in to account when examining current evidence.

Additionally, in the current study there was a difference between males and females in the time taken to move the first disk (in both the 3- and 4-disk task) with females taking significantly longer to move the first disk than males. As previously mentioned, it has been reported that females have, on average, higher anxiety levels than males (Wienrich et al*.,* 1982) and thus levels of anxiety could be a contributing factor towards the differences in the approach to the problem between males and females. Another possibility is that the two groups have a different solving strategy that is not directly focussed around planning but in the way that they move the disks - this is currently being investigated as part of an ongoing study (see Chapter 8, section 8.3. for details of this). The time taken to move the first disk for each group on the first trials of the Tower of Hanoi was longer in the 4-disk condition than in the

3-disk condition. This suggests that the complexity of the problem has an effect on how an individual will tackle it. This finding suggests that more thought has to be given to the more complex problem. However, another factor that might affect this is whether or not the problem is novel to the participant. This issue is also being currently investigated with the 3-, 4- and 5-disk Towers of Hanoi (see Chapter 8, section 8.3.1. number 3).

It was also hypothesised that there would be no difference in the time taken to move the first disk of the second trial of the Tower of Hanoi between left- and right-handers. Again there were two different groups (both did the 4-disk Tower of Hanoi but this was novel to one group). In the condition where the group did the 4-disk Tower of Hanoi for the first time there were no significant main effects of handedness or sex. However, left-handers took longer to move the first disk than right-handers and females took longer to move the first disk than males. This again could be because the problem is still novel in the fact that the participants had never solved the 4-disk problem before and thus left-handers and females were perhaps more inhibited in their approach behaviour than right-handers and males (e.g. Hopkins & Bennett, 1994). In the group that did the 4-disk Tower of Hanoi for the second time the scores were very similar for each group. Males and females took exactly the same time on average to move the first disk on the second trial while left-handers were only marginally slower than right-handers to move the first disk. Again there were no significant main effects found. This group did exactly the same task as their first task and the lack of differences found between groups in this condition suggests that novelty is an important factor in determining individual’s approach behaviours. It also suggests that if levels of anxiety effect an individual’s performance (or the behaviour prior to the task) then novelty also has a significant effect on increasing these levels in particular groups (i.e. left-handers and females). Thus the hypothesis that there would be no difference in the time taken to move the first disk in the second condition of the Tower of Hanoi was supported.

Performance on the first move of the first trial of the Tower of Hanoi was compared with performance of the first move on the second trial of the Tower of Hanoi for each group. In the group that did the 3-disk Tower of Hanoi first and then the 4-disk Tower of Hanoi second there was a significant difference between the first move times taken by left-handers and females. This suggests that these groups might have been more anxious than the other two groups when faced with the 3-disk Tower of Hanoi or alternatively it could mean that the other two groups (males and right-handers) were affected more by the complexity of the problem when faced with the 4-disk

Tower of Hanoi (this was however not the case as females and left-handers took longer to start the 4-disk trial too than the males and right-handers). The difference between the times taken by right-handers and males were not significant. In the group that did the 4-disk Tower of Hanoi twice all groups (males, females, left-handers and right-handers) were significantly slower to move the first disk on the first trial of the 4-disk Tower of Hanoi (when the problem was novel) than on the second trial of the 4-disk Tower of Hanoi. This therefore suggests that the novelty of the task causes a more inhibited approach than when the problem is no longer novel.

With respect to task complexity, very little work has been carried out examining this in conjunction with handedness. One of the only studies that examines this issue was carried out by Bryden, Pryde and Roy (2000). They found that the frequency with which a participant used their preferred hand was not affected by the complexity of the task. However, Bryden et al. examined hand preferences across a series of tasks but were not interested in behavioural responses to these. Bryden et al. were interested in the frequency of use of the preferred hand and the point at which someone has to switch to the non-preferred hand in order to complete a task. Therefore because the aim of Bryden et al.'s study was to examine hand preference on complex tasks this study cannot be used to support the findings in the current study on task complexity. Additionally, in the current Tower of Hanoi study all participants were asked to respond with their preferred hand and thus the difference in skill between the hands could not be compared.

Comparisons were made on the performances of the individuals in the 2 conditions on the time taken to move the first disk on the 3-disk Tower of Hanoi and on the 4-disk Tower of Hanoi (both first trials). It was found that males and females took less time to make the first move on the 3-disk Tower than they did on the 4-disk Tower. However, left-handers took more time to move the first disk on the 3-disk Tower than they did on the 4-disk Tower but right-handers took more time to move the disk on the 4-disk Tower than on the 3-disk Tower. This suggests that left-handers are affected more by the novelty of the task rather than the complexity whereas the right-handers seem to be affected more by the complexity of the task. Also, although the novelty is possibly affecting the performance of left-handers in the approach to the task another reason might be that the simplicity of the problem is also affecting left-hander's performance. The 3-disk Tower of Hanoi is a relatively simple task and as such a number of researchers do not use the 3-disk task as they report it to be too easy for testing purposes (e.g. Mataix-Cols and Bartrés-Faz, 2002) and use a minimum of 4-disks when carrying out experiments. If this is the case then it is possible that the potential to fail to solve this simple task might also have an effect on the left-handed group and thus contribute to the pause before making a first response and to the increased anxiety levels that they display. The increased time taken to make the first move by males and females in the 4-disk condition over the 3-disk condition could possibly be an effect of the complexity of the task or a possible interaction between the novelty of the task and the complexity. The first move time was also examined on the second trials of each group (the 4-disk Tower (first time) by one group and the exact same 4-disk Tower (second time) by the other group. The males and females completing the 4-disk Tower of Hanoi for the first time took longer to make their first move than the males and females who had already completed the same 4-disk Tower of Hanoi earlier in the experimental session. Left- and right-handers also took more time to make their first move when completing the 4-disk Tower of Hanoi for the first time than the left- and right-handers who were completing it for a second time (however, these effects were not significant). This illustrates that task novelty is an important factor when examining the performance on the Tower of Hanoi. In the condition where the group had already completed one 4-disk Tower of Hanoi task before completing a second every sub-group within this condition made their first move quicker than those in the condition where participants completed the 4-disk Tower for the first time. Again it can be argued that as this group had already done the 3-disk Tower of Hanoi previously that the 4-disk task was not novel to the group. However, as the solution is different to the 3-disk task and more importantly the first move is different then the 4-disk task has to be treated with a certain amount of independence from the 3-disk task.

An additional factor that should have been included in order to examine the complexity issue more closely was counterbalancing the order of the 3-disk followed by 4-disk condition, a group of participants should have completed the 4-disk task followed by the 3-disk task. Thus the novel but complex task would have been carried out first and would have been followed by the less complex task which would be expected to be solved much more efficiently and in less time. However, as it was difficult to recruit high numbers of left-handed participants (both due to a lack of availability and time constraints) this condition could not be conducted (however, this is being examined in a current study). When examining the number of moves taken to complete the 4-disk Tower of Hanoi (for the first time for one group and the second time for the other group) it was found that left- and right-handers took fewer moves to solve the 4-disk Tower of Hanoi when they completed it for the second time than the group did that solved the 4-disk Tower for the first time. Again this suggests that although this group had already completed the 3-disk Tower earlier in the experimental session that the 4-disk Tower was still treated with an element of novelty whereas the group who had already completed the 4-disk Tower had experience of this and solved it more efficiently (although this was only the case for males, the other groups only showed a marginal improvement in their performance). However, as the average number of moves taken to solve the 4-disk Tower did not differ significantly between the two conditions then it can also be argued that there was some form of adaptation to the rules of the problem demonstrated by those who completed the 3-disk Tower first and that learning was not highly evident across the two repeated 4-disk trials.

The time taken to complete the 4-disk Tower of Hanoi was also compared between the conditions (those doing the 4-disk Tower for the first time after completing the 3-disk previously and those doing the 4-disk Tower for the second time after already completing the 4-disk trial in the same session). Males who completed the 4-disk Tower for the second time completed the Tower in almost half of the time that those completing it for the first time took. This pattern was also found in right-handers. Females also took an average of around 33 seconds less to complete the Tower when doing it a second time compared to those doing it for the first time and left-handers solved the 4-disk Tower on average 36 seconds faster when doing it for the second time than those doing it for the first time. This shows that although the number of moves did not improve in the repeated session, the time taken to solve the task was much improved. As the group doing the 4-disk Tower for the second time had already experienced exactly the same problem then they knew which rules they had to obey and individuals had all successfully solved the task on the first occasion. However, those who had previously solved the 3-disk Tower did not have the same experience of solving the more complex task that included a number of sub-goals and many more moves. In the 3-disk task one disk for example can be on a single peg at all times, however, on the 4-disk task more than one disk has to be at least on one peg and this makes the rule of not putting a bigger disk on top of a smaller disk important therefore this gives the group who had previously completed the 4-disk task the advantage as they had already become familiar with this strategy. When completing the 3-disk Tower this rule is not used as much as the solution is much more straightforward.

Therefore, it seems that the issue of novelty is important particularly in left-handers but this effect appears to interact with task complexity. However, the issue of task complexity is affected by the simplicity and novelty of the task rather than the difficulty. When the 4-disk Tower of Hanoi is completed for the first time right-handers take longer to start this and the anxiety levels of left- and right-handers are similar. However, when the 3-disk Tower of Hanoi is completed for the first time left-handers take longer to start this and they report themselves to be significantly more anxious at that moment than right-handers. Hembree (1988) stated that the more complex the task, the more anxious a person is if they experience test anxiety. However, the opposite pattern was found in the current study in that, on average, state anxiety was higher before completing the simpler of the two Tower of Hanoi tasks (and this was particularly the case for left-handers). The issue of task simplicity can perhaps be related to the findings of Druckman and Swets (1988) who stated in order for participants to remain focussed throughout a task they required a high state of arousal. Conversely, they stated that complex tasks required lower levels of arousal and thus they concluded that as a task became simpler the level of arousal increased.

It is therefore possible that as the left-handed participants had significantly higher levels of state anxiety that this might explain why the solved the task more efficiently than the right-handers. Although they took longer to begin the task (which might have been caused by high levels of anxiety or possibly time to compose themselves before starting) left-handers completed the 3-disk Tower of Hanoi, on average, in 6 seconds quicker than right-handers. This therefore supports Druckman and Swets' findings. Additionally, Fink and Neubauer (2004) suggested that introverts were more likely to display lower stress levels towards easy tasks compared to more difficult tasks. However, in order to investigate this with respect to left- and right-handers a measurement of introversion or extraversion would need to be taken before drawing any conclusions.

In addition, Mueller et al. (1993) found that there were no differences in terms of test anxiety scores between left- and right-handers. However, Friedman and Bendas-Jacob (1997) stated that test anxiety was a feeling of apprehension in a test situation and this could therefore have contributed to the difference between the behaviour of left- and right-handers with respect to their state anxiety scores in that left-handers were possibly more stressed by the test/experimental situation. However, Friedman and Bendas-Jacob (1997) and Hembree (1988) state that high levels of test anxiety are correlated with deficits in cognitive performance. However, this does not support the current findings as left-handers did not perform any worse than right-handers and in many cases they showed a superior performance.

On the second trials of each condition, the scores (both first move and state anxiety) remain around the same in each condition. On the second trial of the 3-disk/4-disk Tower of Hanoi condition left-handers still take slightly longer to begin the 4-disk task and have higher state anxiety levels than right-handers but this can be argued that the task still has some novelty element to it as it requires a different strategy in order to solve it. Thus, these findings can be linked to the findings of Rogers (1999) and Hopkins and Bennett (1994) on novelty which suggest that novelty may influence a delay in the response of left-handers possibly caused by inhibitory behaviour associated with the right hemisphere. Additionally, the findings by Goldberg et al. (1994) which suggest that a preference for novelty is associated with the right hemisphere and therefore left-handers should show a preference for novelty, is not supported by these findings.

To conclude, the current chapter examines whether there is a difference between state and trait anxiety levels in left- and right-handers and also whether there is a difference between behavioural inhibition and behavioural activation scores between left- and right-handers. The findings of these brief studies were used to form hypotheses for a study involving task novelty and anxiety using the Tower of Hanoi. It was found in the initial state anxiety study that left-handers were significantly more anxious than right-handers when asked to report how they were feeling during the experimental session (state anxiety) but there was no difference between the groups' trait anxiety scores. This led onto a follow up study being carried out using the Behavioural Inhibition and Behavioural Activation Scales. As behavioural inhibition is seen to be a form of anxiety then it was expected that again left-handers would score higher on this scale than right-handers and this was found to be the case. Thus, these two findings suggested that there was an element of increased anxiety in left-handers and suggestions in an earlier chapter (see chapter 4) postulated that one reason for differences between left- and right-handers on a series of tasks could be due to increased anxiety levels in left-handers. It was also suggested (both in previous research (e.g. Cameron and Rogers, 1999 and in the current series of experiments) that the novelty of the task may also affect the behaviour of the participants. As Cameron and Rogers reported that left-handers were more stressed by novel objects and situations than right-handers then it was expected that task novelty in the current study would also have an effect on the participants. One final factor that was considered here was task complexity, this issue is currently being investigated in more depth in an on-going study (see Chapter 8, section 8.3.) but the complexity of the Tower of Hanoi was also varied in the current study in order to see if this made participants more anxious or if it had no effect. It was found that left-handers when faced with the 3-disk Tower of Hanoi for the first time took longer to begin the task than right-handers (but not significantly so) and were significantly more anxious about the current situation (state anxiety). However, when an additional group of left- and right-handers were faced with the 4-disk Tower of Hanoi (which was novel to them and they had not completed any Tower of Hanoi before) left-handers started the task in less time than right-handers and there was no difference between the two groups in their state anxiety levels. The trait anxiety of the participants did not differ.

It therefore is concluded that left-handers appear to be more anxious than right-handers when faced with a novel situation. However, the difficulty or complexity of the situation also has an effect. In the condition where the task was more difficult (4-disk) both groups showed evidence of anxiety but when the task was simple (the 3-disk Tower of Hanoi), anxiety levels were significantly higher in left-handers (and this state anxiety score was the highest, on average, of any of the state anxiety scores recorded). This suggests that left-handers appear to feel inhibited and display an anxious reaction to a task that is not only new to them but also more specifically to a task that is simple and easy to complete. The potential failure to complete such a task could affect and increase left-hander’s anxiety levels.

Finally, as reported by Stuettgen et al. (2005) it is possible that people who experience high levels of anxiety adopt a series of behavioural coping strategies in order to reduce anxiety. Thus, the longer delay observed in left-handers before beginning some of the tasks could be evidence of coping strategy used to reduce their anxiety levels. Therefore, in conclusion state anxiety seems to increase in simple, novel situations in left-handers but this does not necessarily affect their performance and in many cases perhaps increases adrenalin and therefore there might be a fight or flight reaction which improves performance. These concepts are currently being investigated in more detail.

7.14. Overall conclusion

During the course of this thesis different explanations have been investigated as to why left- and right-handers have different response styles when approaching (novel) tasks. Planning and emotional processing explanations have been investigated in Chapters 5 and 6 and this current chapter aimed to investigate the concepts of anxiety, novelty and task complexity. It was proposed that left-handers might have higher anxiety levels than right-handers and thus this might have affected how they approached each task. Anxiety was examined over two different experiments in this chapter using the self-report STAI (Speilberger, 1983) where state anxiety and trait anxiety questionnaires were administered. Also, as part experiment 8 the BIS/BAS questionnaire (Carver & White, 1994) was administered to examine behavioural inhibition and behavioural activation levels in participants in conjunction with the issues of anxiety as the inhibitory system is said to be triggered off by an anxiety response often in concurrence with novelty. It was reported that there was no difference in trait anxiety levels between left- and right-handers. However, it was reported in both anxiety experiments that left-handers reported themselves to feel significantly more anxious on the state questionnaire (and therefore right at that moment in time) than right-handers when faced with a novel task. Also, although there was no difference on any of the behavioural activation scales between left- and right-handers, left-handers had significantly higher behavioural inhibition scores than right-handers. This finding can be related to high anxiety levels and could help explain why there is a delay in responding, on average, by left-handers. Thus, from the studies carried out in this thesis these findings suggest that an anxiety or inhibitory behaviour explanation cannot be ruled out when trying to explain why there is a response style difference between left- and right-handers.

Chapter 8: General discussion and conclusions

8.0 Aims of the thesis

One key concept central to my thesis was the reported differences in response styles between left- and right-handed monkeys and apes (e.g. Cameron & Rogers, 1999; Hopkins & Bennett, 1994). These findings suggested that fundamental differences exist in the way(s) that these primates interact with the world which are related to handedness. It was noted that very few human studies have reported differences between left- and right-handers' behaviour and their interaction with the world and therefore the main aim of my thesis was to investigate the response styles of human left- and right-handers towards a variety of different novel tasks. The investigation of these potential response style differences were carried out over a series of experiments, which were designed according to the findings of each preceding experiment in order to investigate the potential response style differences in humans. The purpose of this chapter is therefore to outline the main findings of each experimental study carried out as part of my thesis and highlight any questions or points for discussion that may result from these. The main implications of my findings will be discussed alongside limitations of the studies. Finally, current pilot work will be briefly discussed and future studies will be outlined. More specifically I will discuss the findings of the studies examining left- and right-handers response styles to novel tasks and will consider the possible reasons for occurring differences through a number of follow up studies.

8.1 Main findings within each chapter

The experiments carried out in my thesis reveal several important points and these will be discussed in the following sections.

8.1.1 Response Styles

The first experimental chapter (Chapter 4) examined response style differences between left- and right-handers using a novel problem-solving task (the 3-disk Tower of Hanoi). As previous comparative studies suggested that there was a time delay demonstrated by left-handers to respond to novel problem-solving tasks and novel objects then it was thought that right-handers might be more impulsive than left-handers. Thus, in order to investigate this idea in human participants two impulsivity measures were developed alongside the novel task (the 3-disk ToH). The first measurement was a self-report impulsivity questionnaire (the Barratt Impulsivity Scale (BIS), Barratt & Patton 1983) and the second was a computerised matching task where participants were given a series of shape matching trials to complete. It was found that there was no difference in self-report impulsivity scores between left- and right-handers (although left-hander's scores were slightly higher). However, it was found that left-handers took significantly longer to respond to the figure matching task suggesting that right-handers might be more impulsive than left-handers in their responses. These findings indicate that although left-handers might consider themselves to be as equally impulsive as right-handers on a self-report scale that their behavioural responses are slower or perhaps more inhibited than right-handers suggesting that right-handers may be more impulsive than them. However, there was no difference in the number of errors made on the matching task between left- and right-handers and this therefore suggests that the performance of the right-handed participants was not impaired by their quicker responses nor was the performance of the left-handers enhanced by their slower responses.

On the novel problem-solving task a significant difference in the response styles of left- and right-handers towards the 3-disk Tower of Hanoi was shown. It was found that left-handers took significantly longer to move the first disk than right-handers on the task. This finding was similar to the findings of Cameron and Rogers (1999) and Hopkins and Bennett (1994) in that there was a delayed response by the left-handed primates in their studies or perhaps a more impulsive response by the right-handed primates. It was also found in the Tower of Hanoi study that left-handers took significantly fewer moves to solve the 3-disk Tower of Hanoi (and males took significantly fewer moves than females). The interaction between sex and handedness was almost significant and when this was analysed further it was found that there was no difference in the number of moves taken to solve the Tower of Hanoi between left-handed males and right-handed males. However, left-handed females solved the Tower of Hanoi in significantly fewer moves than right-handed females. When completion time was compared it was found that there was no difference in the time taken to complete the Tower of Hanoi (when initiation or 'planning' time was also included) between left- and right-handers. However, it was found that males completed the Tower of Hanoi significantly faster than females. When the completion time was analysed minus the initiation or 'planning' time however it was found that the difference between left- and right-handers was almost significant (p=0.057) with left-handers solving the task faster than right-handers. Also, males still completed the task significantly faster than females.

A number of explanations were proposed for why these differences occurred. Rogers (1999) suggested that differences between left- and right-handers in terms of response style behaviour could be attributed to differences in hemispheric specialisation for processing novel stimuli and controlling emotional responses. She adds that the right hemisphere is considered to be specialised for inhibitory or avoidance behaviour and the left hemisphere is specialised for approach or exploratory behaviour (see Davidson, e.g. 1992 for a detailed explanation of this). Therefore as left-handers are right hemisphere dominant then this inhibitory or avoidance behaviour would aid in the explanation of their delayed response time in moving the first disk of the Tower of Hanoi. This explanation could also be applied to right-handers. As right-handers are left hemisphere dominant then the idea of approach or exploratory behaviour would help explain why they approached the Tower of Hanoi and moved the first disk faster than left-handers. It could be inferred from this explanation that left-handers possess a more cautious cognitive style and are more likely to think about their actions before executing them. Thus potential differences in approach strategies towards this novel task were outlined and discussed (see Chapter 4 for details of these). Superficially, it appeared that left-handers were studying the problem for longer and that this possibly caused the difference in approach towards the Tower of Hanoi between left- and right-handers. However, a number of additional (and testable) explanations were proposed and these are outlined below.

One reason for the reported response time difference between left- and right-handers, which has already been partly discussed, is a difference in hemispheric specialisation and more specifically emotional processing. The right hemisphere is often cited as being the ‘emotional’ hemisphere of the brain as many researchers report that it processes both positive and negative emotions (e.g. Christman & Hackworth, 1993). However, the valence specific hypothesis states that negative emotions are processed in the right hemisphere and positive emotions are processed in the left hemisphere (e.g. Jansari et al, 2000). Therefore it is possible that the response style behaviour of right-handers may be related to positive emotions relating to the left hemisphere dominance of their brains. This would suggest that this dominant positive emotional processing would be related to the bold and more impulsive behaviour associated with the left hemisphere and therefore the response style behaviour displayed by right-handers would be a more positive and forthright exploratory approach. In accordance with this the response style behaviour exhibited by left-handers may be related to the dominance of negative emotions relating to the right hemisphere of their brains. If the valence specific hypothesis is supported then it is possible that dominant negative emotional processing would be related to inhibitory and avoidance behaviour and therefore the response style behaviour displayed by left-handers would be more reserved and inhibited. This idea was examined in Chapter 5 where potential emotional processing differences between left- and right-handers were investigated.

Another potential explanation of why a difference in response behaviour was found between left- and right-handers was that the left-handed participants might have been planning a solution to the problem before making their first move and thus response time would be longer. Many researchers have indicated that one of the main functions of the Tower of Hanoi is to investigate planning (e.g. Shallice, 1982). Goel et al. (2001) suggested that in order to effectively solve the Tower of Hanoi that participants have to plan ahead before making any moves. In my Tower of Hanoi study (Chapter 4) it was found that left-handers solved the task in significantly fewer moves than right-handers and this therefore this supported Goel et al.*'s* argument that planning a solution is more effective. The finding that left-handers took significantly fewer moves to solve the task and significantly longer to move the first disk suggests that left-handers were planning a solution to the task during this time. If this were the case then it would also be expected that they would solve the task quicker than right-handers with their more effective solution. When ‘planning’ or ‘thinking’ time was included in completion time there was no difference between the performances of left- and right-handers. However, when the initial ‘planning’ or initiation time was not included in the total completion time of the Tower of Hanoi, left-handers did solve the task faster than right-handers (this finding almost reached significance, p=0.057). Again this superior performance on the time taken to solve the task suggests that the left-handers were planning a solution in the time before they made their first response. However, Phillips et al. (2001) reported that there was little relationship between planning and performance on the Tower of Hanoi and that planning is not necessarily essential for superior performance. Also, the handedness literature does not report any evidence that left-handers plan more than right-handers do and this issue would have to be researched further in order to make such a claim.

Not only were handedness differences reported on the Tower of Hanoi task but sex differences were also found. Males solved the task in significantly fewer moves than females and also completed the task in less time than females (regardless of the inclusion or exclusion of ‘planning/initiation’ time). However, there was no sex difference in the time taken to move the first disk of the Tower of Hanoi. These findings suggest that although males’ performances were superior, on average, to females’ on the Tower of Hanoi that the planning explanation could not be used to support these findings as there was no difference in the time taken to move the first disk and it is during this time that it was proposed that the planning was occurring. Also, the fact that both males and females took less than 1.5 seconds to make their first move, on average, suggests that they could not have made an effective plan in this time. An alternative reason why the performance of males was superior to females was that the Tower of Hanoi is a visuo-spatial task and males are consistently reported to excel on this type of task (e.g. Siegel-Hinson & McKeever, 2002). This explanation can also be used to explain the superior performance of left-handers as literature suggests that they also excel on visuo-spatial tasks compared to right-handers. Therefore it is possible that the nature of the task may have caused both the sex and handedness differences reported for the Tower of Hanoi but this does not fully explain the difference in response times and styles between left- and right-handers. Further experiments examining the nature of the task were also carried out (for example the sorting task in Chapter 6) and this issue will be discussed again in section 8.1.3.

A final possible explanation of why there was a difference in response styles to a novel task was that left-handers might be more inhibited in their responses due to increased stress or anxiety. Hopkins and Bennett (1994) suggested that left-handers took longer to make a motor response in a novel situation due to increased behavioural inhibition. In relation to this a number of studies have reported that left-handers are, on average, more anxious than right-handers and that they tend to worry more about their performances than right-handers (e.g. Orme, 1970; Dillon, 1989). Behavioural inhibition is, according to Gray (1982) a main feature of increased anxiety and thus it is possible that elevated anxiety levels in left-handers caused them to pause before making their first move on the Tower of Hanoi. Thus, left-handers might have worried more about their performance on the Tower of Hanoi and have thought about it more before making their first move. Additionally, it is possible that the novelty of the task might have added to increased anxiety levels and therefore could have affected overall performance.

Thus, three possible reasons were outlined for why there was a difference in response behaviour between left- and right-handers towards a novel task. Firstly, a difference in emotional processing between left- and right-handers might have affected how they approached the Tower of Hanoi. Secondly, a difference in planning strategies might have affected the approach that left- and right-handers took to solve the Tower of Hanoi. Thirdly, a difference in anxiety or stress levels might have affected how left- and right-handers responded to the Tower of Hanoi. In addition the issue of the novelty of the task had to be investigated as this might also have affected the performances of left- and right-handers. Each of these explanations was investigated through a series of experimental studies and the findings are discussed below.

8.1.2. Emotional processing

Chapter 5 examined the lateralisation of emotional processing in left- and right-handers. Previous studies that examined emotional processing tended to only use right-handed participants (e.g. Jansari et al, 2000) and therefore there was little available literature concerning information on emotional processing similarities or differences between left- and right-handers. As previously stated in section 8.1.1 above, it was proposed that a difference in approach strategies towards a novel task might have been caused by differences in hemispheric specialisation in left- and right-handers. More specifically, the dominant right hemisphere of left-handers and the associated inhibitory behaviour and the dominant left hemisphere of right-handers and the associated exploratory and approach behaviour. In accordance with this the valence hypothesis of emotional processing proposes that the left hemisphere is specialised for positive emotions and the right hemisphere is specialised for negative emotions. Therefore if the valence hypothesis is supported then it would be expected that left-handers would display a more negative and inhibitory behavioural style and right-handers would display a more positive and impulsive behavioural style caused by their right hemisphere and left hemisphere dominance respectively. Results of the experiment in Chapter 5 found that both left- and right-handed participants were more accurate at discriminating positive emotions than negative emotions. All participants also identified positive emotions significantly faster than negative emotions. Therefore it was found that handedness did not influence the lateralised processing of emotion on a series of morphed faces and therefore the valence specific hypothesis was not supported with respect to handedness. This finding suggests that the difference in the time taken to move the first disk on the Tower of Hanoi by left- and right-handers was not influenced by a difference in emotional processing (although it could be argued that the location of emotions on the right side would differentially affect left handers and this will be further discussed in section 8.3.2). In order for this idea to be supported it would have been expected that left-handers were more accurate and also faster at identifying negative emotional faces and right-handers would have been faster and more accurate at identifying positive emotional faces. Presumably this would have resulted in a delay in the time taken to move the first disk by left-handers caused by the dominance of the right hemisphere and thus a direct link to avoidance behaviour. Similarly, the quicker response time to move the first disk by the right-handers would have been caused by the dominance of the left hemisphere and thus a direct link to approach and impulsive behaviour. Therefore it was concluded that the delay taken by left-handers to move the first disk of the Tower of Hanoi was probably not caused by differences in emotional processing (and linked approach/avoidance behaviour related to the valence hypothesis) between left- and right-handers. However, one additional important point to note is that these conclusions are based on left- and right-handers abilities to correctly identify positive emotions and as there was no difference found between them then it shows a lack of support for the valence hypothesis of emotional processing with respect to handedness. However, this finding does not rule out the possibility that the left hemisphere of the brain is specialised for approach behaviour and the right hemisphere is specialised for avoidance or inhibitory information. This concept is discussed further in the anxiety section of this chapter (and also see Chapter 7 for a more detailed discussion). As the idea of emotional processing differences between left- and right-handers did not seem to support the findings, the next possible explanation for the difference between left- and right-handers on the time taken to move the first disk of the Tower of Hanoi was investigated.

8.1.3. Planning

Chapter 6 examined the possibility that there was a difference in planning behaviour between left- and right-handers on a series of tasks. These were a manual sorting task, a computerised ‘intelligence’ test and a computerised sequencing task which was based around the ‘Fastest Finger First’ game on the television show ‘Who wants to be a millionaire’.

The manual sorting task (outlined in Chapter 6) was devised as a follow up study to the Tower of Hanoi task outlined in Chapter 4. This task was designed firstly to see if there was a difference between left- and right-handers on the time taken to move the first card (and therefore replicating the initiation time finding of the Tower of Hanoi task), secondly to see if removing the high visuo-spatial element of the task would affect performance of both left-handers and males since they are reported to be superior at these tasks and thirdly, to examine whether there was any evidence of planning occurring if the first move response was replicated. Similarly to the first Tower of Hanoi study an indication that planning had occurred was based on a longer initiation time and a faster completion time indicating that a plan was being formulated during the initiation time and therefore completion was faster due to the execution of the plan.

It was found that left-handers took significantly longer to move the first card of the sorting task than right-handers, however, there was no difference in the time taken to solve the task between left- and right-handers. This finding suggested that the delay taken by left-handers before moving the first card of the task was not obviously used for planning. If left-handers were carrying out planning during this delay then it would have been expected to reduce the completion time of the whole task (if it was assumed that the planning improved performance). It was also found that right-handed males took significantly less time to solve the sorting task than left-handed males. This difference again suggests that left-handed males were not planning in the time it took before they moved the first card as right-handed males, on average, took longer to move the first card but solved the task quicker. However, although it appeared unlikely that planning was being carried out in this time the task consisted of 20 cards and therefore a full and effective plan would have been impossible to create and execute during the initiation time. An alternative explanation might have been that any planning that was carried out might been in the form of on-line planning where individuals plan their first few moves and then plan as they go through the task. One way to examine an on-line planning strategy would be to look at how long a participant took to move each disk or card (to calculate the time taken per move) or examine how long participants took in between moves (thus calculating possible breaks to plan the new few moves to a solution). However, as this task did not require actual moves but merely categorising cards then the idea of on-line planning could not be effectively examined. However, future work will examine this type of task further by using video footage and carrying out Observer analyses on behaviours displayed. This issue was further examined on the ‘Fastest Finger First’ task that is outlined later on in this section.

Additional studies were carried out to examine the responses of left- and right-handers to two novel computerised tasks. The first task involved four different type of question: visuo-spatial (mental rotation); language; number and Raven’s Progressive Matrices (see Chapter 6, section 6.10.). Participants were asked to solve these tasks as accurately as possibly but no time constraints were given. It was found that overall left-handers took significantly more time to respond to the questions but there was no difference between left- and right-handers on accuracy scores. This finding suggested that although left-handers took longer to respond to the questions that once again they were not planning in the fact that they were not solving the questions more effectively than right-handers. When each type of question was analysed it was found that the only handedness difference found was that left-handers were more accurate at solving the mental rotation questions than right-handers. This suggests again that left-handers have superior visuo-spatial skills than right-handers and once again the findings on the Tower of Hanoi task may have been influenced by the visuo-spatial nature of the task. There were no differences between left- and right-handers in the time taken to respond to each individual type of question. Once again this suggested that one handedness group did not plan their responses to the questions any more than the other.

The final 'planning' task that was carried out was the 'Fastest Finger First' task. This task not only investigated planning but also examined task complexity (questions either had 3 or 6 responses to be sorted into according to the question). The time taken to look at the question was also recorded in order to see if one handedness group studied the question longer than the other. It was hypothesised that left-handers would look at the question on its own for longer than right-handers. This was hypothesised for two different reasons; firstly, it was thought that if participants were planning a solution then they might study the question for longer in order to make sure that they fully understood the question and perhaps anticipate potential answers that might be given. Secondly, as it is also proposed that high levels of anxiety might be responsible for the delay in response in left-handers (see the next section on anxiety for further discussion of this) then it was proposed that left-handers might study the question for longer in order to make sure that they fully knew what the question was asking in order to reduce anxiety levels once the answers were actually shown. Thus, they would not have to worry about sorting the responses in order and making sure that they knew what the question was asking and feeling comfortable with what the question was asking at the same time.

However, it was found that there was no difference between left- and right-handers in the time taken to look at the question. With respect to the time taken to make the first response to the questions (overall) it was found that there was no difference in the time taken to make the first response between left and right-handers. When the 3 responses questions and the 6 responses questions were analysed individually it was found that participants took longer to make the first response to the 6 responses than the 3 responses. However, this difference was not affected by sex or handedness. This finding suggested that more planning or perhaps at least cognitive activity was happening when participants had to sort the 6 responses in order and therefore the complexity of the task affected the response time, however, this finding was not affected by the handedness of the participant. Thus, this suggests that one handedness group was perhaps not planning any more than the other. The response times overall and individually to the 3 and 6 response questions were not affected by handedness or sex either and therefore it can be concluded that there were no clear planning differences between left- and right-handers on these tasks. One possible reason why there were no response style differences shown by this task could be due to the lack of novelty of the task. Studies in the animal literature and the findings of a significant delay in response style behaviour by left-handed humans have all been reported to be towards a novel task or object. However, it could be argued that this task is not novel to all of the participants as it is similar to the ‘Fastest Finger First’ game on ‘Who wants to be a millionaire’ and thus many participants will be familiar with the format of this. If this was the case then this might have affected the responses of the participants towards the task. However, actually taking part in this task may have been novel to the participants and this would have to be investigated in order to be able to attribute novelty or lack of novelty as a factor that could have had an effect on the results.

It has to be noted that two out of the three planning tasks were computerised and this may have affected the results of the studies. Many people would have been aware that they were being timed on the computerised planning tasks and possibly felt more pressurised to respond quickly rather than accurately. However, this would have been the same for both left- and right-handers and therefore would not have influenced the results greatly. An additional point to note is that the original planning task (the 3-disk Tower of Hanoi) and the sorting task were both manual and this therefore may have allowed a more ‘natural’ response from participants in that they may not have felt as pressurised as they did when participating in the computerised tasks (even though the manual tasks were measured by stopwatches). In addition, it is possible that these tasks involve a greater level of motor planning (i.e. to execute the moves) as well as planning for the sequencing of events. Therefore, it is a possibility that planning is not causing or influencing the original response style differences.

Another reason why it appeared that there were no planning differences between left- and right-handers might have been caused by the type of task they were being asked to do. Because each task involved a short problem solving task then it might not be as important to the participant to make a plan to solve the task as it would be if there was some importance emphasised on the solution of the task or if it involved some kind of real life situation. If a real life scenario was given to participants then there might have been a difference in the way that the two handedness groups approached this and there may therefore have been a more valid reason to make a plan before tackling the task. This idea is considered further in the future research section of this chapter (section 8.3.2). The third potential factor proposed to explain the differences in response styles to novel tasks between left- and right-handers is anxiety. The following section will discuss this explanation.

8.1.4. Anxiety

As mentioned above, the third explanation proposed in order to explain the reported response style differences between left- and right-handers is different levels of stress and/or anxiety. More specifically, left-handers are hypothesised to have higher anxiety levels than right-handers and therefore this was proposed to possibly affect their responses to tasks and in particular novel tasks. In order to examine anxiety differences between left- and right-handers the State Trait Anxiety Inventory (STAI – Speilberger, 1983) was carried out in two different studies. One important distinction that had to be made was that there were two different types of anxiety being measured and this could therefore affect the interpretation of results. Most studies only measure generalised anxiety which examines how participants feel in general. However, in order to establish how participants felt before taking part in the novel problem solving tasks a different measure of anxiety had to be used in order to collect this information. The trait measure allowed the factor of general differences in anxiety to be discounted as causes for the differences in responses. The state anxiety questionnaire asked participants a series of questions about how they felt right at that moment in time rather than in general. The state anxiety measurements in my two studies were considered to be more important than the trait anxiety measurements as these measurements allowed me to measure the participant’s levels of anxiety towards the novel tasks.

The first study in which the state questionnaire was administered was before participants completed the IQ computerised task (see Chapter 6 for details and section 8.1.3. for further details of this task). In this study half of the participants were given the state questionnaire without being told what the actual task entailed and the other half of the sample were given the instructions for the task and then once they understood what they were they were being asked to do they were given the state questionnaire. The reason for this was to investigate whether state anxiety levels would increase if participants were informed of the task that they were expected to complete. It was expected that state anxiety scores would be lower in those who did not know what they were going to be asked to do compared with those who had a specific task to focus their present feelings on.

It was reported that overall (irrespective of whether participants were given the state anxiety questionnaire before they were shown the task instructions or not) that left-hander's state anxiety scores were significantly higher than right-hander's state anxiety scores. The state anxiety scores of the two groups were analysed individually and it was found that there was no difference between left- and right-hander's state scores when they had not been shown the task instructions previously. However, in the group who had been shown the task instructions before they had been given the state anxiety questionnaire to complete there was a significant effect of handedness with left-handers reporting themselves to be significantly more anxious than right-handers at that moment in time. There were no differences between the trait anxiety scores of left- and right-handers. These findings indicated that left- and right-handers did not differ in their general anxiety scores but they did differ in their anxiety scores relating to how they felt at that particular moment in time. More specifically, this difference was most apparent when participants had been informed of the task they were expected to complete.

In addition to state and trait anxiety scores participants were also given the BIS/BAS questionnaire (Carver & White, 1994) to complete (in conjunction with the 'Fastest Finger First' study outlined in Chapter 6). It was found that there were no differences between left- and right-hander's behavioural activation scores. However, there was a significant difference (one-tailed) between behavioural inhibition scores with left-handers reporting themselves to have higher scores than right-handers. Again this finding can be related to increased anxiety or inhibitory behaviour in left-handers and may explain why there was a delay in responding to a novel task. It has been argued that the inhibitory system is related to the right hemisphere and this would aid in the explanation of why left-handers have higher BIS scores than right-handers. This finding coupled with the original state anxiety difference lead to the development of the second state/trait anxiety investigation.

The second study where the state and trait anxiety questionnaires were carried out was during the Tower of Hanoi experiment outlined in Chapter 7 (see Chapter 7 for a fully comprehensive report and discussion of the Tower of Hanoi findings). In this study state anxiety scores were examined with respect to the issues of task novelty and task complexity. In this study all participants solved two Tower of Hanoi tasks (see Chapter 7 for full details of this). The first Tower of Hanoi task was novel to all participants (one group did the 3-disk Tower and the other did the 4-disk Tower) and each participant was given the state questionnaire to complete after they read and understood the instructions for the Tower of Hanoi that they were going to attempt. Once participants had completed the first Tower of Hanoi they were given an additional Tower of Hanoi to solve. This time the 4-disk Tower of Hanoi was given and thus this task examined the issue of novelty in one group (the group who had already completed the 4-disk ToH) and the issue of complexity in the other group (the group who did the 3-disk ToH and then the 4-disk ToH). Again state anxiety levels were recorded before participants completed the 4-disk Tower of Hanoi (and after they had read and understood the instructions for the 4-disk ToH). It was proposed that the novelty of the task would affect state anxiety levels and more specifically reduce state anxiety levels in left-handers when the task was no longer novel. No specific hypothesis was made about state levels of anxiety and task complexity with respect to handedness, however, it was proposed that the novelty of the task would stress left-handers more than the complexity of the task would particularly when the more complex task was not entirely novel (although see pilot study 2 in section 8.3.1 for details of task complexity and novelty with respect to whether the task can be defined as novel if the number of disks change).

In the condition where participants did the 3-disk Tower of Hanoi first followed by the 4-disk Tower of Hanoi it was found that left-handers reported themselves to be significantly more anxious than right-handers before completing the 3-disk Tower of Hanoi. However, there was no significant difference between the state anxiety levels of left- and right-handers on the second Tower of Hanoi in that condition (the 4-disk ToH). When the state anxiety scores were compared between the first trial and the second trial of this condition it was found that state scores were significantly higher on the first trial than the second trial – irrespective of sex and handedness. Overall, left-handers reported themselves to be more anxious than right-handers irrespective of conditions (however, this was mainly caused by the high state scores of left-handers before completing the first ToH). When state scores were examined in the 4-disk-4-disk Tower of Hanoi condition different results were found. There was no difference in state anxiety scores between left and right-handers before completing the first 4-disk Tower of Hanoi. When participants completed the 4-disk Tower of Hanoi for the second time it was predicted that there would be no difference between left- and right-handers state scores, as the task was no longer novel. This finding was supported. Therefore a difference in state anxiety scores would have been expected on the novel trial of the task but not the non-novel trial of the task but no differences were found for either trial. When these state anxiety scores were compared across trials it was found that there was no effect of sex or handedness. However, there was a difference between the state scores overall on the first and second trials with the state scores being higher before participants completed the first 4-disk Tower of Hanoi compared with the state scores given before participants competed the 4-disk Tower of Hanoi for the second time (this approached significance p=0.057). Trait anxiety scores revealed that there were no sex or handedness differences within the sample.

State anxiety scores were also compared across conditions to examine whether these scores differed with respect to the complexity of the first, novel condition (either the 3-disk or 4-disk ToH depending on condition). It was reported that there was no sex or handedness differences on these state anxiety scores but there was an effect of condition where state scores were, on average, significantly higher before participants did the 3-disk Tower of Hanoi than the group who did the 4-disk Tower of Hanoi first. It was also reported that there was no difference between the state scores of right-handers between the two Tower of Hanoi conditions, however, there was a significant difference between the state scores of left-handers with respect to condition. It was reported that state scores were significantly higher for left-handers who did the 3-disk Tower of Hanoi first than the state anxiety scores of the left-handers who did the 4-disk Tower of Hanoi first. The comparison of the second state anxiety scores across conditions revealed that there were no sex or handedness differences. However, state scores were significantly higher in the group who did the 4-disk Tower of Hanoi for the first time (but as their second ToH trial) than in the group who did the 4-disk Tower of Hanoi for the second time (as an identical second trial to their first trial).

Therefore, it appears that anxiety possibly does influence response style differences between left- and right-handers. However, although a number of studies reveal that anxiety differences exist between left- and right-handers (e.g. Hicks, Pellegrini & Evans, 1978), the type of anxiety being measured has to be considered rather than citing overall anxiety differences that are not related to the current experimental task. Recent studies that have examined state anxiety with respect to handedness (e.g.

French & Richards, 1990) found that there was no relationship between handedness and anxiety. However, this is an exception and there are very few studies that examine state anxiety with respect to handedness and thus most reported laterality and anxiety differences are concerned with trait anxiety data or a similar general measurement.

8.1.5 Conclusion of experimental findings

Previous comparative research reported that there was a difference in response style behaviour towards a novel task or object between left- and right-handed primates where left-handed primates were reported to take significantly longer to respond than right-handers. This finding was examined in this thesis with respect to humans using the 3-disk Tower of Hanoi task and a manual sorting task. It was found that the comparative findings were replicated and left-handed humans took significantly longer to respond to these novel tasks than right-handed humans. Following this, a number of potential explanations of why there was a delay in responding by left-handers or possibly a more impulsive approach by right-handers were proposed. The first potential explanation was that there was a difference in emotional processing between left- and right-handers but a study designed to examine this found that this was not the case (see Chapter 5 for details). The next proposed difference was that there was a difference in the planning behaviour of left and right-handers and that left-handers took longer to respond because they were formulating an effective plan in this time. However, a number of experiments were carried out to investigate planning and it was reported that there was no clear evidence of planning occurring during the delay in responding as the tasks were not completed any more effectively (both in terms of time and accuracy) by left-handers than by right-handers. If there was evidence of planning then it would have been expected that participants who took longer to start a task would complete it both faster and more accurately than someone who did not plan. However, this pattern was not evident from the results of the experimental studies. Finally, it was proposed that left-handers might have higher anxiety levels than right-handers and thus this might have affected how they approached each task. Anxiety was examined over two different experiments using the self-report STAI (Speilberger, 1983) where a state anxiety and a trait anxiety questionnaire were administered. Also, as part of a different study the BIS/BAS questionnaire (Carver & White, 1994) was administered to examine behavioural inhibition and behavioural activation levels in participants. It was reported that there was no difference in general anxiety levels between left- and right-handers. However, it was reported in two different experiments that left-handers reported themselves to feel significantly more anxious than right-handers when faced with a novel task. Also, although there was no difference on any of the behavioural activation scales between left- and right-handers, left-handers had significantly higher behavioural inhibition scores than right-handers. This finding can be related to high anxiety levels and could help explain why there is a delay in responding, on average, by left-handers. Thus, from the studies carried out in this thesis it appears that evidence suggests that the delay in responding to novel tasks is caused by the inhibitory behaviour and increased state anxiety levels of the left-handed participants.

However, it would be presumptuous to suggest that this is the only reason that such a delay is occurring and much more work needs to be done to investigate many of these proposed reasons further. For example, the idea of task novelty was only briefly investigated in the final experiment of this thesis and further work would need to be carried out on both task novelty and task familiarity to see if any differences occurred between left- and right-handers. Also, anxiety levels would have to be investigated in additional ways along with further tests of planning. These ideas will be discussed in the future studies section of this chapter. However, before ongoing pilot studies and proposed future studies are discussed the next section will consider the main limitations of the thesis.

8.2. Limitations of the thesis

The main limitation throughout each experiment was the difficulty in recruiting sufficient numbers of left-handed participants in order to carry out my experiments. There were several reasons why this caused difficulties.

Firstly, the number of available left-handers was limited as the studies were carried out predominantly with staff and students of the University of Abertay (which is a small university) therefore I was not able to recruit as many left-handers for my studies as I would have liked. As a compromise I aimed for 40 left-handers (20 males and 20 females) for each experiment with the exception of the experiment outlined in Chapter 7.

The lack of available left-handers also affected the issue of statistical power in my studies. In order to be able to report large effect sizes then I would have had to increase my sample sizes, however, by increasing the number of right-handers in the studies but not being able to increase the number of left-handers in the time frame available this may have altered the sample size but would have distorted the handedness findings if there were many more right-handers than left-handers in the sample. The experiment in Chapter 7 involved a between subjects design and therefore a bigger sample size had to be recruited. However, only 100 participants were recruited and once again this caused issues concerning statistical power.

Another problem with the study described in Chapter 7 was that more participants were recruited in to the 4-4-disk condition than in the 3-4-disk condition. For example, there were 28 left-handed participants in the 4-4-disk ToH condition and only 24 left-handed participants in the 3-4-disk condition. Although this is not a huge difference in numbers this could still have affected the findings, particularly the time taken to make the first move which was a sensitive finding in terms of subtle differences being found. This was also the case for right-handers; there were more right-handed participants in the 4-4-disk ToH condition (26 participants) than in the 3-4-disk ToH condition (22 participants). The reason for this was that more left-handed participants had offered to participate in this particular study and therefore the original number (around 60 left-handed participants) was randomly assigned to either condition (3-4-disk ToH or 4-4-disk ToH). However, at the end of the study when a number of left-handed participants did not show up to take part in the study a high proportion of these participants has been assigned to the 3-4-disk ToH condition and therefore a higher number of left-handers had already been tested in the 4-4-disk ToH condition which caused there to be more left-handers in one condition than the other. One reason why I was able to recruit more left-handed participants in this study than the previous studies was that participants were paid for their participation in this study and therefore this created a greater amount of interest from potential participants.

Additionally, a high percentage of participants failed to turn up to take part in the experiments and therefore the number of potentially recruited participants was at least 20% higher than the number who actually took part in the experiments. Although there was a considerably high drop out or no-show rate of left-handers it was much easier to recruit additional right-handers to take part in the experiments when this occurred. However, there was no ‘reserve list’ of available left-handed participants who could replace participants who did not show up, as every left-hander who stated that they would like to participate in the experiment was included. Although a target number of left-handed participants was set at the beginning of the study it was not always possible to achieve this number (due to the reasons outlined above) and therefore in order to keep the proportion of left- and right-handers about the same the number of available and willing to participate left-handers dictated how many right-handers were needed in each experiment.

Difficulties with left-handed participants not only occurred with the recruitment of them but also in classifying them into handedness groups. As stated in Chapter 3 there are a number of ways in which handedness can be classified or categorised. This ranges from categorising handedness based on levels of hand skill (i.e. if the left hand is more skilled than the right and vice versa), quantifying handedness through one of a number of handedness questionnaires or inventories or simply classifying handedness through the hand that is used to write with. There are a number of advantages and disadvantages for using each method of classification and these were discussed in Chapter 3. However, in the current studies handedness was classified using a handedness inventory (and adapted version of Peters (1998) questionnaire that also covered Annett's (1970) handedness questionnaire and the Edinburgh Handedness Inventory (Oldfield, 1971). The problem with using the handedness inventory was that participants who agreed to participate in the experiments and gave their hand preference as left-handed were not always true left-handers. In a number of cases these 'left-handed' participants wrote with their left hands but predominantly did most other actions with their right hands (reasons for this are discussed again in Chapter 3) and therefore their data could not be analysed due to the inconsistency of their hand preferences. This was also a contributing factor in the reduced number of potentially available left-handed participants. The opposite pattern where someone wrote with the right hand but were classified as left-handed on the handedness questionnaire only occurred once over 5 separate studies and similarly to the cases of the left-handers, their data could not be analysed.

In order to take these participants in to consideration a third handedness category would have to be created which would include mixed-handers. Mixed-handers would include those who had been forced to change their hand preferences at a younger age (and therefore probably still did a number of actions with what used to be their dominant hand) and also those who scored a left-handed or right-handed score on the questionnaire when they claimed to prefer the opposite hand. However, in order to carry this out a much larger sample size would have to be used. If there was the time to collect such a large sample and the availability of potential participants to create this sample then the left-handed and right-handed groups used in my studies could be further divided in to a group of strong or consistent left- and right-handers (who use their left or right hands to do everything) and a group of moderate left- and right-handers (similar to those in Annett's (1998) example). A group of left mixed-handers and right mixed-handers would also be recruited where left-mixed-handers would consist of those who wrote with their left hands but did most other things with their right hands and right-mixed-handers would be the opposite (write with their right hands but do most other things with their left hands). Additionally left-mixed – handers could also be those who were forced to change their handedness from left-handedness to right-handedness (as they would still perform a number of actions with their left hands and only the actions on which they received pressure to change would have switched – such as writing). Porac, Coren and Searleman (1986) stated that "even with direct intervention and harsh social pressure, only a small percentage of individuals successfully switch handedness. Those who do, often remain left-handed except for that small subset of activities that received direct pressure to change" (p. 255). It is unlikely that any participants would be mixed-right-handers if this classification system were adopted (i.e. being forced to change from the right hand to use the left hand). Once again as stated above it would be difficult and extremely time consuming to be able to recruit participants who were well represented in each of the 6 categories outlined above. For example it would be very difficult to recruit a sufficient number of participants who had been forced to change their hand preference – particularly among the available group of University staff and students. Previous unpublished work (honours project) found that out of a sample of 253 participants that only 13 people had been forced to change their hand preference and therefore it would be difficult to find around 40 or 50 people who had been forced to change. In order to be able to recruit such a sample, a database of potential participants would have to be created over a period of time and also external to the university in order to amass adequate numbers in each category to be able to examine differences between strong, moderate and mixed left- and right-handers.

8.3. Current pilot studies and future research

8.3.1. Current pilot research

The final study examined (ToH study in Chapter 7) issues of anxiety along with task complexity and novelty. It appeared that task complexity did not significantly effect state anxiety levels in that the group who did the 4-disk Tower of Hanoi first did not have higher state anxiety levels on average than the group who did the 3-disk Tower of Hanoi first. Task complexity was also examined in one of the conditions of this study (the 3-disk followed by the 4-disk condition) and it was found that state anxiety levels were higher, on average, both overall and with respect to sex and handedness groups before participants completed the 3-disk Tower of Hanoi (the first and novel task) than they were before completing the 4-disk Tower of Hanoi (which was the second and therefore not a novel task). The other condition (the 4-disk ToH followed by the same task as a second trial) examined task novelty with respect to state anxiety levels. It was found that there was no clear effect of task novelty on state anxiety scores. However, when all conditions were examined it was found that task complexity appeared to have an inverse effect on state scores of left-handers in that left-handers reported themselves to be more anxious when presented with an easier task than a more complex task. This finding needs to be investigated further and pilot studies are currently being carried out using the Tower of Hanoi and the Tower of London (Shallice, 1982) in order to compare firstly, responses to a novel task and secondly whether task complexity affects state anxiety scores (again with respect to the novelty of the task). These tasks and their preliminary findings are outlined in sections 2 and 3 below.

1. Handedness, novel problem solving and stress.

This task was designed in order to examine problem-solving and response behaviour towards a novel task. State anxiety scores were recorded before participants undertook the task in order to examine any potential handedness differences and also to examine whether state scores correlated with the time taken to make the first response. This idea combined many of the findings outlined in the section above and the main emphasis was put on the time taken to move the first piece of the puzzle and its relationship to the state anxiety scores. Participants were asked to fill in the state anxiety questionnaire before they under-took the task but had read the instructions for the task before completing this questionnaire. Additional details of the task are outlined below.

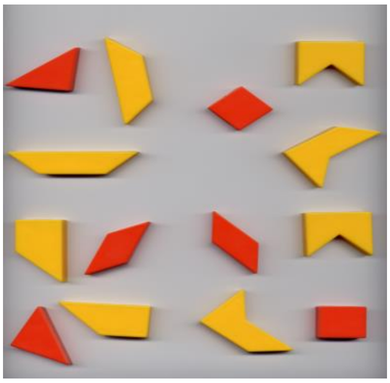


Figure 8.1: Arrangement of the pieces of the puzzle before participants begin (initial state)

Figure 8.2: Picture of the completed task (goal state)

This study examines handedness and anxiety levels in response to a novel task. 30 left-handed and 30 right-handed participants completed the state anxiety questionnaire (Speilberger, 1983) before solving a novel problem (a shape sorting problem in which 14 red and yellow pieces could be arranged and fitted together to form the shape of a Chihuahua as seen in figures 8.1 and 8.2 above). The time taken to move the first piece of the puzzle was recorded and a maximum of 10 minutes was given to each participant in which to solve the puzzle before a time out rule was used. Therefore, although completion times were recorded for those who successfully solved the puzzle these were not analysed due to the incomplete set of data for those who ‘timed-out’.

Alongside the time taken to move the first piece of the puzzle the state anxiety score of each participant was recorded using the Speilberger state anxiety questionnaire (Speilberger, 1983). A note of the order in which the participant moved each piece of the puzzle (as seen in figure 8.1 above) in order to examine whether there was a side bias pattern emerging when participants solved the puzzle was also recorded. Participants finally completed the trait questionnaire of the State Trait Anxiety Questionnaire (Speilberger, 1983). It was hypothesised that state anxiety levels would be significantly higher in left-handers than in right-handers when performing a novel task and that left-handers would take longer to move the first piece of the puzzle than right-handers.

The main components that were analysed were the time taken to move the first piece of the puzzle and the order that they pieces were chosen in. All of the pieces of the puzzle were laid out in the same order for each participant and the side favoured by the participant was recorded. Each piece was numbered on the board so that the experimenter could keep track of the order that the pieces were moved in. A bias of left or right was noted (as determined by the choice of the first piece) in order to see if there was any pattern of side bias by left- and right-handers.

Preliminary analyses has shown that there was a significant effect of hand preference on the time taken to move the first piece of the puzzle where left-handers took significantly longer to respond than right-handers. However, there was no evidence of side bias in the preliminary analysis except for left-handed males who had a bias for choosing the first piece from the left side. Additionally, there were no reported differences between left- and right-handers' state anxiety scores when the preliminary analysis was carried out.

Tower of Hanoi, novelty and complexity

The main aim of this study is to further investigate self-reported anxiety in left- and right-handers when faced with a novel problem, and more specifically when faced with varying levels of complexity of a novel problem (do the anxiety levels increase as the task complexity increases?). The second aim of this study is to examine the time taken to respond to the novel problem. It is thought that if planning is a factor in the potential delay before responding to a novel problem then by increasing the complexity of the problem the initial delay should be longer to allow participants to come up with an effective solution.

The novel problem in this research is the Tower of Hanoi. Participants are presented over three experimental sessions with the 3-, 4- or 5-disk version (the order of this is counterbalanced) and are given a set of instructions explaining what they have to do and outlining the rules of the Tower of Hanoi. Before solving the Tower of Hanoi participants are asked to complete the state questionnaire of the STAI (Spielberger, 1983) to report how they are feeling (the level of anxiety) at that moment before they solve the Tower of Hanoi (in each of the three experimental sessions). Timing starts from the moment the Tower of Hanoi is revealed and the time taken to move/touch the first disk is recorded along with the number of moves taken to solve the Tower and the total time taken to solve it. Each experimental session is video recorded in order to check the reliability of the timings and the number of moves made.

It is predicted that if it is stress/anxiety that is playing a part in the delay of the initial response then the task complexity will also affect this (the more complex the task then the more stressed/anxious the participant will be). Alternatively, if it is planning that is happening during the initial response time then the time before initial response should be longer as the problem is more complex (to allow the problem to be effectively solved). Some may argue that the Tower of Hanoi will not be a novel problem after the first experimental trial. However, as the three trials consist of a different number of disks on each trial and for each number of disks there are a set number of optimal moves and a specific starting peg to achieve this then each problem should be treated as a novel one. In fact, not treating the problem as novel will cause the participant to solve it in a less effective manner if they try to learn from a prior trial of the Tower of Hanoi.

Preliminary analysis has shown that there is no effect of handedness or task complexity on state anxiety scores. This suggests that the complexity of the task does not affect anxiety levels. However, preliminary mean scores show that left-handers report a higher mean state score on the 3-disk Tower of Hanoi but not on the 4- or 5-disk Tower of Hanoi. Again, although the study is ongoing the pattern tends to suggest an interaction between task complexity (and more specifically simplicity) and handedness.

With respect to initiation time preliminary analysis shows that there is no effect of handedness or task complexity.

Tower of London and task complexity

The novel task used is the Tower of London. Behavioural style shown towards the Tower of London will be examined in left- and right-handers. The time taken by participants to begin, the number of moves taken to solve and complete the task, in relation to sex, hand preference and task complexity will be measured. An additional factor that will be examined is task complexity and thus each participant is presented with two different ToL problems (one difficult and one easy – see figures 8.4. and 8.5. below for examples). Based on previous findings it is hypothesised that greater avoidance or inhibitory behaviour will be observed in left-handed participants, which will increase with task complexity, demonstrated by an increased time taken to begin the task. Any evidence of pre-planning will be examined and future work related to this study will video the participants in order to analyse their performances and study their behaviour in more detail. In addition a reflective questionnaire is given to participants in order to gain an insight in to their feelings and approaches towards the Tower of London.

A preliminary 2 X 2 X 2 mixed model ANOVA (sex; handedness and complexity level) showed that there was no significant effect of task complexity on the time taken to move the first ball. There was no significant effect of handedness on the time taken to move the first ball of the task and no main effect of sex on the time taken to move the first ball. These findings were analysed further by examining each complexity group individually. There was no significant effect of handedness on the time taken to move the first ball of the Tower of London when the first trial was the easy version and there was no significant main effect of handedness when the first trial was the difficult version. However, left-handers took longer to start the both the easy trial and the difficult trial than right-handers (9.5 vs. 6 seconds respectively for the easy trial and 8.1 vs. 6.1 seconds respectively for the difficult trial). Preliminary analysis also revealed that there were no other significant effects of handedness (for example on the time taken to solve the tasks). However, this study is ongoing and therefore results may change.

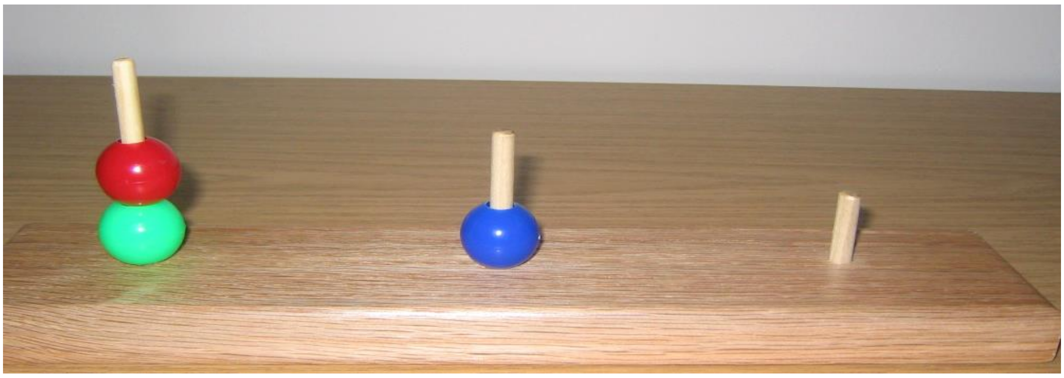


Figure 8.3: Starting position of the TOL

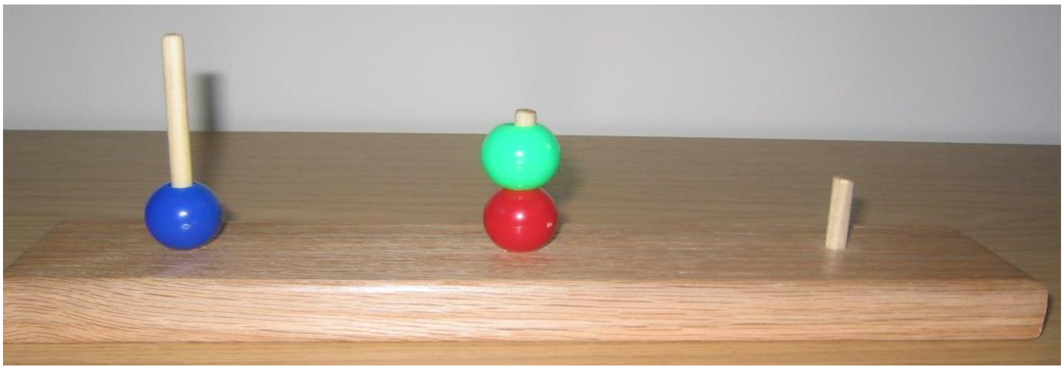


Figure 8.4: Easy TOL problem (goal state)

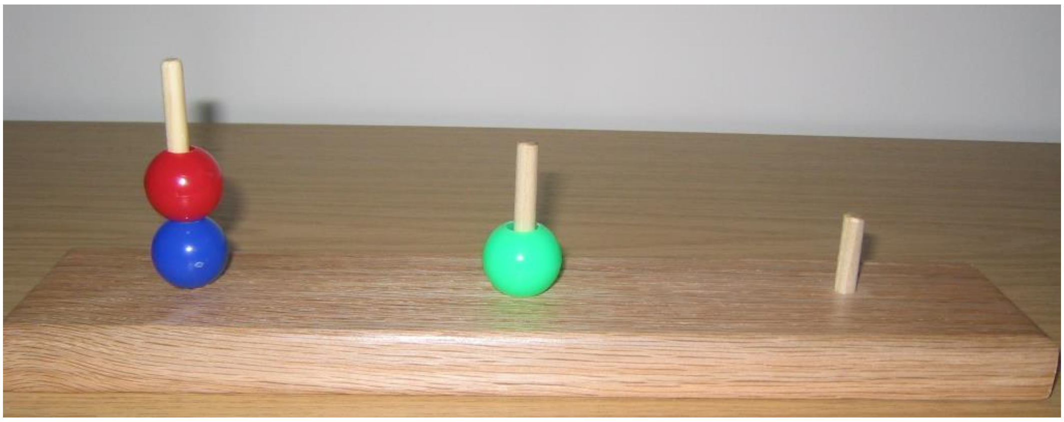


Figure 8.5: Difficult TOL problem (goal state)

2. Follow up manual sorting task

This experiment replicates the previous manual sorting task procedure outlined in Chapter 6 but uses a different set of sorting cards (see Figure 8.6 below). The basic procedure requires participants to move 20 labelled cards containing different sports into 4 different categories each with 5 cards in it. Each of the groups had to have a separate rule decided by the participant that describes the category (for example it might be that all the sports in one category are played with a ball). The time taken by participants to respond (or move the first card) is recorded, as well as the time taken to complete the entire task. It is hypothesised in line with the previous manual sorting task that left-handers will take longer to begin the task than right-handers, but there will be no difference in the time taken to complete the task overall between left- and right-handers. In addition to the manual sorting task and as an extension of the original manual-sorting task the experiment also measures the state anxiety levels of participants before solving the sorting task (using the STAI, Speilberger, 1983) and trait anxiety levels at the end of the experiment. It is predicted that there will be a difference in state anxiety scores between left-handers and right-handers (with increased scores being shown by left-handers) but no difference in trait anxiety scores between the two groups.

Preliminary analysis showed that there was a significant main effect of handedness on the time taken to move the first card (p=0.028 1-tailed) with left-handers taking significantly longer than right-handers (with a mean initiation time of 12.6 seconds vs. 7 seconds respectively). There was a significant main effect of handedness on state anxiety scores (before completing the task) (p=0.034). However, this finding was in the opposite direction than what was expected with right-handers reporting themselves to be significantly more anxious than left-handers (mean state anxiety scores of 42.5 vs. 38.1 respectively). There were no other significant main effects of handedness on this task, however, right-handers reported themselves to be more anxious than left-handers after the task (35.1 vs. 39.5); left-handers solved the task faster than right-handers overall (including the time taken to start) (mean time of 107.1 seconds vs. 126.9 seconds) and left-handers took less time to solve the task when the start time was not included than right-handers (mean time of 94.5 seconds vs. 108.91 seconds). There were no significant main effects of sex and there were no significant interactions on any of the dependent variables measured. Thus, it appears that the delay taken by left-handers to start the task is supported here as was reported on the sorting task in Chapter 6. However, the explanation that it may be caused by an increased anxiety levels in left-handers is not supported. However, data for this study is still being collected and thus these results may change.

Figure 8.6: Two examples of the 20 sports cards used in the manual-sorting task

8.3.2. Future studies

In order to follow up, investigate further and extend many of the findings that have been reported during the course of this thesis a number of future studies are proposed here.

Firstly, the current studies in this thesis have predominantly been carried out with students (and a few staff members) from UAD. However, future studies will examine potential response style differences firstly between left- and right-handed older adults (possibly using the 3-disk Tower of Hanoi again) to see if the same delay is repeated in this age group. One important point that has to be taken in to consideration, however, is the limited numbers of left-handed older adult participants. Many older adults in our society were still subjected to pressures to switch their hand preferences and thus it is difficult to ascertain the number of available left-handed participants among this age group. Additionally, future studies will also examine potential differences in response styles between left- and right-handed children. Possible tasks that will be used to investigate this will be the Tower of London. It is proposed to use the Tower of London rather than the Tower of Hanoi as a simpler task can be presented to a child using the Tower of London (for example, a task that requires only 4 moves). However, only children of around 6 years and over will be permitted to participate in this study in order for a reliable measurement of handedness to be recorded. Children under the age of 6 years may still swap their hand preferences and therefore will not be included in this study. Mataix-Cols and Bart́ès-Faz (2002) stated that 10-year-old children were able to perform the 3-disk Tower of Hanoi easily and thus a potential future study using children to solve the Tower of Hanoi would be carried out with children of this age or above. An additional task that might also be used in order to investigate response style differences in children is a variant of the manual sorting task where fewer cards would be used but the same rules would still apply. Thus, these studies would allow us to investigate potential response style differences between left- and right-handers across the lifespan.

Other future studies that are planned include further investigations of the reasons proposed during the course of the thesis for why the delay in initial response towards a novel task by left-handers is occurring. These studies include potential brain scanning work which would involve presenting participants with problem solving tasks and scanning their brains while they solved the task. This would allow us to investigate the regions that are activated particularly during the time before they make their first responses to the tasks. This would allow us to gain more of an insight into which regions of the brain of participants are activated and whether these differ across handedness groups. More specifically, this would also allow us to investigate potential planning explanations that were inconclusive from the studies carried out during the course of this thesis. In conjunction with this a series of planning studies are also intended where participants will be instructed to plan before they solve the task in order to see if this alters the performances between left- and right-handers. These findings will be contrasted with the performances and response behaviours of participants who will be allowed to approach the task in any way they choose. Participants who will be instructed to plan will be asked to verbalise their plans in order to examine any potential differences either in the actual planning or in the time taken to plan.

An additional planning study will involve a problem-solving task such as the one used in section 8.3.1, number 1. In this study participants will be instructed to solve the problem but will not be given specific instructions about the approach that they should take (and therefore will not be specifically instructed to plan). Once participants begin to solve the puzzle a stopwatch will be started and when participants make their first move on the apparatus they will be asked to stop and the stopwatch will be stopped. If a delay is observed between the starting time and the first move time, participants will be asked to describe what they were doing or thinking during that time. However, if no delay is observed then participants will still be stopped upon their first move and asked about their strategy (if they had one).

Another variation of the sorting task will also be carried out but instead of participants being faced with all of the cards set out in front of them (but concealed) participants will be given the cards in a pile and face down in order to see how they sort out the cards. The reason for this is to see if there appears to be a different approach between left- and right-handers. Although this variation would not give us an as obvious clear first move time it would allow us to see exactly how the participants would organise themselves to solve the task. However, a first move time could still be recorded as a board would be given to place the cards in the categories on and thus the first move would be counted as the first card to be placed on the board. It would be expected that if there is any evidence of more planning or anxiety in left-handers then they would go through all of the cards before placing their first card on the board. Conversely, if there were a lack of planning or lower levels of anxiety in right-handers then it would be expected that they would place their first card on the board quicker and would not necessarily go through the whole pack of cards before making their first response.

As well as further investigations of planning, further investigations of anxiety in response to novel problem solving tasks will be carried out. So far only self-report measurements of anxiety have been reported, however, in order to examine this explanation further physiological measurements will be assessed. Blood pressure measurements and pulse rate data were taken as part of the Tower of Hanoi, novelty and complexity study (see section on pilot studies (2) above) however; results are not available at this time. Further physiological measurements will be investigated such as galvanic skin response in order to investigate stress levels before undertaking a problem-solving task. Levels of the stress hormone cortisol may also be investigated in future work as Westergaard, Chavanne, Lussier, Houser, Cleveland, Suomi and Higley (2003) have reported that there is a significant positive correlation between levels of cortisol and left-handedness. However, this process will be both difficult and costly to set up and therefore it might not be carried out in the near future.

Leading on from these studies the issue of task novelty will be investigated further. Task novelty was examined in Chapter 7 but only with respect to the Tower of Hanoi in order to investigate whether doing a task for the second time would affect anxiety levels and the way in which participants responded to it. Cameron and Rogers (1999) and Hopkins and Bennett (1994) stated that the novelty of the task was an important factor in influencing the response styles in the left- and right-handed primates. However, one important factor in Cameron and Roger's findings was that the task involved the participants being rewarded for successfully solving the problem. In order to investigate task novelty further it may be beneficial to impose some form of reward in to the problem and thus successful solution of the task would result in participants being rewarded. Therefore this might result in a different or more thoughtful approach to the task by the participants or alternatively if anxiety is influencing the response behaviour of the left-handed participants then this might increase their anxiety levels further due to the added pressure of successfully solving the task and thus obtaining the reward. In order to examine this further more ‘real life’ scenarios would perhaps have to be introduced in order to see a more ‘natural’ response from participants.

Differences in approaches to studying between left- and right-handers will also be investigated. If increased levels of anxiety are prevalent in left-handers then it is possible that left-handers might be disadvantaged in stressful situations such as exams. Therefore a study will be designed in order to investigate whether higher anxiety levels in left-handers is a disadvantage in exams compared to right-handers. Alternative methods of assessment will be investigated with respect to performance and also anxiety levels between left- and right-handers. These alternative methods will include poster presentations, oral presentations and coursework based assessments in order to see if left-handers are detrimentally affected by this kind of assessment or if there is no real difference between the performance and anxiety levels of left- and right-handers on such tasks. Additionally, different anxiety questionnaires will also be used in order to see if different questionnaires result in different or consistent findings.

Although task novelty has been, and will be, investigated fairly extensively an additional factor that also needs to be investigated is not task complexity but task simplicity. It has been found both in the Tower of Hanoi study in Chapter 7 and in the Tower of London pilot study that it seems to be the simpler of the two tasks that induced higher levels of state anxiety among left-handers (in the ToH study) and significantly longer initiation times in left-handers than in right-handers (in the ToL study). Therefore it appears that the simplicity of the task is perhaps having an effect on the response styles of the left- and right-handers. More specifically, it appears that the simplicity of the task is affecting the anxiety levels of the left-handers because they possibly feel pressured, as they should be able to easily solve these tasks and are therefore afraid of the failure. Therefore, when task simplicity is investigated in future studies a questionnaire will be devised (similar to the questionnaire completed after the ToL) in order to collect the feelings and attitudes of the participants after completing a relatively simple task. Additionally, further tasks of the Tower of Hanoi can be carried out to investigate this. For example, the task in Chapter 7 looks at the 3-disk task and then the 4-disk or the 4-disk task followed by the same 4-disk task. If task simplicity was being investigated then useful data would be collected from carrying out the 3-disk Tower of Hanoi twice in order to see how participants approach the relatively simple task for a second time (thus we would see if doing an easy task for a second time decreased anxiety levels among left-handed participants). In the same vain a complete set of data could be collected by carrying out the 4-disk Tower of Hanoi followed by the 3-disk Tower of Hanoi as the secondary task. Thus, if task novelty increased state anxiety levels then it would be expected that state anxiety scores would be similar in the first Tower of Hanoi trial regardless of the complexity of the task. However, if task complexity was more important in affecting state anxiety levels then it would be expected that the 4-disk condition would result in higher state scores and this was not the case and therefore issues of task simplicity need to be investigated.

One thing to add was that the manual tasks used during this thesis all had a spatial component to them. This might have had an effect on the overall completion or the solving of the task as left-handers and males are said to have a superior spatial ability. However, this type of task would not effect the response style behaviour in that being a spatial task would not have an effect on how long it took a participant to make their first move or response. A series of computerised tasks were designed in addition to the manual tasks in order to remove some of the possible spatial biases, however, it was found that there was very little difference in the response behaviour of left- and right-handers on computerised tasks and this was explained due to the fact that most computerised tasks are collecting reaction time data and therefore this might have biased the responding towards reacting as quickly as they could.

One future task that will be carried out in order to address the problems with the spatial elements of the tasks and also the possible biases in responding on a computerised task is a variant of the manual sorting task. Instead of having a series of cards with pictures and words on them the cards would just contain words and instead of manually moving the cards around in to potential categories, participants would be asked to verbalise their solution in order to remove the spatial part. The reason that only words would be used rather than pictures is to remove the visual aspect of the task.

Finally, as previously outlined during the limitations section of this chapter the analysis of the hand preferences of participants throughout this thesis was limited purely to left-hand preference and right-hand preference. This was due to the lack of left-handers willing to take part in the experiments in the time available. However, future studies will examine a group of participants who are often neglected in the handedness literature – mixed-handers. Data from mixed-handers are most often cited in research that looks at schizophrenia or language impairments (See chapter 2 for a discussion). Therefore it would be important to collect a large enough sample to at least include a third handedness group and therefore have a group of strong left-handers, a group of strong right-handers and a group of mixed-handers. Therefore this sample would allow us to gain an insight in to the response style behaviours of mixed-handers to see if there are any similarities or differences in both behaviour and temperament of this group compared with left- and right-handers.

8.4. Summary of major findings

This thesis explored differences in response styles between left- and right-handed individuals. This was based upon the evidence from comparative studies that found that left-handed primates took longer to approach novel objects than right-handed primates. Therefore a series of experiments were conducted to investigate these potential response style differences in humans. The first experiment (reported in Chapter 4) investigated the approach behaviour of left- and right-handers towards a novel problem-solving task (the 3-disk Tower of Hanoi) and it was found that left-handers took significantly longer to start the task than right-handers, it was also found that left-handers solved the task in significantly fewer moves than right-handers and that in general left-handers solved the task faster than right-handers (although this difference only approached significance). Therefore as there was evidence of a response style difference in humans, potential explanations were given for why this might be occurring. Comparative research had reported that there might be a difference in the emotional processing of left- and right-handed primates linked to the dominant hemispheres and therefore influencing the approach and avoidance behaviour of these animals. Also, the comparative literature reported that there might be a difference in the stress or anxiety levels of left- and right-handed primates which could influence how they approach or react to a novel object or task. In addition to this because the results of experiment 1 in this thesis suggested that left-handers were performing better on the task than right-handers (in that they completed it faster and in fewer moves) then a final potential explanation that left-handers might be planning out their solution to the task before starting it was proposed. These 3 possible explanations were explored through a series of experimental studies in this thesis.

In order to investigate further response styles towards a novel task a manual sorting task was carried out (experiment 4 – see Chapter 6, section 6.3.). It was found that left-handers took significantly longer to start the task than right-handers but they did not complete the task any faster than right-handers which did not support the idea that participants were perhaps planning a solution before they moved the first card. In order to investigate emotional processing in left- and right-handers an emotion discrimination task was carried out (see experiment 3, Chapter 5, section 5.4.) but no clear effects were found and results suggested that participants were able to distinguish positive emotions more accurately than negative emotions. Additionally, females showed evidence of the valence specific effect but males did not. These findings suggest that there is no clear difference in discriminating emotions with respect to the valence and the side presented between left- and right-handers. However, perhaps this task did not effectively investigate emotional processing with respect to hemispheric dominance and approach and avoidance behaviour and therefore this would need to be investigated further.

Tasks that were designed to investigate the planning explanation showed very little evidence that this was occurring. For example, the Fastest Finger First task (experiment 5, see Chapter 6, section 6.7.) did not reveal either a difference in the time taken to respond to the questions or a more effective solution.

Finally, a number of tasks were carried out to investigate the possibility that there might be a difference between the anxiety levels of left- and right-handers. When the state and trait questionnaires of the State Trait Anxiety Inventory (Speilberger, 1983) were given results revealed that left-handers reported themselves to feel significantly more anxious than right-handers at that specific moment in time (after completing the state questionnaire) but completion of the trait questionnaire (asking how the participant felt in general) revealed that there was no difference in anxiety scores between left- and right-handers (see experiment 7, Chapter 7, section 7.4). The idea of anxiety and inhibitory behaviour was investigated further (see experiment 8, Chapter 7, section 7.6.) using the BIS BAS Scale (Carver & White, 1994) and results revealed that there was no difference between left- and right-handers on their behavioural activation scores, however, left-handers reported themselves to be significantly more inhibited (on the BIS scale) than right-handers. Finally, all of the previously investigated ideas were combined to investigate the issues of anxiety, novelty and task complexity using the Tower of Hanoi task (both the 3-disk version and the 4-disk version). See experiment 9, Chapter 7, section 7.10. for details of this. Results showed that there was no difference between left- and right-handers on the time taken to make the first move on the 3-disk or 4-disk Tower of Hanoi. This was also found for the number of moves taken to complete the task and the time taken to complete it. However, left-handers reported themselves to be significantly more anxious than right-handers before completing the 3-disk Tower of Hanoi but there was no difference between left- and right-handers' state anxiety scores before completing the 4-disk Tower of Hanoi (when both tasks were novel). These findings suggest that task novelty and task complexity might contribute towards the anxiety levels of left- and right-handers but these issues would need to be investigated in much more depth.

8.5. Overall conclusion

Therefore, response style differences have been reported in non-human primates and human parallels carried out during the course of this thesis have revealed that these differences were also found. However, although the differences in response styles between left- and right-handed non-human primates have been explained through differences in hemispheric dominance related to approach and avoidance behaviour and/or increased anxiety in left-handers the explanation for these differences in humans is not so straightforward. The results of the experiments carried out in this thesis suggest that increased state anxiety levels or more inhibited responses by left-handers perhaps influence differences in response styles. However, this explanation alone does not clearly explain the results found during the thesis and important factors such as task novelty and task complexity also had to be considered. It was found that novel tasks tended to increase the state anxiety levels of left-handers significantly more than right-handers and therefore the novelty of the task may affect the individual's response style. Additionally, a complex (and novel) task tended to affect left- and right-handers similarly, however, a more simplistic (and also novel) task tended to make left-handers more anxious than right-handers and therefore more research needs to be done to investigate task simplicity and anxiety. When these complex tasks were not novel there was no difference between the state anxiety scores of left- and right-handers. Thus, although a number of factors appear to be contributing towards the response style differences between left- and right-handers the clearest explanation that can be given at this point of this research program is that the response of left-handers is influenced by high levels of state anxiety which themselves are influenced by the novelty, and perhaps the simplicity, of the task. These explanations will be developed and investigated further in the future.

References

Adolphs R., Damasio H.,Tranel D., & Damasio A. R. (1996). Cortical systems for the recognition of emotion in facial expressions. *Journal of Neuroscience, 16*, 7678-7687.

Ahern, G. L., & Schwartz, G. E. (1979). Differential lateralization for positive versus negative emotions. *Neuropsychologia, 17*, 693-697.

Ahern, G. L., & Schwartz, G. E. (1985). Differential lateralization for positive and negative emotions in the human brain: EEG spectral analysis. *Neuropsychologia, 23*, 745-755.

Ajersch, M. K. & Milner, B. (1983). Handwriting posture as related to cerebral speech lateralisation, sex and writing hand. *Human Neurobiology, 2*, 143-145.

Amunts, K., Jäncke, L., Mohlberg, H., Steinmetz, H., & Zilles, K. (2000). Interhemispheric asymmetry of the human motor cortex related to handedness and gender. *Neuropsychologia, 38* (3), 304-312.

Amunts, K., Schlaug, G., Schleicher, A., Steinmetz, H., Dabringhaus, A., Roland, P. E., & Zilles, K. (1996). Asymmetry in the human motor cortex and handedness. *Neuroimage, 4*, 216-222.

Anderson, P., Anderson, V., & Lajoie, G. (1996). The Tower of London test: Validation and standardization for pediatric populations. *The Clinical Neuropsychologist, 10* (1), 54-65.

Andrew, R. J. (1988). The development of visual lateralization in the domestic chick. *Behavioural Brain Research, 29*, 201-209.

Andrew, R. J. (1991). The nature of behavioural lateralisation in the chick. In R. J. Andrew (Ed.), *Neural and behavioural plasticity: The use of the domestic chick as a model* (pp. 536-554). Oxford, UK: Oxford University Press.

Andrew, R.J., & Rogers L.J. (2002). The nature of lateralization in tetrapods. In L.J. Rogers, & R.J. Andrew (Eds.), *Comparative Vertebrate Lateralization* (pp. 94-125). Cambridge, UK: Cambridge University Press.

Annett, M. (1964). A model of inheritance and cerebral dominance. *Nature*, 204, 59-60.

Annett, M. (1967). The binomial distribution of right, mixed and left-handedness. *Quarterly Journal of Experimental Psychology, 19*, 327-333.

Annett, M. (1970). A classification of hand preference by association analysis. *British Journal of Psychology, 61*, 303-321.

Annett, M. (1972). The distribution of manual asymmetry. *British Journal of Psychology, 63*, 43-358.

Annett, M. (1976). A coordination of hand preference and hand skill replicated. *British Journal of Psychology, 67*, 587-592.

Annett, M. (1978). Genetic and nongenetic influences on handedness. *Behavior Genetics, 8*, 227-249.

Annett, M. (1983). Hand preference and skill in 115 children of two left-handed parents. *British Journal of Psychology, 74*, 17-32.

Annett, M. (1985). *Left, right, hand and brain: the right shift theory*. Hillsdale, NJ: Lawrence Erlbaum Associates.

Annett, M. (1992). Spatial ability in subgroups of left and right-handers. *British Journal of Psychology, 83,* 493-515.

Annett, M. (1994). Handedness as a continuous variable with dextral shift: Sex, generation and family handedness in subgroups of left- and right-handers. *Behavior Genetics, 24*, 51-63.

Annett, M. (1995). The right shift theory of a genetic balanced polymorphism for cerebral dominance and cognitive processing. *Current Psychology of Cognition, 14*, 427-480.

Annett, M. (1998a). The stability of handedness. In Connolly K. J. (Ed.), *The Psychobiology of the Hand. Clinics in Developmental Medicine No. 147* (pp. 63-76)*.* London: Mac Keith Press.

Annett, M. (1998b). Handedness and cerebral dominance: The right shift theory. *Journal of Neuropsychiatry, 10* (4), 459-469.

Annett, M. (2002). *Handedness and brain asymmetry: The right shift theory*. Hove, UK: Psychology Press.

Annett, M. (2003). Cerebral asymmetry in twins: predictions of the right shift theory. *Neuropsychologia, 41* (4), 469-479.

Annett, M., & Annett, J. (1991). Handedness for feeding in gorillas. *Cortex, 17*, 269-276.

Annett, M., & Kilshaw, D. (1983). Right- and left-hand skill II: Estimating the parameters of the distribution of L-R differences in males and females. *British Journal of Psychology, 74*, 269-283.

Annett, M., & Manning, M. (1989). The disadvantages of dextrality for intelligence. *British Journal of Psychology, 80*, 213–226.

Annett, M., & Manning, M. (1990). Arithmetic and laterality. *Neuropsychologia, 28* (1), 61-69.

Annett, M., Hudson, P. T. W., & Turner, A. (1974). The reliability of differences between the hands in motor skill. *Neuropsychologia, 12*, 527-531.

Asthana, H. S., & Mandal, M. K. (2001). Visual-field bias in the judgment of facial expression of emotion. *Journal of General Psychology, 128* (1), 21-29.

Bailey, L. M., & McKeever, W. F. (2004). A large-scale study of handedness and pregnancy/birth risk events: Implications for genetic theories of handedness. *Laterality, 9* (2), 175-188.

Bakan, P. (1971). Handedness and birth order. *Nature, 229*, 195.

Bakan, P. (1977). Left-handedness and birth order revisited. *Neuropsychologia, 15* (6), 837-839.

Bakan, P., Dibb, G., & Reed, P. (1973). Handedness and birth stress. *Neuropsychologia, 11*, 363-366.

Baker, S. C., Rogers, R. D., Owen, A. M., Frith, C. D., Dolan, R. J., Frackowiak, R. S. J., & Robbins, T. W. (1996). Neural systems engaged by planning: A pet study of the Tower of London task. *Neuropsychologia. 34* (6), 513-526.

Bard, K.A., Hopkins, W .D., & Fort, C.L. (1990). Lateral bias in infant chimpanzees *(Pan troglodytes). Journal of Comparative Psychology, 104*, 309-321.

Barratt, E. S. (1983). The biological basis of impulsiveness: The significance of timing and rhythm disorders. *Personality and Individual Differences, 4* (4), 387-391.

Barratt, E. S. (1985). Impulsiveness defined within a systems model of personality. In C.D.B. Spielberger, & J. N. Butcher (Eds.), *Advances in personality assessment* (5th ed.) (pp 113-131). New Jersey: Lawrence Erlbaum Associates.

Barsley, M. (1970). *Left-handed man in a right-handed world*. London: Pitman.

Barthelemy, S., & Boulinguez, P. (2001). Manual reaction time asymmetries in human subjects: The role of movement planning and attention. *Neuroscience Letters, 315 (*1-2), 41-44.

Bauer, R. H. (1993). Lateralization of neural control for vocalization by the frog (*Rana pipiens*). *Psychobiology, 21*, 243-248.

Beaton, A. A., & Moseley, L. G. (1984). Anxiety and the measurement of handedness. *British Journal of Psychology, 75*, 275-278.

Beaton, A. A., & Moseley, L.G. (1991). Hand preference scores and completion of questionnaires: Another look. *British Journal of Psychology, 82* (4), 521.

Benbow, C. P. (1986). Physiological correlates of extreme intellectual precocity. *Neuropsychologia, 24*, 719–725.

Bennett, G. K., Seashore, H. G., & Wesman, A. G. (1975). Differential Aptitude Test (Form S) – British Edition. Berks, UK: NFER Publishing Co ltd.

Bisazza, A., Cantalupo, C., Robins, A., Rogers, L. J., & Vallortigara, G. (1997). Pawedness and motor asymmetries in toads. *Laterality, 2* (1), 49-64.

Bisazza, A., Rogers, L. J., & Vallortigara, G. (1998). The origins of cerebral asymmetry: a review of evidence of behavioural and brain lateralization in fishes, amphibians and reptiles. *Neuroscience and Biobehavioral Reviews, 22*, 411-426.

Bishop, D. V. M. (1984). Using nonpreferred hand skill to investigate pathological left-handedness in an unselected population. *Developmental Medicine and Child Neurology, 26*, 214-226.

Bishop, D. V. M. (1989). Does hand proficiency determine hand preference? *British Journal of Psychology, 80*, 191-199.

Bishop, D. V. M. (1990). *Handedness and developmental disorder*. Hove, UK: Lawrence Erlbaum Associates.

Bishop, D. V. M., Aamodt-Leeper, G., Creswell, C., McGurk, R., & Skuse, D. H. (2001). Individual differences in cognitive planning on the Tower of Hanoi task: Neuropsychological maturity or measurement error? *Journal of Child Psychology and Psychiatry. 42* (4), 551-556.

Bishop, D. V. M., Ross, V., Daniels, M.S., & Bright, P. (1996). The measurement of hand preference: A validation study comparing three groups of right-handers. *British Journal of Psychology, 87*, 269-285

Boesch, C. (1991). Handedness in wild chimpanzees. *International Journal of Primatology, 12*, 541-558.

Boklage, C. E., (1981). On the distribution of non-right-handedness that this study should settle the unending nature – nurture among twins and their families. *Acta Genetica Med Gemellol, 30*, 167–187.

Borod, J. C. (1993). Cerebral mechanisms underlying facial, prosodic, and lexical emotional expression: A review of neuropsychological studies and methodological issues. *Neuropsychology, 7*, 445-463.

Borod, J. C., Caron, H. S., & Koff, E. (1984). Left-handers and right-handers compared on performance and preference measures of lateral dominance. *British Journal of Psychology, 75*, 177-186.

Borod, J. C., Koff, E., Perlman-Lorch, M., & Nicholas, M. (1986). Expression and perception of facial emotion in brain-damaged patients. *Neuropsychologia, 24*, 169-177.

Bourassa, D. C., McManus, I. C., & Bryden, M.P. (1996). Handedness and eye-dominance: A meta-analysis of their relationship. *Laterality, 1*, 5-34.

Bradshaw, J. L. (1989). *Hemispheric specialization and psychological function*. Oxford, UK: John Wiley and Sons.

Bradshaw, J. L., & Taylor, M. J. (1979). A word naming deficit in non-familial sinistrals? Laterality effects of vocal responses to tachistoscopically presented letter strings. *Neuropsychologia, 17*, 21-32.

Bradshaw, J.L., & Rogers, L.J. (1993). *The evolution of lateral asymmetries, language, tool use and intellect*. San Diego, CA: Academic Press.

Briggs, G. G., & Nebes, R. D. (1976). The effects of handedness, family history and sex on the performance of a dichotic listening task. *Neuropsychologia, 14* (1), 129-133.

Bryden M. P. (1977). Measuring handedness with questionnaires. *Neuropsychologia, 15*, 617-624.

Bryden, M. P. (1988). Correlates of the dichotic right-ear effect. *Cortex, 24*, 313-319.

Bryden, M. P., McManus, I. C., & Bulman-Fleming, M. B. (1994). Evaluating the empirical support for the Geschwind-Behan-Galaburda model of cerebral lateralization. *Brain and Cognition 26*, 103-167.

Bryden, P. J., & Allard, F. (1998). Does extended practice affect the magnitude of manual asymmetries on a pegboard task? Brain and Cognition, 37 (1), 44-46.

Bryden, P. J., Pryde, K. M., & Roy, E. A. (2000). A Performance Measure of the Degree of Hand Preference. *Brain and Cognition, 44* (3), 402-414.

Burton, L. A., & Levy, J. (1989). Sex differences in the lateralized processing of facial emotion. *Brain and Cognition, 11*, 210-228.

Byrne, R.W., & Byrne, J. M. E. (1991). Hand preferences in the skilled gathering tasks of mountain gorillas (*Gorilla g. beringei*). *Cortex*, *27*, 521-546.

Calkins, S. D., Fox, N. A., & Marshal, T. R. (1996). Behavioral and physiological antecedents of inhibited and uninhibited behavior. *Child Development, 67*, 523-540.

Cameron, R., & Rogers, L. J. (1999). Hand preference of the Common Marmoset (*Callithrix jacchus):* Problem solving and responses in a novel setting. *Journal of Comparative Psychology, 113*, 149-157.

Camposano, S., Corail, J., & Lolas, F. (1991). Relationship between sex, handedness and Eysenck's personality traits (EPQ-R). *Personality and Individual Differences, 12* (11), 1185-1186*.*

Carlson, N. R. (2001). *Physiology of Behavior* (7th ed.). USA: Allyn and Bacon.

Carrillo de la Pena, M. T., Otero, J. M., & Romero, E. (1993) Comparison among various methods of assessment of impulsiveness. *Perceptual and Motor Skills, 77*, 567-575.

Carter-Saltzman, L., Scarr, S., Barker, W. F., & Katz, S. H. (1976). Left-handedness in twins: Incidence and patterns of performance in an adolescent sample. *Behavior Genetics, 6* (2), 189-203.

Carver, C. S., & White, T. L. (1994). Behavioral inhibition, behavioral activation and affective responses to impending reward and punishment: the BIS/BAS Scales. *Journal of Personality and Social Psychology, 67*, 319–33.

Christian, J. C., Hunter, D. S., Evans, M. M., & Standeford, F. M. (1979). Association of handedness and birth order in monozygotic twins. *Acta Gentiticae Medicae et Gemellologiae, 28*, 67-68.

Christman, S. D., & Hackworth, M. D. (1993). Equivalent perceptual asymmetries for free viewing of positive and negative emotional expressions in chimeric faces. *Neuropsychologia, 31*, 621-624.

Colell, M., Segarra, M. D., & Sabater-Pi, J. (1995). Manual laterality in chimpanzees *(Pan troglodytes*) in complex tasks. *Journal of Comparative Psychology, 109*, 298-307

Collins, R. L. (1969). On the inheritance of handedness: II. Selection for sinistrality in mice. *Journal of Heredity, 60*, 117-119.

Collins, R. L. (1970). The sound of one paw clapping: An enquiry in to the origin of left-handedness. In G. Lindzey, & D. D. Thiessen (Eds.), *Contribution to behavior-genetic analysis – the mouse as a prototype* (p115-136). New York: Appleton.

Cooper, L. A., & Podgorny, P. (1976). Mental Transformations and Visual Comparison Processes: Effects of Complexity and Similarity. *Journal of Experimental Psychology: Human Perception and Performance, 2* (4), 503-514.

Corballis, M. C. (1989). Laterality and human evolution. *Psychological Review, 96*, 492-505.

Corballis, M. C. (1991). *The lopsided ape: Evolution of the generative mind*. New York: Oxford University Press.

Corballis, M. C. (1997). The genetics and evolution of handedness. *Psychological Review, 104*, 714–27.

Corballis, M. C. (1998). Cerebral asymmetry: Motoring on. *Trends in Cognitive Sciences, 2*, 152-158.

Corballis, M. C. (1998). Evolution of language and laterality: A gradual descent? *Current Psychology of Cognition,17* (6), 1148-1155.

Corballis, M. C. (2002). *From hand to mouth: the origins of language.* New Jersey: Princeton University Press.

Corballis, M. C., & Morgan, J. (1978). On the biological basis of human laterality: 1. Evidence for maturational left-right gradient. *Behavioural and Brain Science, 1*, 261-269.

Coren, S. (1990). Relative risk of left-handedness in offspring as a function of maternal age at parturition. *New England Journal of Medicine, 322*, 1673.

Coren, S. (1992). *The left-hander syndrome: The causes and consequences of left-handedness*. USA: Vintage Books.

Coren, S., & Porac, C. (1979). Normative data on hand position during writing. *Cortex, 15*, 679-792.

Coren, S., & Searleman, A. (1990). Birth stress and left-handedness: The rare trait marker model. In S. Coren (Ed.), *Left-handedness: Behavioral implications and anomalies (Advances in Psychology Series)* (pp. 3-32). New York: Elsevier Science Publishers/North-Holland Book Series.

Coren, S., Searleman, A., & Porac, C. (1982). The effects of specific birth stressors on four indexes of lateral preferences. *Canadian Journal of Psychology, 36*, 478-487.

Crovitz, H.F., & Zener, K.A. (1962). Group test for assessing hand and eye dominance. *American Journal of Psychology, 75*, 271–276

Crow, T. J. (1997). Is schizophrenia the price that Homo sapiens pay for language? *Schizophrenia Research, 28*, 127-141.

Crow, T. J., Crow, L. R., Done, D. J., & Leask, S. (1998). Relative hand skill predicts academic ability: Global deficits at the point of hemispheric indecision. *Neuropsychologia, 36* (12), 1275-1282.

Cunningham, D., Forsythe, C., & Ward, J.P. (1989). A report of behavioral lateralization in an infant orangutan (*Pongo pygmaeus*). *Primates*, 30, 249-253.

Cutler, G. H., Gilgen, A. R., & Gilpin, A. R. (1985). Effects of stimulus characteristics and sex of subject on perceived emotion. *Perceptual and Motor Skills, 61*, 307-313.

Davidson H., Cave K. R., & Sellner D. (2000). Differences in visual attention and task interference between males and females reflect differences in brain laterality. *Neuropsychologia, 38*, 508-519.

Davidson, R. J. (1992). Anterior cerebral asymmetry and the nature of emotion. *Brain and Cognition, 20*, 125-151.

Davidson, R. J. (1993). Parsing affective space: Perspectives from neuropsychology and psychophysiology. *Neuropsychology, 7*, 464-475.

Davidson, R.J. (1995). Cerebral asymmetry, emotion, and affective style. In R.J. Davidson, & K. Hugdahl (Eds.), *Brain Asymmetry* (pp. 361-387). Cambridge: MIT Press.

Davidson, R. J., Mednick, D., Moss, E., Saron, C., & Schaffer, C. E. (1987). Ratings of emotion in faces are influenced by the visual field to which stimuli are presented. *Brain and Cognition, 6*, 403-411.

Davidson, R. J. & Schaffer, C. E. (1983). Affect and disorders of affect. In P. Flor-Henry, & J. Gruzelier (Eds.), *Hemisphere asymmetries of function in psychopathology*. New York: Elsevier.

De Vries, J. I. P., Visser, G. H. A., & Prechtl, H. F. R. (1985). The emergence of fetal behavior II, quantitative aspects. *Early Human Development, 12*, 99-120.

Dickman, S. J. (1990). Functional and dysfunctional impulsivity: Personality and cognitive correlates. *Journal of Personality and Social Psychology, 5* (1), 95-102.

Dickman, S. J., & Meyer, D. E. (1988). Impulsivity and speed accuracy tradeoffs in information processing. *Journal of Personality and Social Psychology, 54* (2), 274-290.

Dillon, K. M. (1989). Lateral preference and students' worries: A correlation. *Psychological Reports, 65*, 496-498.

Druckman, D., & Swets, J. (1988). *Enhancing Human Performance*. Washington, DC: National Academy Press.

Ekman, P., & Freisen, W. (1976). *Pictures of facial affect*. Palo Alto, CA: Consulting Psychologists Press.

Esslen, M., Pascual-Marqui, R. D., Hell, D., Kochi, K, & Lehmann, D. (2004). Brain areas and time course of emotional processing. *NeuroImage, 21* (4), 1189-1203.

Evenden, J. L. (1999). Varieties of impulsivity. *Psychopharmacology. 146*, 348-361.

Everhart, D. E., Harrison, D. W., & Crews, W. D. (1996). Hemispheric asymmetry as a function of handedness: Perception of facial affect stimuli. *Perceptual and Motor skills, 82*, 264-266.

Eviatar, Z., Hellige, J. B., & Zaidel, E. (1997). Individual differences in lateralization: Effects of gender and handedness. *Neuropsychology, 11*, 562-576.

Fagot, J., & Vauclair, J. (1988). Handedness and manual specialization in the baboons. *Neuropsychologia*, 6, 795-804.

Fagot, J., & Vauclair, J. (1991). Manual laterality in nonhuman primates: A distinction between handedness and manual specialization. *Psychological Bulletin*, *109*, 76-89

Fink, A., & Neubauer, A. C. (2004). Extraversion and cortical activation: Effects of task complexity. *Personality and Individual Differences, 36*, 333-34.

Finn, P. R., Justus, A., Mazas, C., & Steinmetz, J. E. (1999). Working memory, executive processes and the effects of alcohol on go/no-go learning: Testing a model of behavioral regulation and impulsivity. *Psychopharmacology. 146*, 465-472.

Forsythe, C., & Ward, J.P. (1988). Black lemur *(Lemur macaco)* hand preference in food reaching. *Primates, 29*, 369-374.

Fox, N. A., Henderson, H. A., Rubin, K. H., Calkins, S. D., & Schmidt, L. A. (2001). Continuity and discontinuity of behavioral inhibition and exuberance: Psychophysiological and behavioral influences across the first four years of life. *Child Development, 72*, 1-21.

French, C.C., & Richards, A. (1990). The relationship between handedness, anxiety and questionnaire response patterns, *British Journal of Psychology, 81*, (February, Issue 1), 57.

Friedman, I.A., & Bendas-Jacob, O. (1997). Measuring perceived test anxiety in adolescents: A self-report scale. *Educational and Psychological Measurement, 57*, 1035-1047.

Gable, S. L., Reis, H.T., & Elliot, A. J. (2000). Behavioral activation and inhibition in everyday life. *Journal of Personality and Social Psychology*, *78,* 1135–1149.

Gale, A. (1973). The psychophysiology of individual differences: Studies of extraversion and the EEG. In P. Kline (Ed.), *New approaches in psychological measurement.* (pp. 211-256). London: Wiley.

Gangestead, S. W., & Yeo, R. A. (1994). Parental handedness and relative hand skill: A test of the developmental instability hypothesis. *Neuropsychology, 8* (4), 572-578.

Geschwind, N., & Galaburda, A.M. (1985a). Cerebral lateralization: Biological mechanisms, associations, and pathology: I. A hypothesis and a program for research. *Archives of Neurology, 42*, 428-459.

Geschwind, N., & Galaburda, A.M. (1985b). Cerebral lateralization: Biological mechanisms, associations, and pathology: I. A hypothesis and a program for research. *Archives of Neurology, 42*, 564-578.

Geschwind, N., & Galaburda, A.M. (1985c).. Cerebral lateralization: Biological mechanisms, associations, and pathology: I. A hypothesis and a program for research. *Archives of Neurology, 42*, 634-654.

Gilhooly, K. J., Phillips, L. H., Wynn, V., Logie, R. H., & Della Sala, S. (1999). Planning processes and age in the five-disc Tower of London task. *Thinking and Reasoning, 5* (4), 339-361.

Goel, V., & Grafman, J. (1995). Are the frontal lobes implicated in "planning" functions? Interpreting data from the Tower of Hanoi. *Neuropsychologia, 33* (5), 623-642.

Goel, V., Pullara, S. D., & Grafman, J. (2001). A computational model of frontal lobe dysfunction: Working memory and the Tower of Hanoi Task. *Cognitive Science, 25*, 287-313.

Goldberg, E. (2001). *The executive brain: frontal lobes and the civilized mind.* New York: Oxford University Press.

Goldberg, E., Podell, K., & Lovell, M. (1994). Lateralization of frontal lobe functions and cognitive novelty. *Journal of Neuropsychiatry and Clinical Neurosciences, 6*, 371-378.

Goodwin, R.S., & Michel, G. F. (1981). Head orientation position during birth and infant neonatal period, and hand preference at 19 weeks. *Child Development, 52*, 819-826.

Gray, J. & McNaughton, N. (2000). *The neuropsychology of anxiety* (2nd ed.). Oxford, UK: Oxford University Press.

Gray, J. A. (1981). A critique of Eysenck's theory of personality. In H. J. Eysenck (Ed.), *A model for personality* (pp. 246-277). Berlin: Springer.

Gray, J. A. (1982). *The neuropsychology of anxiety: An enquiry of the septo-hippocampal system*. Oxford, UK: Oxford University Press.

Green, S. (1995). *Principles of biopsychology*. Hove, UK: Lawrence Erlbaum Associates.

Grimshaw, G. M., Bryden, M. P., & Finegan, J. K. (1995). Relations between prenatal testosterone and cerebral lateralization in children. *Neuropsychology, 9*, 68-79.

Halpern, D. F., Haviland, M. G., & Killian, C. D. (1998). Handedness and sex differences in intelligence: Evidence from the medical college admission test. *Brain and Cognition, 38* (1), 87-101.

Hardyck, C., Petronovich, L. F., & Goldman, R. D. (1976). Left-handedness and cognitive deficit. *Cortex,12*, 266–279.

Harris, L. J. (1993). Do left-handers die sooner than right-handers? Commentary on Coren and Halpern's (1991) "Left-Handedness: A marker for decreased survival fitness". *Psychological Bulletin, 114* (2), 203-234.

Harris, L. J., & Carlson, D. F. (1988). Pathological left-handedness: An analysis of theories and evidence. In D.L., Molfese, & S.J. Segalowitz (Eds.). *Brain Lateralization in Children. Developmental Implications* (pp 289-372). New York: Guilford Press.

Hartikainen, K. M., Ogawa, K. H., & Knight, R. T. (2000). Transient interference of right hemispheric function due to automatic emotional processing. *Neuropsychologia, 38*, 1576-1580.

Hatta, T., & Koike, M. (1991). Left-hand preference in frightened mother monkeys in taking up their babies. *Neuropsychologia, 29*, 207-209.

Hausmann, M., & Gunturkun O. (1999). Sex differences in functional cerebral asymmetries in a repeated measures design. *Brain and Cognition, 41*, 263-275.

Heim, A. W. (1973). *AH4 Group test of general intelligence*. England, NFER Publishing Co Ltd.

Heller, W., & Levy, J. (1981). Perception and expression of emotion in right handers and left handers. *Neuropsychologia, 19*, 263-272.

Hellige, J. B. (2001). *Hemispheric Asymmetry*. Cambridge, MA: Harvard University Press.

Helmers, K. F., Young, S. N., & Pihl, R. O. (1995). Assessment of Measures of Impulsivity in Healthy Male Volunteers. *Personality and Individual Differences, 19* (6), 927-935.

Hembree, R. (1988). Correlates, causes, effects, and treatment of test anxiety. *Review of Educational Research, 58*, 47-77.

Hepper, P. G., McCartney, G. R., & Shannon, E. A. (1998). Lateralised behaviour in first trimester human foetuses. *Neuropsychologia, 36* (6), 531-534.

Hepper, P. G., Shahidullah, S., & White, R. (1991). Handedness in the human fetus. *Neuropsychologia, 29* (11), 1107-1111.

Hepper, P. G., Wells, D. L., & Lynch, C. (2005). Prenatal thumb sucking is related to postnatal handedness. *Neuropsychologia, 43*, 313-315.

Hicks, R. A., & Pellegrini, R. J. (1978). Handedness and anxiety. *Cortex, 14*, 119-121.

Hicks, R. A., Pellegrini, R. J., & Evans, E. A. (1978). Handedness and birth risk. *Neuropsychologia, 16*, 243-245.

Hook-Costigan, M.A., & Rogers, L.J. (1995). Hand, mouth and eye preferences in the common marmoset *(Callithrix jacchus). Folia Primatologica, 64*,180-191.

Hook-Costigan, M.A., & Rogers, L.J. (1998). Lateralized use of the mouth in production and vocalizations by marmosets. *Neuropsychologia, 36*, 1265-1273.

Hopkins, W. D., & Bennett, A. J. (1994). Handedness and approach avoidance behavior in chimpanzees (*Pan*.). *Journal of Experimental Psychology: Animal Behavior Processes, 20*, 413-418.

Hopkins, W. D., Cantalupo, C., Freeman, H., Russell, J., Kachin, M., & Nelson, E. (2005). Chimpanzees are right-handed when recording bouts of hand use. *Laterality, 10* (2), 121-130.

Hopkins, W. D., Dahl, J. F., & Pilcher, D. (2000). Birth order and left-handedness revisited: some recent findings in chimpanzees (*Pan troglodytes*) and their implications for developmental and evolutionary models of human handedness. *Neuropsychologia, 38* (12), 1626-1633.

Hopkins, W.D. (1994). Hand preferences for bimanual feeding in 140 captive chimpanzees *(Pan troglodytes):* Rearing and ontogenetic determinants. *Developmental Psychobiology*, *27*, 395- 407.

Hopkins, W.D. (1995a). Hand preference for a coordinated bimanual task in 110 chimpanzees (*Pan troglodytes*): Cross-sectional analysis. *Journal of Comparative Psychology*, *109*, 291-297.

Hopkins, W.D. (1995b). Hand preferences for simple reaching in juvenile chimpanzees (*Pan troglodytes*): Continuity in development. *Developmental Psychobiology*, *31*, 619-625.

Hopkins, W.D. (1996). Chimpanzee handedness revisited: 55 years since Finch (1941). *Psychonomic Bulletin and Review*, *3*, 449-457.

Hopkins, W.D., & Morris, R.D. (1993). Handedness in apes: A review of findings. *International Journal of Primatology*, *14*, 1-25.

Hubbard, J. I. (1971). Handedness not a function of birth order. *Nature, 232*, 276-277.

Hugdahl, K., Iverson, P. M., & Johnsen, B. H. (1993). Laterality of facial expressions: Does the sex of the subject interact with the sex of the face? *Cortex, 29*, 325-331

Iaccino, J. F. (1993). *Left brain-right brain differences*. New Jersey: Lawrence Erlbaum Associates.

Inglis, J., & Lawson, J. S. (1981). Sex-differences in the effects of unilateral brain damage on intelligence. *Science, 212*, 693-695.

James, W. H., & Orlebeke, J. F. (2002). Determinants of handedness in twins. *Laterality, 7,* 301-307.

Jansari, A., Tranel, D., & Adolphs, R. (2000). A valence-specific lateral bias for discriminating emotional facial expressions in free field. *Cognition and Emotion, 14*, 341-353.

Jones, N. A., & Fox, N. A. (1992). Electroencephalogram asymmetry during emotionally evocative films and its relation to positive and negative affectivity. *Brain and Cognition, 20*, 280-299.

Kafer, K. L., & Hunter, M. (1997). On testing the face validity of planning/problem solving tasks in a normal population. *Journal of the International Neuropsychological Society, 3*, 108-119.

Kalin, N. H., Larson, C., Shelton, S. E., & Davidson, R. J. (1998). Asymmetric frontal brain activity, cortisol and behavior associated with fearful temperament in rhesus monkeys. *Behavioral Neuroscience, 112*, 286-292.

Kells, A. R., & Goulson, D. (2001). Evidence for handedness in bumblebees. *Journal of insect behavior, 14* (1), 47-55.

Kimura, D. (1977). Acquisition of a motor skill after left hemisphere damage. *Brain, 100*, 527-542.

King, J.E. (1995). Laterality in hand preferences and reaching accuracy of cotton-top tamarinds (*Saguinus oedipus*). *Journal of Comparative Psychology, 109* (1), 34-41.

Klar, A. J. S. (1996). A single locus, RGHT, specifies preference for hand utilization in humans. Cold Spring Harbor Symposium. *Quantitative Biology, 61*, 59-65.

Klar, A. J. S. (1999). Genetic models for handedness, brain lateralization, schizophrenia, and manic-depression. *Schizophrenia Research, 39* (3), 207-218.

Klar, A. J. S. (2003). Human handedness and scalp hair-whorl direction develop from a common genetic mechanism. *Genetics, 165* (1), 269-76

Kolb, B., & Whishaw, I. Q. (1999). *Fundamentals of human neuropsychology.* (4th ed.). New York, W. H. Freeman and Company.

Kovac, D. (2000). Anxiety and Laterality: cause and effect? *Studia Psychologia, 42* (1), 15-23.

Kowner, R. (1995). Laterality in facial expressions and its effect on attributions of emotion and personality: A reconsideration. *Neuropsychologia, 33*, 539-559.

Lacreuse, A., & Fragaszy, D.M. (1999). Left hand preferences in Capuchins (*Cebus apella*): Role of spatial demands in manual activity. *Laterality, 4* (1), 65-78.

Ladavas, E., Umilatà, C., & Ricci-Bitti, P. E. (1980). Evidence for sex differences in right-hemisphere dominance for emotions. *Neuropsychologia, 18*, 361-366.

Laland K.N., Kumm, J., Van Horn, J.D., & Feldman, M.W. (1995). A gene-culure model of handedness. *Behaviour Genetics,* 25 (5), 433-445.

Langford, S. (1995). *The left-handed book: how to get by in a right-handed world* (2nd edition). Great Britain: Panther Books.

Larson, C.F., Dodson, D., & Ward, J.P. (1989). Hand preferences and whole-body turning biases of lesser bush babies (*Galago senegalensis). Brain, Behaviour and Evolution,* 33,261-267.

Lehman R.A.W. (1993). Manual preference in prosimians, monkeys and apes. In J.P. Ward, & W.D. Hopkins (Eds.) *Primate Laterality* (pp. 149-181). New York: Springer.

Leslie, K. R., Johnson-Frey, S. H., & Grafton, S. T. (2004). Functional imaging of face and hand imitation: towards a motor theory of empathy. *NeuroImage, 21* (2), 601-607.

Lester, D. (1987). The relationship between handedness and personality traits (extraversion and neuroticism). *Personality and Individual Differences, 8, 437*

Leviton, A., & Kilty, T. (1976). Birth order and left-handedness. *Archives of Neurology, 33*, 664.

Levy, J., & Gur, R. C. (1980). Individual differences in psychoneurological organization. In J. Herron (Ed.), *The Neuropsychology of Left-Handedness* (pp. 142-152). New York, Academic Press.

Levy, J., & Nagylaki, T. (1972). A model for the genetics of handedness. *Genetics, 72,* 117-128.

Levy, J., Heller, W., Banich, M. T., & Burton, L. (1983). Are variations among right-handed individuals in perceptual asymmetries caused by characteristic arousal differences between hemispheres? *Journal of Experimental Psychology: Human Perception and Performance, 9*, 329-359.

Ley, R. G., & Bryden, M. P. (1979). Hemispheric differences in processing emotions and faces. *Brain and Language, 7*, 127-138.

Li, C., Zhu, W., & Nuttall, R. L. (2003). Familial handedness and spatial ability: A study with Chinese students aged 14–24. *Brain and Cognition, 51* (3), 375-384.

Lippolis, G., Bisazza, A., Rogers, L. J., & Vallortigara, G. (2001). Lateralization of predator avoidance responses in three species of toads. *Laterality, 7,* 163-183.

MacNeilage, P. F., Studdert-Kennedy, M. G., & Lindblom, B. (1987) Primate handedness reconsidered. *Behavioral and Brain Sciences, 10*, 247-303.

Magurran, A. E., & Seghers, B. H. (1990). Population differences in predator recognition and attack cone avoidance in the guppy (*Poecilia reticulate)*. *Animal Behaviour, 40*, 443-452.

Mandal, M. K., & Singh, S. K. (1990). Lateral asymmetry in identification and expression of facial emotions. *Cognition and Emotion, 4*, 61-70.

Mandal, M. K., Tandon, S. C., & Asthana, H. S. (1991). Right brain damage impairs recognition of negative emotions. *Cortex, 27,* 247-253.

Manning, J. T. (2002). *Digit ratio: a pointer to fertility, behavior and health.* New Jersey: Rutgers University Press.

Marchant, L.F. and McGrew, W.C. (1996). Laterality of limb function in wild chimpanzees of Gombe National Park: Comprehensive study of spontaneous activities*. Journal of Human Evolution*, 30, 427-443.

Marchant, L.F., & McGrew, W.C. (1991). Laterality of function in apes: A meta-analysis of methods. *Journal of Human Evolution,* 21, 425-438.

Marchant, L.F., McGrew, W.C., & Eibl-Eibesfeldt, I. (1995). Is human handedness universal? Ethological analyses from three traditional cultures. *Ethology, 101*, 239-258.

Masataka, N. (1990). Handedness of capuchin monkeys. *Folia Primatologica,* 55, 189- 192.

Masur, E.F. (1988). Infants imitation of novel and familiar behaviors. In R. Zentall, & B. G. Galef (Eds.). *Social Learning. Psychological and Biological Perspectives* (pp. 301-318). Hillsdale, NJ: Lawrence Erlbaum.

Mataix-Cols, D., & Bartrés-Faz, D. (2002). Is use of the wooden and computerised versions of the Tower of Hanoi puzzle equivalent? *Applied Neuropsychology, 9* (2), 117-120.

Mayringer, H., & Wimmer, H. (2002). No deficits at point of hemispheric indecision. *Neuropsychologia, 40*, 701–704.

McGrew, W.C., & Marchant, L.F. (1997). On the other hand: Current issues in and meta-analysis of the behavioural laterality of hand function in nonhuman primates. *Yearbook of Physical Anthropology*, *40*, 201-232.

McKeever, W. F. (1979). Hand writing posture in left-handers: sex, familial sinistrality and language laterality correlates. *Neuropsychologia, 17*, 429-444.

McKeever, W. F. (2004). An X-linked three allele model of hand preference and hand posture for writing. *Laterality, 9* (2), 149-174.

McKeever, W. F., Suter, P. J., & Rich, D. A. (1995). Maternal age and parity correlates of handedness: Gender but no parental handedness modulation effects. *Cortex, 31*, 543-553.

McManus, I. C. (1981). Handedness and birth stress. *Psychological Medicine, 11*, 485-496.

McManus, I.C. (1983) Pathological left-handedness: Does it exist? *Journal of Communication Disorders 16*, 315-344.

McManus, I.C. (1984). The power of a procedure for detecting mixture distributions in laterality data. *Cortex. 20*, 421-426.

McManus, I.C. (1985). Right- and left-hand skill: failure of the right shift model. *British Journal of Psychology 76*, 1-16.

McManus, I.C. (2002). *Right hand, left hand: the origins of asymmetry in brains, bodies, atoms and cultures*. UK: Weidenfield & Nicolson.

McManus, I.C., Murray, B., Doyle, K., & Baron-Cohen, S. (1992) Handedness in childhood autism shows a dissociation of skill and preference. *Cortex, 28*, 373-381.

Merckelbach, H., de Ruiter, C., & Olff, M. (1989). Handedness and anxiety in normal and clinical populations. *Cortex, 25*, 599-606.

Messinger, H. B., & Messinger, M. I. (1995). Factoring handedness data. I. Item analysis. *Cortex, 31*, 757-765.

Meulenbroek, R. G. J., & Van Galen, G. P. (1989). Variations in cursive handwriting performance as a function of handedness, hand posture and gender. *Journal of human movement studies, 16*, 239-254.

Meyer, B., Olivier, L., & Roth, D. A. (2005). Please don't leave me! BIS/BAS, attachment styles, and responses to a relationship threat. *Personality and Individual Differences, 38* (1), 151-162.

Michel, G. F., & Goodwin, R. (1979). Intrauterine birth position predicts newborn supine head position preferences. *Infant Behavior Development, 2,* 29-38.

Miller, D. C., & Byrnes, J. P. (1997). The Role of Contextual and Personal Factors in Children's Risk Taking. *Developmental Psychology, 33* (5), 814-823.

Morph 2.5. (1997). Gryphon Software Corporation. San Diego, CA.: USA.

Morris, R. G., Miotto, E. C., Feigenbaum, J. D., Bullock, P., & Poplkey, C. E. (1997). Planning ability after frontal and temporal lobe lesions in humans: The effects of selection equivocation and working memory load. *Cognitive Neuropsychology, 14* (7), 1007-1027.

Mueller, J. H., Grove, T. R., & Thompson, W. B. (1991). Mood dependent retrieval and mood awareness. *Cognition and Emotion, 5*, 331-349.

Murphy, K., & Peters, M. (1994). Right-handers and left-handers show differences and important similarities in task integration when performing manual and vocal tasks concurrently. *Neuropsychologia, 32* (6), 663-674.

Nettle, D. (2003). Hand laterality and cognitive ability: a multiple regression approach. *Brain and Cognition, 52*, 390-398.

Noorozian, M., Lotfi, J., Gassemzadeh, H., Emami, H., & Mehrabi, Y. (2002). Academic achievement and learning abilities in left-handers: Guilt or gift? *Cortex, 38* (5), 779-785.

O'Callaghan, M. J., Tudehope, D. I, Dugdale, A.E., Mohay, H, Burns, Y., & Cook, F. (1987). Handedness in children with birthweights below 1000g. *Lancet, 1*, 1155.

O'Boyle, M. W., & Benbow, C. P. (1990). Enhanced right hemisphere involvement during cognitive processing may relate to intellectual precocity. *Neuropsychologia, 28*, 211-216.

Oldfield, R. C. (1971). The assessment and analysis of handedness: The Edinburgh inventory. *Neuropsychologia, 9*, 97-113.

Orlebeke, J. F., van Baal, G. C., Boomsma, D. I., & Neeleman, D. (1993). Birth weight in opposite sex twins as compared to same sex dizygotic twins. *European Journal of Obstetrics, Gynecology and Reproductive Biology, 50*, 95-98.

Orme, J. (1970). Left-handedness, ability and emotional instability. *British Journal of the Society of Clinical Psychology, 9, 87-88.*

Orme, J. E. (1970). A practical guide to estimating intelligence, attainments and intellectual deficits. *Acta Psychologia, 32*, 145-161.

Owen, A. M. (1997). Cognitive planning in humans: Neuropsychological, neuroanatomical and neuropharmacological perspectives. *Progress in Neurobiology, 53*, 431-450.

Palmer, R.A. (2002). Chimpanzee Right-Handedness Reconsidered: Evaluating the Evidence With Funnel Plots. *American Journal of Physical Anthropology*, *118*, 191-199.

Patton, J. H., Stanford, M. S., & Barratt, E.S. (1995) Factor Structure of The Barratt Impulsiveness Scale. *Journal of Clinical Psychology, 51* (6), 768-774.

Peters, M. (1987). A nontrivial motor performance difference between right-handers and left-handers: attention as intervening variable in the expression of handedness. *Canadian Journal of Psychology, 41*, 91-99.

Peters, M. (1990). Subclassification of non-pathological left-handers poses problems for theories of handedness. *Neuropsychologia, 28*, 279-289.

Peters, M. (1996). Hand preference and performance in left-handers. In D. Elliot, & E. A. Roy (Eds), *Manual asymmetries in motor performance* (pp 99-120). Boca Raton: CRC Press.

Peters, M. (1998). Description and validation of a flexible and broadly usable handedness questionnaire. *Laterality, 3*, 77-96.

Peters, M., & McGrory, J. (1987). Dichotic listening performance and writing posture in right- and left-handers. *Brain and Language, 32*, 253-264.

Peters, M., & Perry, R. (1991). No link between left-handedness and maternal age and no elevated accident rate in left-handers. *Neuropsychologia, 29* (12), 1257-1259.

Peters, M., & Servos, P. (1989). Performance of subgroups of left-handers and right-handers. *Canadian Journal of Psychology, 43*, 341-358.

Phillips, L. H., Wynn, W. E., McPherson, S., & Gilhooly, K. J. (2001). Mental planning and the Tower of London Task. *The Quarterly Journal of Experimental Psychology, 54A*, 579-597.

Phillips, L.H., Wynn, V., Gilhooly, K. J., Della Sala, S., & Logie, R. H. (1999). The role of memory in the Tower of London task. *Memory, 7*, 209-231.

Ponton, C. W. (1987). Enhanced articulatory speed in ambidexters. *Neuropsychologia, 25* (18), 305-311.

Porac, C., & Coren, S. (1981). *Lateral preferences and human behavior.* New York: Springer-Verlag.

Porac, C., Coren, S., & Searleman, A. (1986). Environmental factors in hand preference formation: Evidence from attempts to switch the preferred hand. *Behavior Genetics, 16*, 251-261.

Poreh, A. M. (1994). Reexamination of mixed handedness in psychosis-prone college students. *Personality and Individual Differences, 17* (3), 445-448

Poreh, A. M., Levin, J., Teves, H., & States, J. (1997). Mixed handedness and schizotypal personality in a non-clinical sample - The role of task demand. *Personality and Individual Differences, 23* (3), 501-507.

Provins, K. A. (1997). Handedness and speech: A critical reappraisal of the role of genetic and environmental factors in the cerebral lateralization of function. *Psychological Review, 104* (3), 554-571.

Provins, K. A., & Cunliffe, P. (1972). The reliability of some motor performance tests of handedness. *Neuropsychologia, 10*, 199-206.

Provins, K. A., & Magliaro, J. (1993). The measurement of handedness by preference and performance tests. *Brain and Cognition. 22*, 171-181.

Quilty, L. C., & Oakman, J. M. (2004). The assessment of behavioural activation – the relationship between impulsivity and behavioural activation. *Personality and Individual Differences, 37* (2), 429-442.

Raczkowski, D., Kalat, J. W., & Nebes, R. (1974). Reliability and validity of some handedness questionnaire items. *Neuropsychologia, 12*, 43-47.

Regolin, L., Vallortigara, G., & Zanforlin, M. (1994). Object and spatial representations in detour problems by chicks. *Animal Behaviour, 47*, 195-199.

Reuter-Lorenz, P., & Davidson, R. J. (1981). Differential contributions of the 2 cerebral hemispheres to the perception of happy and sad faces. *Neuropsychologia, 19*, 609-613.

Reuter-Lorenz, P., Givis, R. P., & Moscovitch, M. (1983). Hemispheric specialization and the perception of emotion: Evidence from right-handers and from inverted and noninverted left-handers. *Neuropsychologia, 21*, 687-692.

Robins, A., Lippolis, G., Bisazza, A., Vallortigara, G., & Rogers, L. J. (1998). Lateralized agonistic responses and hind limb use in toads. *Animal Behaviour, 56*, 875-881.

Rogers, L. J. (1997). Early experiential effects on laterality: Research on chicks has relevance to other species. *Laterality, 2*, 199-219.

Rogers, L. J. (1999). Factors associated with exploration in marmosets: Age, gender and hand preference. *International Journal of Comparative Psychology, 12,* 93-109.

Rogers, L. J. (2000). Evolution of hemispheric specialization: advantages and disadvantages. *Brain and Language, 73*, 236-253.

Rogers, L.J., & Andrew, R. J. (2002). *Comparative Vertebrate Lateralization*. Cambridge, UK: Cambridge University Press.

Rosen, G.D., Sherman, G.F., & Galaburda, A.M. (1991). Ontogenesis of neocortical asymmetry: A [3H]Thymidine study. *Neuroscience, 41*, 779–90.

Rosenthal, R. (1965). The Volunteer Subject. *Human Relations, 18*, 389-406.

Ross, E. D., Homan, R. W., & Buck, R. (1994). Differential hemispheric lateralization of primary social emotions: Implications for developing a comprehensive neurology for emotions, repression, and the subconscious. *Neuropsychiatry, Neuropsychology and Behavioural Neurology, 7*, 1-19.

Ross, G., Lipper, E., & Auld, P. A. M. (1992). Hand preference, prematurity and developmental outcome at school age. *Neuropsychologia, 30* (5), 483-494.

Sabaté, M., González, B., & Rodriguez, M. (2004). Brain lateralization of motor imagery: motor planning asymmetry as a cause of movement lateralization. *Neuropsychologia, 42*, 1041-1049.

Sackeim, H., Gur, R. C., & Saucy, M. C. (1978). Emotions are expressed more intensely on the left side of the face. *Science, 202,* 434-436.

Safer, M. A. (1981). Sex and hemisphere differences in access to codes for processing emotional expressions in faces. *Journal of Experimental Psychology: General, 110*, 86-100.

Sanz-Martin A., & Loyo J. R. (2001). Sex differences in emotional processing. *Revista Mexicana de Psicologia, 18*, 373-386.

Satz, P. (1972). Pathological left-handedness: An explanatory model. *Cortex, 8,* 121-135.

Satz, P. (1973). Left-handedness and early brain insult: An explanation. *Neuropsychologia,11* (1),115-117.

Satz, P., Orsini, D.L., Saslow, E., & Henry, R. (1985). The pathological left-handedness syndrome. *Brain and Cognition, 4*, 27-46.

Satz. P., Baymur, L., & Van Der Vlugt, H. (1979). Pathological left-handedness: Cross-cultural tests of a model. *Neuropsychologia, 17* (1), 77-81.

Schmidt, L. A., & Fox, N. A. (1996). Frontal EEG correlates of dysregulated social behavior in children. *Psychophysiology, 33* (Suppl. 1), 58

Schmidt, L. A., Fox, N. A., Schulkin, J., & Gold, P. W. (1999). Behavioral and psychophysiological correlates of self-presentation in temperamentally shy children. *Developmental Psychobiology, 35*, 119-135.

Scholnick, E. K., & Friedman, S. L. (1993). Planning in context: Developmental and situational characteristics. *International Journal of Behavioral Development, 16,* 145–167.

Schwartz, M. (1977). Left-handedness and high-risk pregnancy. *Neuropsychologia, 15* (2), 341-344.

Searleman, A., Porac, C., & Coren, S. (1989). Relationship between birth order, birth stress, and lateral preferences: A critical review. *Psychological Bulletin, 105* (3), 397-408.

Shallice, T. (1982). Specific impairments of planning. *Philosophical Transactions of the Royal Society of London B, 298*, 199-209.

Shaw, J., Claridge, G., & Clark, K. (2001). Schizotypy and the shift from dextrality: A study of handedness in a large non-clinical sample. *Schizophrenia Research, 50* (3), 181-189.

Siegel-Hinson, R. I., & McKeever, W. F. (2002). Hemispheric specialisation, spatial activity experience and sex differences on tests of mental rotation ability. *Laterality, 7*, 59-74.

Silberman, E. K., & Weingartner, H. (1986). Hemispheric lateralization of functions related to mood. *Brain and Cognition, 5*, 322-353.

Smart, J. L., Jeffrey, C., & Richards, B. (1980). A retrospective study of the relationship between birth stress and handedness at six years. *Early Human Development, 4*, 79-88.

Soper, H. V., & Satz, P. (1984). Pathological left-handedness and ambiguous handedness: A new explanatory model. *Neuropsychologia, 22* (4), 511-515.

Spere, K. A., Schmidt, L. A. Riniolo, T. C., & Fox, N. A. (in press). Is a lack of cerebral hemisphere dominance a risk factor for social “conflictedness”?: Mixed-handedness in shyness *and* sociability. *Personality and Individual Differences.*

Spielberger, C. D. (1983). State-Trait Anxiety Inventory (From Y). California: Mind Garden, Inc.

Spinozzi, G., & Cacchiarelli, B. (2000). Manual laterality in haptic and visual reaching tasks by tufted capuchin monkeys (*Cebus apella*). An association between hand preference and hand accuracy for food discrimination. *Neuropsychologia*, *38*, 1685-1692.

Spitz, H. H., Minsky, S. K., & Bessellieu, C. L. (1984). Subgoal length versus full solution length in predicting Tower of Hanoi problem solving performance. *Bulletin of the Psychonomic Society, 22* (4), 301-304.

Springer, S. P., & Deutsch, G. (1998). *Left brain right brain: perspectives from cognitive neuroscience* (5th ed.). USA: W.H. Freeman & Company.

Stauss, E., & Moscovitch, M. (1981). Perception of facial expression. *Brain and Language, 13,* 308-332.

Steenhuis, R. E., & Bryden, M. P. (1989). Different dimensions of hand preference that relate to skilled and unskilled activities. *Cortex, 25*, 289-304.

Stein, M. (1973). Personality correlates of left-handedness. *Dissertation Abstracts International, 34B.*

Steiner, S.M. (1990). Handedness in chimpanzees. *Friends Washoe*, *9*, 9-17.

Stuettgen, M. C., Hennig, J., Reuter, M., & Netter, P. (2005). Novelty seeking but not BAS is associated with high dopamine as indicated by a neurotransmitter challenge test using mazindol as a challenge substance. *Personality and Individual Differences, 38* (7). 1597-1608.

Tapley, S. M., & Bryden, M. P. (1985). A group test for the assessment of performance between the hands. *Neuropsychologia, 23*, 215-221.

Teasdale, T. W., & Owen, D. R. (2001). Cognitive abilities in left-handers: writing posture revisited. *Neuropsychologia, 39*, 881-884.

Tucker, D. M. (1981). Lateral brain function, emotion and conceptualization. *Psychological Bulletin, 89*, 19-46.

Vallortigara, G. (2000). Comparative neuropsychology of the dual brain: a stroll through animals' left and right perceptual worlds. *Brain and Language, 73*, 189-219.

Vallortigara, G., Rogers, L. J., Bisazza, A., Lippolis, G., & Robins, A. (1998). Complementary right and left hemifield use for predatory and agonistic behaviour in toads. *NeuroReport, 9*, 3341-3344.

Van Strien, J, W., & Van Beek, S. (2000). Ratings of emotion in laterally presented faces: Sex and handedness effects. *Brain and Cognition, 44*, 645-652.

Vauclair, J., Fagot, J., & Dépy, D. (1999). Nonhuman primates as models of hemispheric specialization. In Haug M., & Whalen R. E. (Eds.). *Animal Models and Human Emotion and Cognition* (pp. 247-259). New York: APA Books.

Ververs, I. A. P., de Vries, J. I. P., van Geijn, H. P., & Hopkins, B. (1994). Prenatal head position from 12 to 38 weeks. I. Developmental aspects. *Early Human Development, 39,* 83-91.

Volpe, B. T., Sidtis, J. J., & Gazzaniga, M. S. (1981). Can left-handed writing posture predict cerebral language laterality? *Archives of Neurology, 38*, 637-638.

Voyer D., & Rodgers M. A. (2002). Reliability of laterality effects in a dichotic listening task with nonverbal material. *Brain and Cognition, 48*, 602-606.

Ward, G., & Allport, A. (1997). Planning and problem-solving using the five-disk Tower of London task. *The Quarterly Journal of Experimental Psychology. 50A* (1), 49-78.

Ward, J.P., & Hopkins, W.D. (Eds.). (1993). *Primate Laterality: Current Behavioral Evidence of Primate Asymmetries*. New York: Springer.

Ward, J.P., Milliken, G.W., & Stafford, D.K. (1993). Patterns of lateralized behaviour in prosimians. In J.P. Ward, & W.D. Hopkins (Eds.). *Primate Laterality: Current Behavioral Evidence of Primate Asymmetries* (pp. 43-74). New York: Springer Verlag

Ward, J.P., Milliken, G.W., Dodson, D.L., Stafford, D.K., & Wallace, M. (1990). Handedness as a function of sex and age in a large population of Lemur. *Journal of Comparative Psychology, 104* (2), 167-173.

Watson, S. L., & Ward, J. P. (1996), Temperament and problem solving in the small-eared busybaby (*Otolemur garnettii*). *Journal of Comparative Psychology, 110*, 377-385.

Warren, J.M. (1980). Handedness and laterality in humans and other animals. *Physiological Psychology*, *8*, 351-359.

Welsh, M. C. (1991). Rule-guided behavior and self-monitoring on the Tower of Hanoi disk-transfer task. *Cognitive Development. 6*, 59-76.

Welsh, M. C., Satterlee-Cartmell, T., & Stine, M. (1999). Towers of Hanoi and London: Contribution of working memory and inhibition to performance. *Brain and Cognition, 41*, 231-242.

Westergaard, A.C., & Suomi, S.J. (1996). Hand preference for stone artifact production and tool-use by monkeys: Possible implications for the evolution of right-handedness in homonids. *Journal of Human Evolution*, *30*, 291-298.

Westergaard, G. C., Byrne, G., & Suomi, S. J. (2000). Handedness and cortisol in tufted capuchin monkey infants. *Developmental Psychobiology, 36*, 213-217.

Westergaard, G. C., Champoux, M., & Suomi, S. J. (2001). Plasma cortisol is associated with handedness in rhesus monkeys. *Developmental Psychobiology, 38*, 116-122.

Westergaard, G. C., Chavanne, T. J., Houser, L., Cleveland, A., Snoy, P. J., Suomi, S. J., & Higley, J. D. (2004). Biobehavioural correlates of hand preference in free-ranging female primates. *Laterality, 9* (3), 267-285.

Westergaard, G. C., Lussier, I. D., Suomi, S. J., & Higley, J. D. (2001). Stress correlates of hand preference in rhesus macaques. *Developmental Psychobiology, 38*, 110-115.

Westergaard, G.C. (1991). Hand preference in the use and manufacture of tools by tufted capuchin *(Cebus apella)* and lion tailed macaque *(Macaca silenus)* monkeys*. Journal of Comparative Psychology, 105*,172-176.

Wienrich, A. M., Wells, P. A., & McManus, C. (1982). Handedness, anxiety and sex differences. *British Journal of Psychology, 73*, 69-72.

Witelson S. F. (1991). Sex differences in neuroanatomical changes with aging. *New England Journal of Medicine, 325* (3), 211-212.

Wright, L., Hardie, S., & Rodway, P. (2004). Pause before you respond: Handedness influences response style on the Tower of Hanoi Task. *Laterality, 9* (2), 133-147.

Appendix 1

Items covered in the handedness questionnaires of Annett (1970) and Oldfield (1971).

Annett (1970)

1) Write
2) Throw a ball
3) Hold a racket
4) Hold a match while striking it
5) Cut with scissors
6) Guide thread through the eye of a needle
7) Which hand is at the top of a broom while sweeping
8) Which hand is at the top of a shovel while moving sand
9) To deal cards
10) To hammer a nail
11) Hold a toothbrush
12) Unscrew the lid of a jar

Oldfield (1971)

1) Writing
2) Drawing
3) Throwing
4) Scissors
5) Toothbrush
6) Knife (without fork)
7) Spoon
8) Broom (upper hand)
9) Striking match (match)
10) Opening box (lid)

Appendix 2

Adapted version of Peter's (1998) Handedness Questionnaire

Student Matriculation Number: ______________________________

Course: ____

Sex: Male Female (please circle)

Were you born in the: 1940's ( ) 1950's ( ) 1960's ( ) 1970's ( ) 1980's ( )

Assuming that your hands are empty (except as indicated), please state which hand you would normally use for the following activities by circling **Ra** (for **right hand always**), **Rm** (for **right hand most of the time**), **E** (for **either hand**), **Lm** (for **left hand most of the time**) and **La** (for **left hand always**).

Draw	Ra	Rm	E	Lm	La
Knife	Ra	Rm	E	Lm	La
Comb Hair	Ra	Rm	E	Lm	La
Pick up a very small object	Ra	Rm	E	Lm	La
Pick up book	Ra	Rm	E	Lm	La
Screw in light bulb	Ra	Rm	E	Lm	La
Dial pushbutton phone	Ra	Rm	E	Lm	La
Wave goodbye	Ra	Rm	E	Lm	La
Pet dog or cat	Ra	Rm	E	Lm	La
Which hand washes face with cloth	Ra	Rm	E	Lm	La
Pick up heavy object	Ra	Rm	E	Lm	La
Pick up heavy suitcase	Ra	Rm	E	Lm	La

Appendix 2 continued

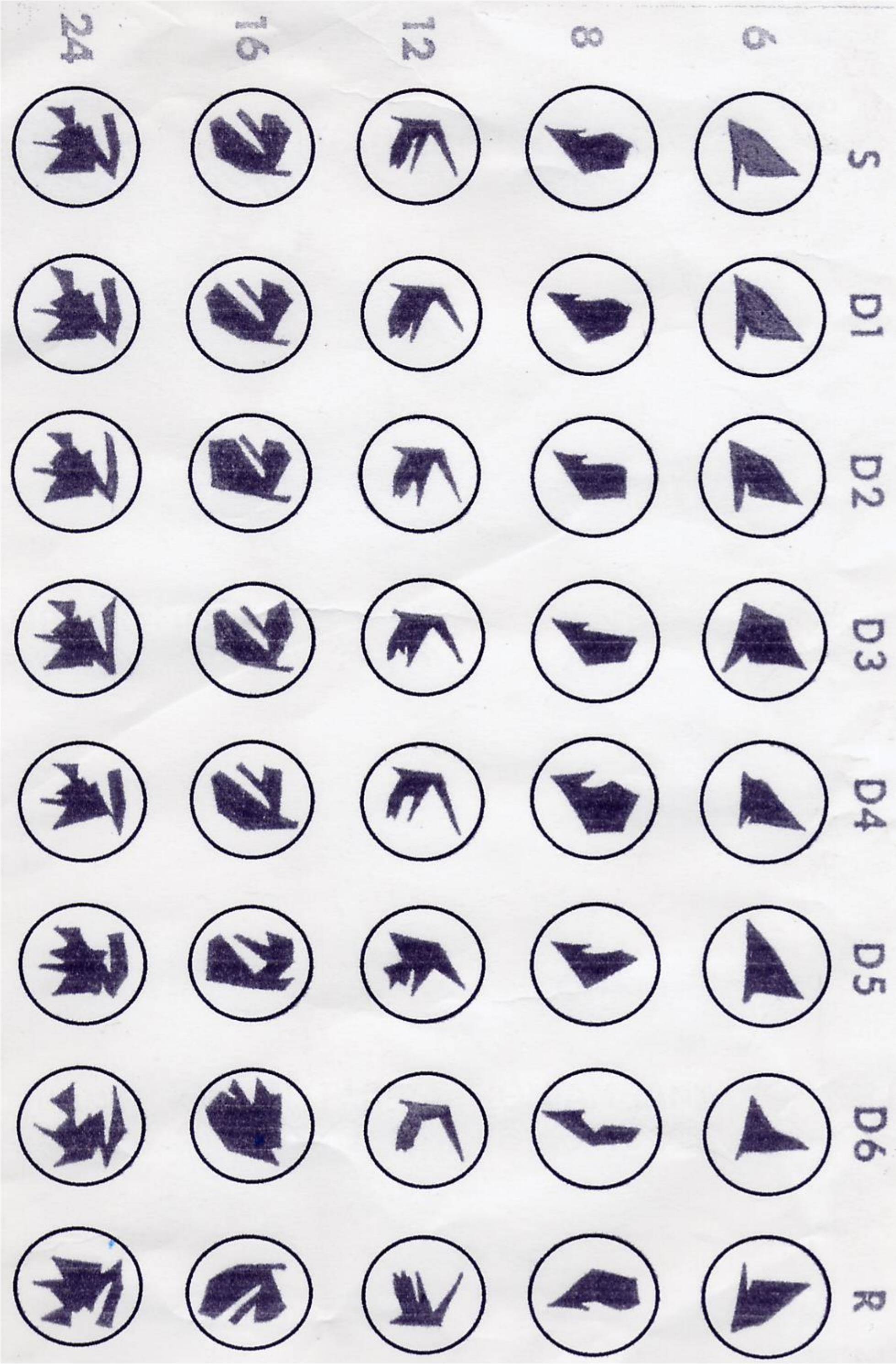
Bat baseball	Ra	Rm	E	Lm	La
Write	Ra	Rm	E	Lm	La
Brush teeth	Ra	Rm	E	Lm	La
Throw ball	Ra	Rm	E	Lm	La
Hold tennis racket	Ra	Rm	E	Lm	La
Hammer in a nail	Ra	Rm	E	Lm	La
Use Scissors	Ra	Rm	E	Lm	La
Eats with spoon	Ra	Rm	E	Lm	La
Strike match	Ra	Rm	E	Lm	La
Thread needle (hand that moves)	Ra	Rm	E	Lm	La
Sweep with broom (lower hand) *	Ra	Rm	E	Lm	La
Shovel with large shovel (lower hand) *	Ra	Rm	E	Lm	La
Which hand deals cards	Ra	Rm	E	Lm	La
Opens the lid of a box	Ra	Rm	E	Lm	La
Which hand unscrews jar lid	Ra	Rm	E	Lm	La

Note that all of Annett's (1970) questionnaire items are included within the questionnaire and the two highlighted questions above indicate the two Edinburgh handedness inventory items (Oldfield, 1971) that are not included in the questionnaire. These items were added in order to analyse data with respect to different handedness inventories.

The two asterisked questions (sweep with a brush and use a shovel) indicate that scoring should be reversed on these questions.

Appendix 3

Cooper and Podgorny's (1976) alternative form shapes used as stimuli in impulsivity matching experiment

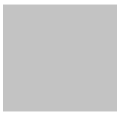


Appendix 4

Matching Figures Task

The aim of this task is to compare two figures and decide whether they are the same or whether they are different. The task will begin when any key is pressed, you will then see a small * in the centre of the screen to indicate that a stimulus is about to appear. The stimulus (similar to the shape shown below) will then briefly flash on the screen and will be followed by a black square which will also flash briefly. After the black square disappears the second shape will appear (the one which you have to compare to the first shape). When this second shape appears a decision has to be made on whether it was the same as the stimulus shape or different. **If it is the same press N, if it is different press B.** The shape will not disappear until you have made a decision. Once the decision has been made the whole process begins again with another stimulus and shape pairing. This task should be done as quickly and as accurately as possible.

E.g. Press a key to begin

* then  then  then 

Then answer B or N

Appendix 5

Barratt Impulsivity Scale (version 11)

1.	I “squirm” at plays or lectures.	rarely/never	occasionally	often	almost always/always
2.	I am restless at the theatre or lectures.	rarely/never	occasionally	often	almost always/always
3.	I don’t “pay attention”.	rarely/never	occasionally	often	almost always/always
4.	I concentrate easily.*	rarely/never	occasionally	often	almost always/always
5.	I am a steady thinker.*	rarely/never	occasionally	often	almost always/always
6.	I act “on impulse”.	rarely/never	occasionally	often	almost always/always
7.	I act on the spur of the moment.	rarely/never	occasionally	often	almost always/always
8.	I buy things on impulse.	rarely/never	occasionally	often	almost always/always
9.	I make up my mind quickly.	rarely/never	occasionally	often	almost always/always
10.	I do things without thinking.	rarely/never	occasionally	often	almost always/always
11.	I spend or charge more than I earn.	rarely/never	occasionally	often	almost always/always
12.	I am happy-go-lucky.	rarely/never	occasionally	often	almost always/always
13.	I am a careful thinker.*	rarely/never	occasionally	often	almost always/always
14.	I plan tasks carefully.*	rarely/never	occasionally	often	almost always/always
15.	I am self-controlled.*	rarely/never	occasionally	often	almost always/always
16.	I plan trips well ahead of time.*	rarely/never	occasionally	often	almost always/always
17.	I plan for job security.*	rarely/never	occasionally	often	almost always/always
18.	I say things without thinking.	rarely/never	occasionally	often	almost always/always
19.	I like to think about complex problems.*	rarely/never	occasionally	often	almost always/always
20.	I like puzzles.*	rarely/never	occasionally	often	almost always/always
21.	I save regularly.*	rarely/never	occasionally	often	almost always/always
22.	I am more interested in the present than the future.	rarely/never	occasionally	often	almost always/always

23. I get easily bored when solving thought problems. rarely/never occasionally often almost always/always

24. I change residences. rarely/never occasionally often almost always/always

25. I change jobs. rarely/never occasionally often almost always/always

26. I am future oriented.*[4] rarely/never occasionally often almost always/always

27. I can only think about one problem at a time. rarely/never occasionally often almost always/always

28. I often have extraneous thoughts when thinking. rarely/never occasionally often almost always/always

29. I have “racing” thoughts. rarely/never occasionally often almost always/always

30. I change hobbies. rarely/never occasionally often almost always/always

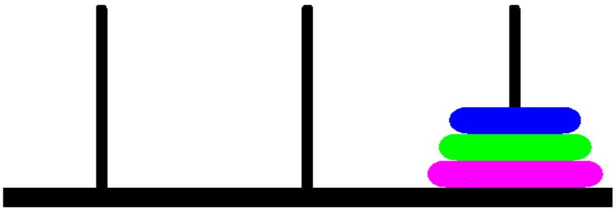
---

[4] The asterisk (*) beside a question signifies that the scoring should be reversed on such statements.

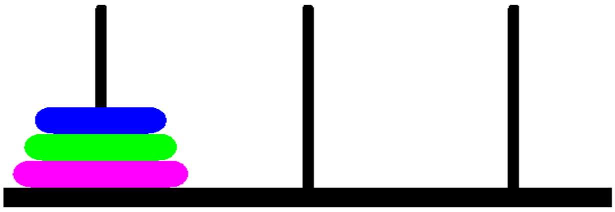
Instruction sheet for the 3-disk Tower of Hanoi (right side start)

You are going to be presented with the “Tower of Hanoi” problem. This will consist of three vertical pegs in a row, the first of which will have three disks piled on it in order of size (the largest disk on the bottom and the smallest disk on the top). The aim is to have all the disks piled in the same order but on the last peg (moving from right to left). BUT, disks can only be moved in certain ways. Only one disk can be moved at a time and a larger disk can never be placed on top of a smaller disk.

INITIAL STATE



GOAL STATE

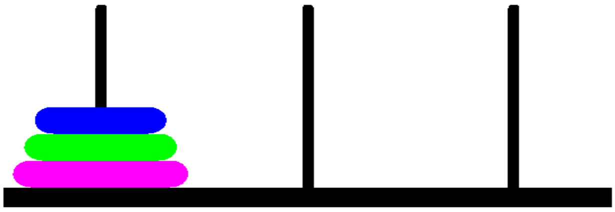


Appendix 6b

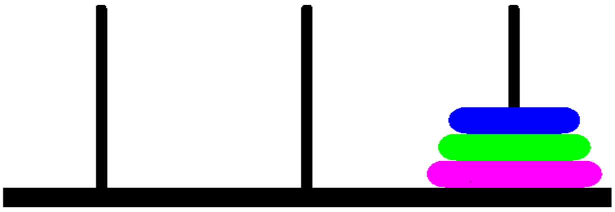
Instruction sheet for the 3-disk Tower of Hanoi (left side start)

You are going to be presented with the "Tower of Hanoi" problem. This will consist of three vertical pegs in a row, the first of which will have three disks piled on it in order of size (the largest disk on the bottom and the smallest disk on the top). The aim is to have all the disks piled in the same order but on the last peg (moving from right to left). BUT, disks can only be moved in certain ways. Only one disk can be moved at a time and a larger disk can never be placed on top of a smaller disk.

INITIAL STATE



GOAL STATE



Appendix 7

Tower of Hanoi Task – Scoring Sheet

Matriculation Number: ____

Course (and year): ____

Are you: Male Female (please circle)

Were you born in the: 1940's 1950's 1960's 1970's 1980's

Do you consider yourself to be left- or right-handed: ___________________

Which hand do you use to write with: _____________________________

Have you done the Tower of Hanoi Task before now? _________________

Time taken before moving first disk	
Time taken to complete the task	
Number of moves taken to complete task	
Number of errors made	

Appendices 8-12 (pp. 405-420) have been removed from this e-thesis due to copyright restrictions

Appendix 13

'Fastest Finger First' Instruction sheet

You are going to be shown a series of questions that ask you to order the answers in some way. Half of the questions will have three answers and the other half will have five answers that you need to order (these will be presented randomly). Firstly, you will be shown the question and when you understand what it is asking for press a key to be shown the answers. For the questions that have three answers respond using keys 1, 2 and 3 (each answer is numbered). For the questions that have five answers respond using keys 1, 2, 3, 4 and 5. An example of a three-answer question and a five-answer question is given below. **You should respond with your dominant hand.**

Example of a three-answer question:

Put the following words in alphabetical order

1. Coat **2. Cold**

3. Coconut

Response: 1 3 2

Example of a five-answer question:

Starting with the lowest put these numbers in order

1. 56 **2. 42**

3. 17 **4. 73**

5. 32 **6. 9**

Response: 6 3 5 2 1 4

Fastest Finger First Experimental stimuli

Three-response questions and answers:

Put the following cities in the order they appear on a map from north to south:

1. Newcastle
2. London
3. Manchester

Put these parts of the body in the order that they appear from the bottom of the body to the top:

1. Shoulders
2. Knees
3. Elbows

Put the following colours in the order that they appear in a rainbow:

1. Red
2. Blue
3. Green

Fastest Finger First Experimental stimuli

Put the following words in alphabetical order:

1. Apple

2. Antelope

3. Art

Starting with the highest put the answers to the following sums in numerical order:

1. 2+3

2. 3+1

3. 4+2

Starting with the largest put the following groups in numerical order:

1. U2

2. UB40

3. Level 42

Fastest Finger First Experimental stimuli

Put the following words in the order that they appear in the song title:

1. **Will**
2. **I**
3. **Survive**

Put the following words in alphabetical order:

1. **Cracker**
2. **Crow**
3. **Crab**

Starting from the bottom put these features in the order that they appear on the face:

1. **Nose**
2. **Lips**
3. **Eyebrows**

Appendix 14 continued

Fastest Finger First Experimental stimuli

Put the following football teams in reverse alphabetical order:

1. Liverpool
2. Leeds
3. Leicester

Questions with 6 responses:

Starting with the smallest put the following fractions in order:

1. 1/4
2. 1/2
3. 1/8
4. 1/16
5. 1/10
6. 1/12

Put the following numbers in numerical order from highest to lowest:

1. 27
2. 73
3. 45
4. 18
5. 39
6. 32

Appendix 14 continued

Fastest Finger First Experimental stimuli

Starting with the smallest put these words in order according to how many letters they have:

1. **Monkey**
2. **Mouse**
3. **Mammoth**
4. **Mare**
5. **Marmalade**
6. **Mum**

Starting with the largest put these words in order according to how many letters they have:

1. **Bottle**
2. **Bone**
3. **Brother**
4. **Bacon**
5. **Birmingham**
6. **Boy**

Starting with the lowest put the answers to the following sums in numerical order:

1. **5 x 2**
2. **4 x 3**
3. **3 x 3**
4. **6 x 1**
5. **2 x 7**
6. **7 x 1**

Put these numbers in numerical order from lowest to highest:

1. 1047
2. 1487
3. 1178
4. 1564
5. 1349
6. 1268

Put the following words in alphabetical order:

1. Pig
2. Pencil
3. Paper
4. Painter
5. Pin
6. Penguin

Put the following words in the order that they appear in the television programme:

1. Millionaire
2. Wants
3. Be
4. Who
5. To
6. A

Put the following cities in reverse alphabetical order:

1. Edinburgh
2. London
3. Cardiff
4. Belfast
5. Dublin
6. Dundee

Put the following points in the order that they would appear on a compass:

1. South West
2. South East
3. North East
4. West
5. North West
6. North

Chapter 6 – additional results.

A6.0. ‘FASTEST FINGER FIRST’ (Study 1)

Table A6.1: Average time (in milliseconds) spent looking at the question by left- and right-handers (with standard deviations in parentheses).

Hand Preference	Chapter 3 Mean time
Left	4113.76 (1160.8)
Right	4665.8 (1478.27)
Total	4378.43 (1342.2)

The above table shows that, on average, the time spent looking at the question by left and right-handers was similar with right-handers spending around 500ms longer. To see if there was a significant difference between left and right-handers on the time spent looking at the question a Oneway ANOVA was carried out F(1, 72) = 3.175, p=0.079 and it was found that there was no significant difference. (However, this approached significance).

Table A6.2: Average time (in milliseconds) spent looking at the question by males and females (with standard deviations in parentheses).

Sex	Chapter 4 Mean time
Male	4491.04 (951.29)
Female	4292.38 (1205.9)
Total	4391.71 (1078.6)

The above table shows that, on average, the time spent looking at the question by males and females was very similar with males spending slightly more time. To see if there was a significant difference between males and females on the time spent looking at the question a Oneway ANOVA was carried out F(1, 72) = 0.355, p>0.05 and it was found that there was no significant difference.

A6.1. First response – Correct responses only

Table A6.3: Mean time taken (in milliseconds) for male and female left and right – handers to make the first response to questions with 3 options (with standard deviations in parentheses).

	Left	**Right**	**Total**
Chapter 5 Male	6179.00 (3891.25)	5435.15 (1960.41)	5807.08 (2925.83)
Female	6282.97 (3430.48)	5884.07 (1999.96)	6083.52 (2715.22
Total	6230.99 (3660.87	5659.61 (1980.19)	

The above table shows that for questions that contained three options to be ordered, left-handed females, on average, took the longest to make their first response to the question followed by left-handed males and then right-handed females. Right-handed males responded the quickest. Left-handers overall took longer to make their first response than right-handers and females took longer than males to make their first response.

To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 0.156, p>0.05. There was no main effect of handedness F(1, 72) = 0.668, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 0.061, p>0.05.

Table A6.4 : Mean time taken (in milliseconds) for male and female left and right-handers to make the first response to questions with 6 options (with standard deviations in parentheses).

	Left	**Right**	**Total**
Chapter 6 Male	6533.06 (4357.56)	6308.63 (3140.89)	6420.85 (3749.23)
Female	7194.03 (3755.19)	7314.68 (2970.23)	7254.36 (3362.71)
Total	6863.55 (4056.38)	6811.66 (3055.56)	

The above table shows that for questions that contained five options to be ordered as answers, right-handed females, on average, took the longest to make their first response to the question followed by left-handed females and then left-handed males. Right-handed males responded the quickest. There was very little difference between the first response times of left-handers and right-handers and females took longer than males to make their first response. To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 0.966, p>0.05. There was no main effect of handedness F(1, 72) = 0.004, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 0.041, p>0.05.

Table A6.5: Mean first response times (in milliseconds) for each sex and handedness group for 3 and 6 options averaged (with standard deviations in parentheses).

	Left	**Right**	**Total**
Chapter 7 Male	9739.10 (5578.96)	9826.75 (6306.30)	9782.93 (5942.63)
Female	9883.41 (2780.69)	8059.37 (2460.26)	8971.39 (2620.48)
Total	9811.26 (4179.83)	8943.06 (4383.28)	

The above table shows that when the first response times are averaged across three and five options left-handed females, on average, take the longest to respond (9883.41 ms) closely followed by right-handed males (9826.75 ms on average) and left-handed males (9739.10 ms on average). Right-handed females, on average over three and five options, responded the quickest (8059.37 ms). Males, on average, took longer to respond than females (9782.93 ms Vs. 8971.39 ms) and left-handers took longer to respond than right-handers (9811.26 ms Vs. 8943.06 ms).

To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 0.575, p>0.05. There was no main effect of handedness F(1, 72) = 0.658, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 0.798, p>0.05.

Table A6.6: Comparison of mean correct first response times between three options and six options (with standard deviations in parentheses).

	Left Male	Right Male	Left Female	Right Female	Total
3 options	6179.00 (3891.25)	5435.15 (1960.41)	6282.97 (3430.48)	5884.07 (1999.96)	5945.30 (2820.53)
5 options	6533.06 (4357.56)	6308.63 (3140.89)	7194.03 (3755.19)	7314.68 (2970.23)	6837.61 (3555.97)

The above table shows that for each group the mean correct first response times for the questions with 6 options were longer than the first response times for the questions with 3 options. The total times showed that overall the correct first response times for 6 options were, on average, longer than the first responses to the questions with 3 options.

A 2 x 2 x 2 mixed model ANOVA was carried out with type of question as the within subjects factor (3 options or 6 options) and sex and handedness the between subjects factors. A significant main effect of question was found F(1, 69) = 14.975, p=0.000 where correct first response times to the 6 option questions were significantly longer than first response times to the 3 option questions (6837.61 ms vs. 5945.30 ms respectively). However, the main effect of sex failed to reach significance F(1, 69) = 0.559, p>0.05 as did the main effect of handedness F(1, 69) = 0.176, p>0.05. The interaction between sex and handedness also failed to reach significance F(1, 69) = 0.054, p>0.05 Therefore, the number of options to the questions had an effect on first response time but sex or handedness played no part in this effect – it appeared to be the complexity rather than sex or handedness.

A6.2. Total time taken (correct responses only)

Table A6.7: Mean total time taken (in seconds) for male and female, left and right-handers to answer questions with three options (with standard deviations in parentheses).

	Left	**Right**	**Total**
Chapter 8 Male	7967.34 (5128.83)	8394.01 (2497.94)	8180.68 (3813.39)
Female	7695.16 (2303.91)	6650.98 (1922.37)	7173.07 (2113.14)
Total	7831.25 (3716.37)	7522.50 (2210.16)	

The above table shows that right-handed males, on average, took the longest to answer each question with three options (8394.01 ms). Left-handed males took the next longest (7967.34 ms on average) followed by left-handed females (7695.16 ms on average) and right-handed females took the shortest time (6650.98 ms on average). Males took longer than females, on average, to solve the three option questions (all correct) (8180.68 ms Vs. 7173.07 ms) and left-handers took longer to solve the questions than right-handers (7831.25 ms Vs. 7522.50 ms).

To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 1.490, p>0.05. There was no main effect of handedness F(1, 72) = 0.140, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 0.794, p>0.05.

Table A6.8: Mean total time taken (in seconds) for male and female, left and right-handers to answer questions with six options (with standard deviations in parentheses).

	Left	**Right**	**Total**
Chapter 9 Male	13846.04 (7326.28)	15279.36 (3446.82)	14562.7 (5386.55)
Female	13862.21 (3363.07)	12352.10 (2830.65)	13107.16 (3096.86)
Total	13854.13 (5344.68)	13815.73 (3138.74)	

The above table shows that right-handed males, on average, took the longest to answer each question with five options (15279.36 ms). Left-handed males and left-handed females took similar times, on average, to solve the five option questions (13846.04 ms and 13862.21 ms respectively). Right-handed females solved the five option questions the fastest (12352.10 ms on average). Males took longer than females, on average, to solve the six option questions (14562.7 ms Vs. 13107.16 ms) and left-handers took slightly longer to solve the questions than right-handers but only a difference of 38.4 ms on average (13854.13 ms Vs. 13815.73 ms).

To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 0.223, p>0.05. There was no main effect of handedness F(1, 72) = 0.974, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 0.218, p>0.05.

Table A6.9: Mean total time taken (in seconds) for male and female, left and right-handers to answer questions overall (with standard deviations in parentheses).

	Left	**Right**	**Total**
Chapter 10 Male	14038.18 (5375.75)	15265.88 (4378.54)	14652.03 (4877.15)
Female	14373.49 (3043.96)	12887.71 (2422.60)	13630.6 (2733.28)
Total	14205.84 (4209.86)	14076.80 (3400.57)	

The above table shows that right-handed males, on average, took the longest to answer each question over three and six options (15265.88 ms). Left-handed males and left-handed females took similar times, on average, to solve the three and five option questions (combined) (14038.18 ms & 14373.49 ms respectively). Right-handed females took the shortest time, on average, to solve the three and five options combined (12887.71 ms). Males took longer than females, on average, to solve the three and six option questions (combined) (14652.03 ms Vs. 13630.6 ms) and left-handers took slightly longer to solve the questions than right-handers

(14205.84 ms Vs. 14076.80 ms).To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 1.199, p>0.05. There was no main effect of handedness F(1, 72) = 0.019, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 2.115, p>0.05.

Table A6.10: Comparison of mean total time taken to answer the questions (correct answers only) between three options and six options (with standard deviations in parentheses).

	Left Male	**Right Male**	**Left Female**	**Right Female**	**Total**
3 options	7967.34 (5128.83)	8394.01 (2497.94)	7695.16 (2303.91)	6650.98 (1922.37)	7676.87 (2963.63)
5 options	13846.04 (7326.28)	15279.36 (3446.82)	13862.21 (3363.07)	12352.10 (2830.65)	13834.93 (4241.71)

The above table shows that for each group the mean total time for the questions with 6 options were longer than the mean total time for the questions with 3 options. The total times showed that overall the mean total time (correct responses only) for 5 options was, on average, longer than the mean total time for the questions with 3 options.A 2 x 2 x 2 mixed model ANOVA was carried out with type of question as the within subjects factor (3 options or 6 options) and sex and handedness the between subjects factors. A significant main effect of question was found F(1, 69) = 281.450, p=0.000 where mean total time taken to answer the 6 option questions was significantly longer the mean total time taken to answer the 3 option questions (13834.93 ms vs. 7676.87 ms respectively). However, the main effect of sex failed to reach significance F(1, 69) = 0.110, p>0.05 as did the main effect of handedness F(1, 69) = 0.039, p>0.05. The interaction between sex and handedness also failed to reach significance F(1, 69) = 0.012, p>0.05 Therefore, the number of options to the questions had an effect on total completion time although this is a straightforward logical explanation, related to the time to physically press the buttons in the 6 choice condition..

Appendix 15 continued

A6.3. Time per move (correct responses only)

Table A6.11: Mean time per response for male and female, left and right-handers (correct only) for questions with three options (with standard deviations in parentheses).

	Left	**Right**	**Total**
Chapter 11 Male	2543.51 (1646.55)	2611.77 (842.12)	2577.64 (1244.34)
Female	2532.03 (733.36)	2216.99 (640.79)	2374.51 (687.08)
Total	2537.77 (1189.96)	2414.38 (741.46)	

The above table shows that each of the four groups took a similar time, on average, to make each individual response to the question for three options. Right-handed females were slightly faster (2216.99 ms on average) but left-handed males, right-handed males and left-handed females took similar times, on average, per response (2543.51 ms; 2611.77 ms & 2532.03 ms). Males and females also took similar times per response, on average. Males took slightly longer per response than females (2577.64 ms Vs. 2374.51 ms). Left-handers took slightly longer per response than right-handers (2537.77 ms Vs. 2414.38 ms).

To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 0.675, p>0.05. There was no main effect of handedness F(1, 72) = 0.249, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 0.601, p>0.05.

Table A6.12: Mean time per response (correct only) for male and female, left and right-handers for questions with six options (with standard deviations in parentheses).

	Left	**Right**	**Total**
Chapter 12 Male	2563.06 (684.89)	2972.23 (1440.89)	2767.65 (1062.89)
Female	2710.97 (666.39)	2494.69 (587.50)	2602.83 (626.95)
Total	2637.02 (675.64)	2733.46 1014.20)	

The above table shows that each of the four groups took a similar time, on average, to make each individual response to the question for six options. Right-handed males took the longest per response (2972.23 ms on average) followed by left-handed females (2710.97 ms on average), left-handed males (2563.06 ms on average) and right-handed females took the least time per response (2494.69. Males and females also took similar times per response, on average. Males took slightly longer per response than females (2767.65 ms Vs. 2602.83 ms). Right-handers took slightly longer per response than left-handers on average (2733.46 ms Vs. 2637.02 ms).

To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 0.436, p>0.05. There was no main effect of handedness F(1, 72) = 0.211, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 2.213, p>0.05.

Table A6.13: Mean time per correct response for male and female, left and right-handers for questions overall (with standard deviations in parentheses).

	Left	**Right**	**Total**
Chapter 13 Male	2553.29 (920.48)	2792.00 (830.72)	2672.65 (875.6)
Female	2621.50 (458.15)	2355.84 (435.30)	2488.67 (446.73)
Total	2587.40 (689.32)	2573.92 (633.01)	

The above table shows that when averaging the time per response (for correct responses only) for three and six options right-handed males took the longest time per response (2792.00 ms on average), they were closely followed by left-handed females who took, on average, 2621.50 ms per response. Male left-handers took 2553.29 ms on average and right-handed females took the shortest time per move on average (2355.85 ms). Males took slightly longer, on average, per response than females (2672.65 ms Vs. 2488.67 ms) and left- and right-handers took almost the same time per response (2587.40 ms Vs. 2573.92 ms on average).

To see if any of these differences were significant, a 2 x 2 (sex v handedness) ANOVA was carried out. There was no main effect of sex F(1, 72) = 1.128, p>0.05. There was no main effect of handedness F(1, 72) = 0.007, p>0.05 and the interaction between sex and handedness also failed to reach significance F(1, 72) = 2.228, p>0.05.

Table A6.14: Comparison of mean time per response (correct answers only) between three options and six options (with standard deviations in parentheses).

	Left Male	Right Male	Left Female	Right Female	Total
3 options	2543.51 (1646.55)	2611.77 (842.12)	2532.03 (733.36)	2216.99 (640.79)	2476.08 (965.71)
6 options	2563.06 (684.89)	2972.23 (1440.89)	2710.97 (666.39)	2494.69 (587.50)	2685.22 (844.92)

The above table shows that for each group the mean correct time per response for the questions with 6 options were longer than the first response times for the questions with 3 options but the scores were very similar. The total time per response showed that overall time per response for 6 options was, on average, longer than time per response to the questions with 3 options. A 2 x 2 x 2 mixed model ANOVA was carried out with type of question as the within subjects factor (3 options or 6 options) and sex and handedness the between subjects factors. There was no significant main effect of question F(1, 69) = 1.760, p>0.05). The main effect of sex also failed to reach significance F(1, 69) = 1.128, p>0.05 as did the main effect of handedness F(1, 69) = 0.007, p>0.05. The interaction between sex and handedness also failed to reach significance F(1, 69) = 2.288, p>0.05.

Appendix 16

Sorting task stimuli

1 Swift

2 Dog

3 **Cow**

Appendix 15

Sorting task stimuli

Appendix 15

Sorting task stimuli


7

Monkey


8

Parrot

9

Pig

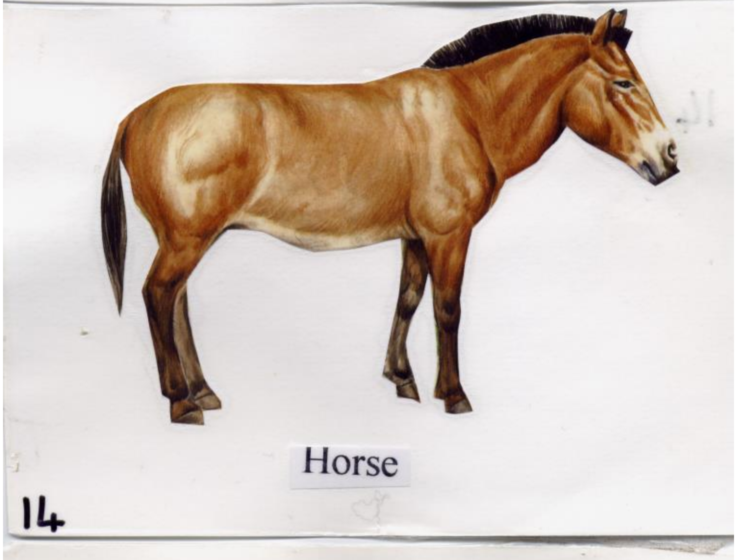
Appendix 15

Sorting task stimuli

12 **Chimpanzee**

Appendix 15

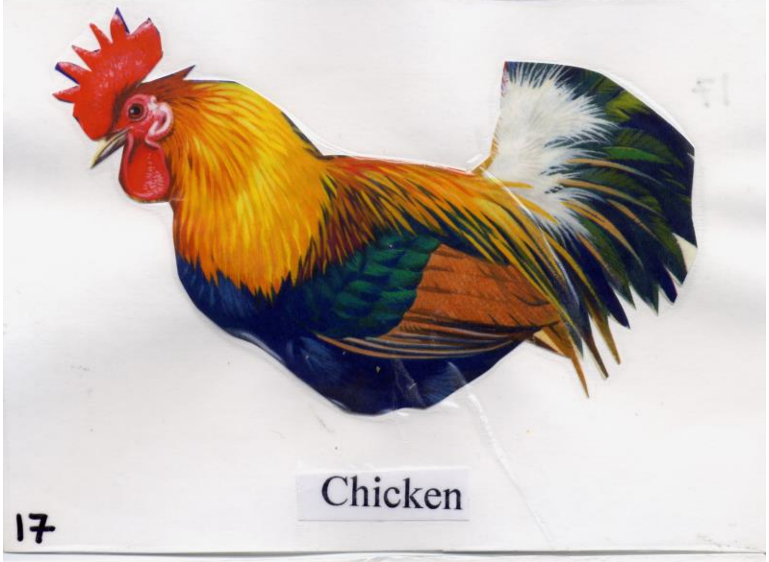
Sorting task stimuli



15 **Rat**

Appendix 15

Sorting task stimuli



18 **Penguin**

Sorting task stimuli

Sheep

19

Elephant

20

Appendix 17

Sorting Task Instructions

You are going to be presented with a set of 20 cards.

Your task is to sort them into different categories.

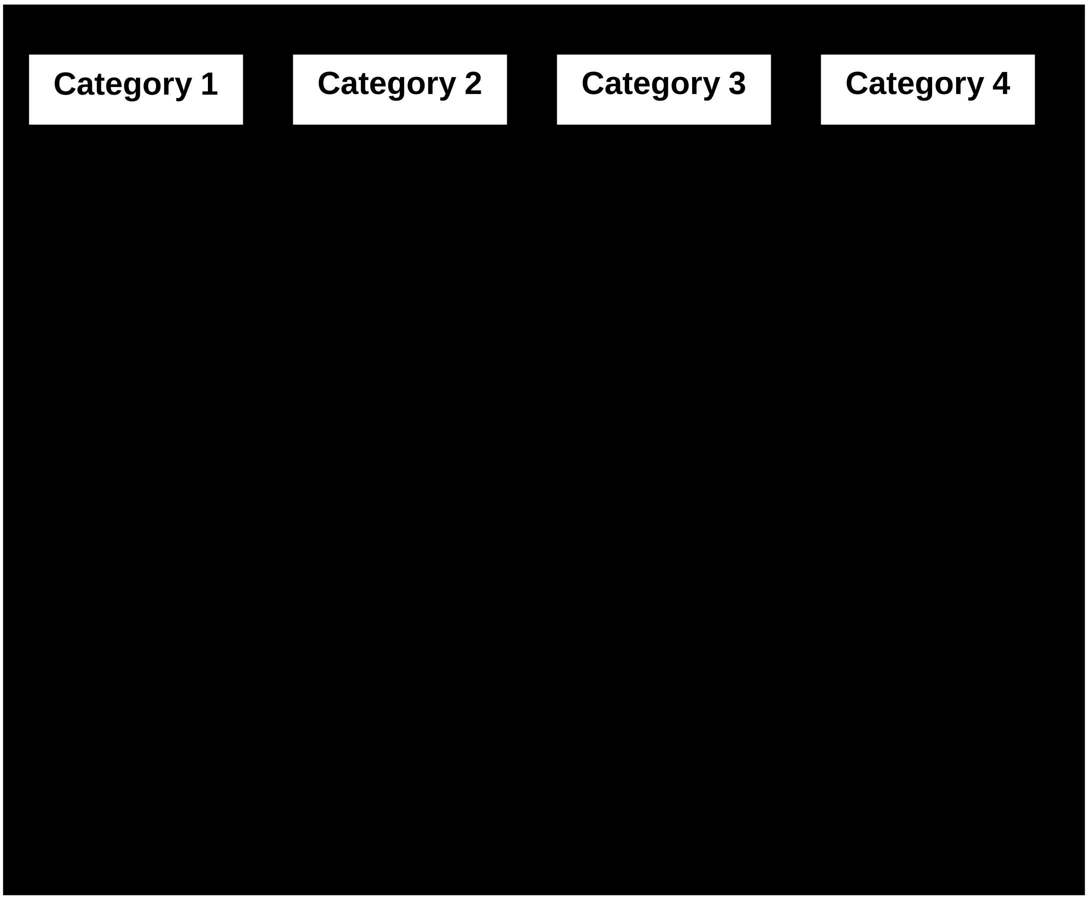
You should make 4 categories, each with 5 items in them. You should move them the cards in to a space on the board provided.

Each category that you make should follow a rule decided by you – but all groups don't have to follow the same rule.

When you have finished making the categories you will be asked to write down the rule that each category follows.

Appendix 18

Sorting Board



Appendix 19

Sorting Task Scoring Sheet

Matriculation Number:____
Age: ____
Course:____
Are you: Male Female
With which hand do you write? Left Right Either
Which do you consider to be your dominant hand? Left Right Either

Time taken to move first picture	
Total time taken to make all categories	

Category 1 Rule

____

Category 2 Rule

____

Category 3 Rule

____

Category 4 Rule

____

Pictures in each category (by number):

Category 1	Category 2	Category 3	Category 4

Appendices 20-24 (pp. 449-472) have been removed from this e-thesis due to copyright restrictions

Appendix 25

BIS/BAS Questionnaire

Each item of this questionnaire is a statement that a person may either agree with or disagree with. For each item, indicate how much you agree or disagree with what the item says. Please respond to all the items; do not leave any blank. Choose only one response to each statement. Please be as accurate and honest as you can be. Respond to each item as if it were the only item. That is, don't worry about being "consistent" in your responses. Choose from the following four response options:

1 = very true for me 2 = somewhat true for me 3 = somewhat false for me 4 = very false for me

(THE BIS QUESTIONS ARE HIGHLIGHTED IN BLUE)

1. A person's family is the most important thing in life.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

2. Even if something bad is about to happen to me, I rarely experience fear or nervousness.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

3. I go out of my way to get things I want.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

4. When I'm doing well at something I love to keep at it.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

5. I'm always willing to try something new if I think it will be fun.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

6. How I dress is important to me.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

7. When I get something I want, I feel excited and energized.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

8. Criticism or scolding hurts me quite a bit.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

Appendix 25

BIS/BAS Questionnaire continued

9. When I want something I usually go all-out to get it.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

10. I will often do things for no other reason than that they might be fun.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

11. It's hard for me to find the time to do things such as get a haircut.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

12. If I see a chance to get something I want I move on it right away.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

13. I feel pretty worried or upset when I think or know somebody is angry at me.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

14. When I see an opportunity for something I like I get excited right away.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

15. I often act on the spur of the moment.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

16. If I think something unpleasant is going to happen I usually get pretty "worked up."

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

17. I often wonder why people act the way they do.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

18. When good things happen to me, it affects me strongly.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

19. I feel worried when I think I have done poorly at something important.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

BIS/BAS Questionnaire continued

20. I crave excitement and new sensations.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

21. When I go after something I use a "no holds barred" approach.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

22. I have very few fears compared to my friends.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

23. It would excite me to win a contest.

1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

24. I worry about making mistakes.

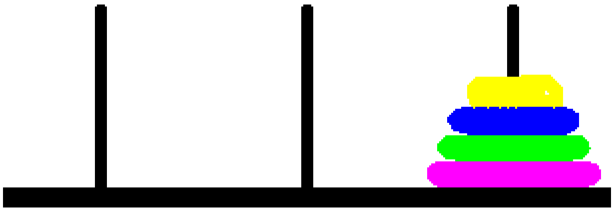
1 = very true for me	2 = somewhat true for me	3 = somewhat false for me	4 = very false for me

Thank you

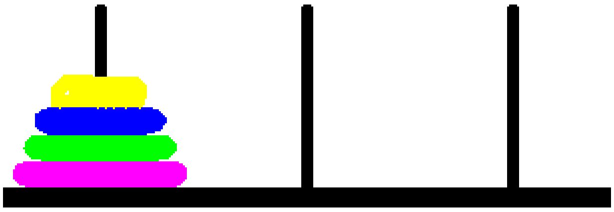
4-disk Tower of Hanoi Instructions

You are going to be presented with the 4-disk Tower of Hanoi. The aim is to move all 4 disks to the opposite peg so that they are sitting in the same order. There are 3 rules– firstly, you can only move one disk at a time (you cannot hold another disk in your hand while moving a disk), you can never place a bigger disk on top of a smaller disk and you can only use one hand to move the disks with (this should be your dominant hand).

Initial State



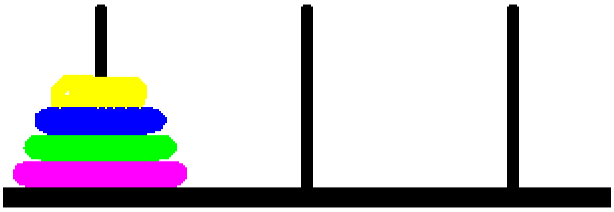
Goal State



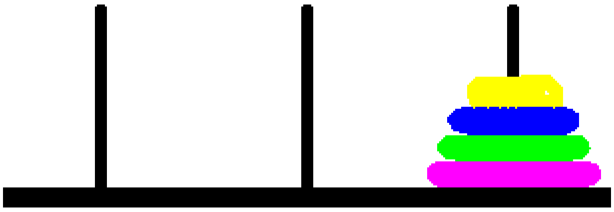
4-disk Tower of Hanoi Instructions

You are going to be presented with the 4-disk Tower of Hanoi. The aim is to move all 4 disks to the opposite peg so that they are sitting in the same order. There are 3 rules – firstly, you can only move one disk at a time (you cannot hold another disk in your hand while moving a disk), you can never place a bigger disk on top of a smaller disk and you can only use one hand to move the disks with (this should be your dominant hand).

Initial State



Goal State



Tower of Hanoi Scoring Sheet (novelty and complexity)

Participant # ________

1st trial 3-disk 4-disk

Time taken before moving first disk	
Time taken to complete the task	
Number of moves taken to complete task	

2nd trial 4-disk (1st time) 4-disk (2nd time)

Time taken before moving first disk	
Time taken to complete the task	
Number of moves taken to complete task	

Appendix 28

A7.0. Chapter 7: Additional analyses

These results (both state and trait anxiety measurements) were reanalysed using different handedness classification systems (these different handedness measurements are ones that are used most often in the handedness literature). A summary of these findings can be found in the table below.

A7.1. Before state overall

Table A7.1: Summary of state/trait findings (overall) using different handedness classification systems.

Classification System	State Analysis	Trait Analysis
Own overall	Significant (left)	Not Significant
Peters Consistent	**Significant (left)**	Not Significant
Own Strong	Not Significant	Not Significant
Own Mixed	Not Significant	Not Significant
EHI Strong	**Significant (left)**	Not Significant
EHI Mixed	Not Significant	Not Significant
Waterloo Strong	**Significant (left)**	Not Significant
Waterloo Mixed	Not Significant	Not Significant
Bishop Weak	Not Significant	Not Significant
Bishop Predominant	Not Significant	Not Significant
Annett Consistent	**Significant (left)**	Not Significant
Annett Mixed	Not Significant	Not Significant

The significant differences between left and right-handers' responses to the state questionnaire are consistent using Peter's consistent classification system, the Edinburgh Handedness Inventory strong classification system, the Waterloo handedness inventory strong classification system and Annett's consistent left- or right-hander classification system (as well as the initial classification system (Peters 1998 adapted questionnaire)). All of the classification systems that show significant differences between left- and right-handers are ones that identify strong right- and left-handers rather than ones that identify some degree of weak left- and right-hander or mixed-hander.

A7.2. State/trait: Before

Table A7.2: Summary of state/trait findings (before instructions were shown to the participant) using different handedness classification systems.

Classification System	State Analysis	Trait Analysis
Own overall	Not Significant	Not Significant
Peters Consistent	Not Significant	Not Significant
Own Strong	Not Significant	Not Significant
Own Mixed	Not Significant	**Significant (left)**
EHI Strong	**Significant (left)**	Not Significant
EHI Mixed	**Significant (interaction)**	Not Significant
Waterloo Strong	**Significant (left)**	Not Significant
Bishop Weak	Not Significant	Not Significant
Bishop Predominant	Not Significant	Not Significant
Annett Consistent	Not Significant	**Approaching (left)**
Annett Mixed	Not Significant	**Significant (female)**

The lack of significant differences between left and right-handers' responses to the state questionnaire are consistent using all classification systems except for both Edinburgh handedness inventory classifications and the strong classification of the Waterloo handedness inventory. There are significant differences between the mixed classification of the original questionnaire used (Peters 1998 adapted questionnaire) and of Annett's mixed classification group on the trait questionnaire. This is inconsistent with the original overall findings.

A7.3. State/trait: After

Table A7.3: Summary of state/trait findings (after instructions were shown to the participant) using different handedness classification systems.

Classification System	**State Analysis**	**Trait Analysis**
Own overall	Significant (left)	Not Significant
Peters Consistent	Significant (left)	Not Significant
Own Strong	Not Significant	Not Significant
Own Mixed	Significant (left + Interact)	Significant (left)
EHI Mixed	Not Significant	Significant (left)
Waterloo Strong	Not Significant	Not Significant
Bishop Predominant	Not Significant	Not Significant
Annett Mixed	Not Significant	Significant (left)

The above table shows that among those that were shown the instructions before completing the state anxiety questionnaire using the current questionnaire (adapted version of Peters 1998) left-handers had a significantly higher state anxiety score than right-handers. When the data was reanalysed using a variety of other popular handedness inventories Peter's consistent classification also revealed significant differences between the groups but no other handedness inventories did. With respect to the trait anxiety questionnaire three mixed classifications all revealed significant differences between weak left- and right-handers with the left-handers in the current mixed category, the Edinburgh handedness Inventory mixed classification and Annett's mixed classification all scoring significantly higher on the trait anxiety questionnaire than right-handers.

A7.4. Tower of Hanoi – Study 3.

Table A7.4: Participant's mean handedness scores with standard deviations in parentheses

	Left	Right
Male	-19.3 (14.5)	32.2 (9.1)
Female	26.6 (13.2)	33 (8.4)
Total	-23.5 (13.9)	32.6 (8.5)

Table A7.4 shows that on average right-handed males and females scored similar scores on the handedness questionnaire with right-handed males scoring slightly lower and having more variability in their scores. Left-handed females had on average stronger left-hand preferences than left-handed males (-26.6 v –19.3 respectively).

* This supports Annett's work that states that females have a stronger shift to the right and thus who do not shift must have a stronger left-hand preference.

A7.5. Condition 2 – 4-4-disk

Table A7.5: Participant's mean handedness scores with standard deviations in parentheses

	Left	**Right**
Male	-23.6 (14.4)	32.8 (8.7)
Female	-30.3 (12.5)	40.6 (7.3)
Total	-27.2 (13.6)	36.7 (8.8)

Table A7.5 shows that on average right-handed males scored lower on the handedness questionnaire than right-handed females indicating a weaker right-hand preference among right-handed males than females. Left-handed females had on average stronger left-hand preferences than left-handed males (-30.3 v –23.6 respectively).

- Again this supports Annett's work that states that females have a stronger shift to the right and thus who do not shift must have a stronger left-hand preference.

A7.6. Two-way interaction on time taken to move the first disk on 4-4 condition – condition X handedness

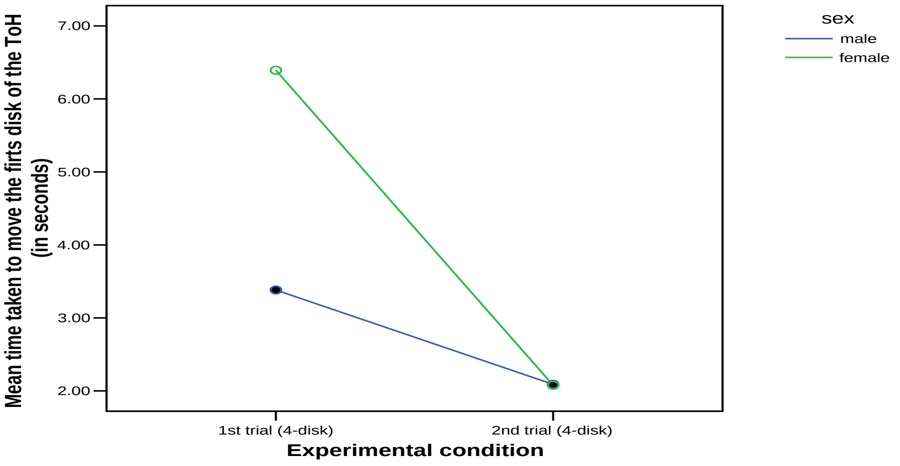


Figure: A7.1: Two-way interaction of trial and sex on the 4-4-disk condition of the Tower of Hanoi on the time taken to move the first disk of the task.

The graph shows that on the first trial of the 4-disk ToH that females took longer to start, on average than males (3.4 seconds vs. 6.2 seconds respectively). However, on the second trial males and females took a similar amount of time to move the first disk on the 4-disk ToH (2.1 seconds for both groups on average).

This significant two-way interaction was examined further by conducting two one-way between subjects ANOVAS – the first examined sex differences on the time taken to move the first disk on the first 4-disk trial and it was found that the difference approached significance F(1, 52) = 3.588, p=0.064 The second one-way between subjects ANOVA examined sex differences on the time taken to move the first disk on the second 4-disk trial and it was found that there was no significant difference between the groups F(1, 52) = 0.001, p>0.05. This was caused by males and females having identical average initiation times to move the first disk on the second trial. It therefore looks possible that the significant interaction between trial and handedness was caused by the slow initiation time of the females on the first task.

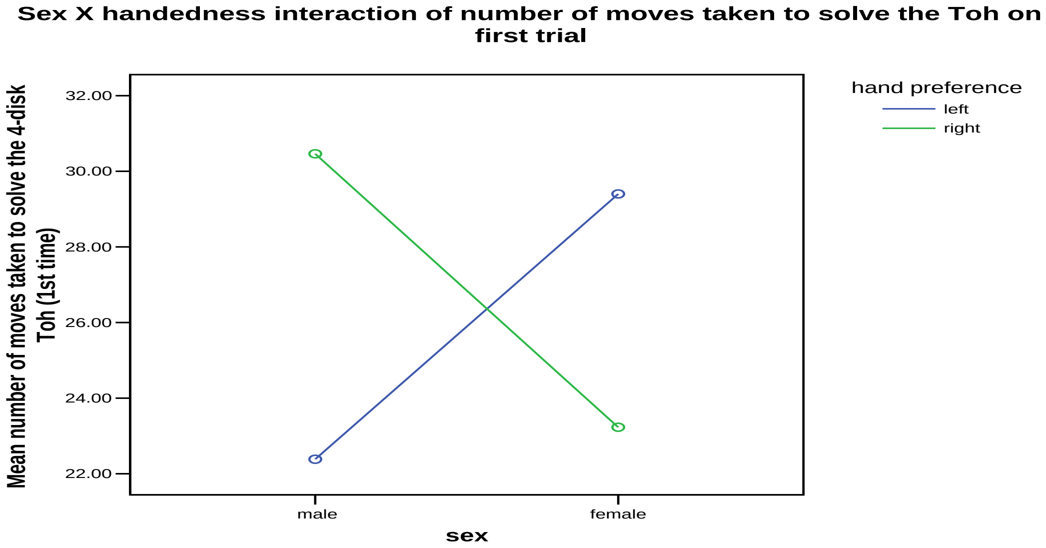


Figure A7.2: Two-way sex X handedness interaction of the number if moves taken to solve the 4-disk ToH on the first trial.

The above graph shows that when solving the 4-disk ToH for the first time that left-handed males solved it in fewer moves (22.4), on average, than right-handed males (30.5) and in fewer moves than left-handed females (29.4) but took around the same number of moves to solve it as right-handed females (23.2).

This significant interaction was examined further by conducting a series of one-way ANOVAs.

A one-way ANOVA was conducted to examine the number of moves taken to complete the 4-disk Tower of Hanoi (first trial) by right-handed males and left-handed males F(1, 24) = 4.268, p=0.05. This suggests that right-handed males took significantly more moves to complete the 4-disk Tower of Hanoi than left-handed males.

A one-way ANOVA was conducted to examine the number of moves taken to complete the 4-disk Tower of Hanoi (first trial) by right-handed females and left-handed females. This was not significant F(1, 26) = 2.815, p>0.05.

Therefore, the significant interaction seems to have been influenced by the performance of left-handed males and right-handed females who took the fewest moves, on average, to solve the 4-diskTower of Hanoi first time. Also, left-handed females and right-handed males took the most moves to solve the Tower of Hanoi and this also contributed to the significant interaction.

A7.7. Comparisons were carried out between the number of moves taken to complete the first trial and the number of moves taken to complete the second trial of the 4-4-disk condition of the ToH. :

A 2 X 2 X 2 mixed model ANOVA was conducted to examine any differences between trials on the number of moves taken to complete the 4-disk Tower of Hanoi. This revealed that there was no significant effect of the Trial (whether it was trial 1 or trial 2) on the number of moves taken to complete the 4-disk Tower of Hanoi F(1, 50) = 0.057, p>0.05. There was no significant main effect of sex F(1, 50), 0.808, p>0.05 or handedness F(1, 50) = 0.127, p>0.05. There were no significant two-way interactions (trial X sex; trial X handedness & sex X handedness all p>0.05). However, there was a significant 3-way interaction between trial, sex and handedness F(1, 50) = 7.152, p=0.01.

The 3-way interaction is further examined below and is split according to hand preference:

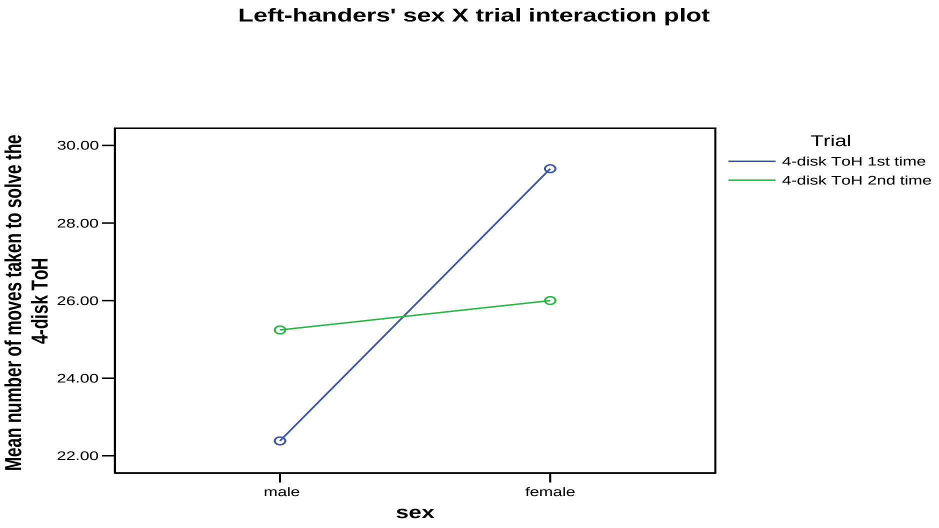


Figure A7.3: Left-handed participant's two-way interaction of sex and trial for the number of moves taken to solve the 4-disk ToH.

The above figure shows that left-handed males took fewer moves to solve the 4-disk ToH on the first trial (22.3 moves) than the second trial (25.2 moves). However, females took fewer moves to solve the second trial (26 moves) than the first trial (29.4 moves). Females took more moves than males on the first trial but around the same number of moves on the second trial..

In order to examine these effects further two one-way between subjects ANOVA's were carried out. The first was carried out on the first 4-disk ToH trial and examined the effect of sex on the number of moves taken to solve the first trial in left-handers F(1, 26) = 3.884, p=0.059. It was found that the difference between male and female left-handers on the number of moves taken to solve the first 4-disk trial of the ToH approached significance with males taking fewer moves to solve it than females. The second ANOVA examined the effect of sex on the number of moves taken to solve the 4-disk ToH second trial in left-handers F(1, 26) = 0.028, p>0.05. It was found that there was no significant difference in the number of moves taken between left-handed males and left-handed females to solve the 4-disk ToH on the second trial.

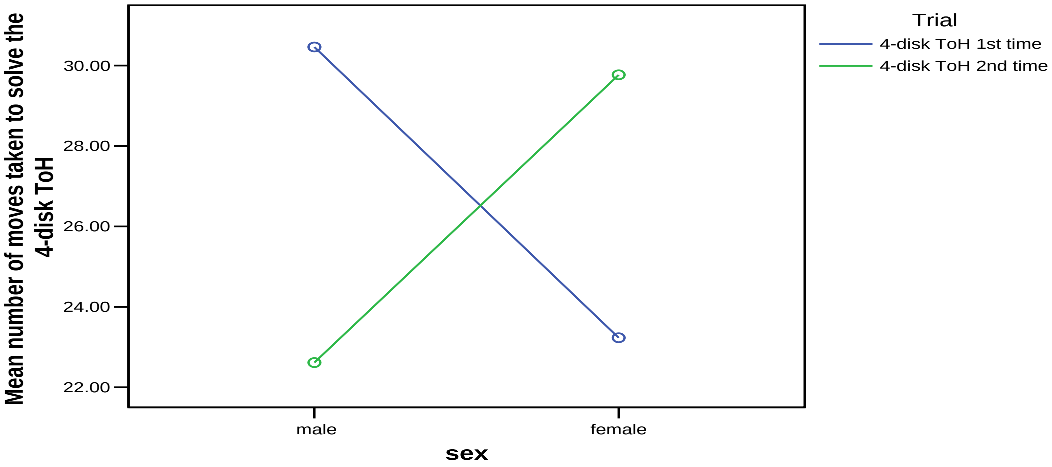


Figure A7.4: Right-handed participant's two-way interaction of sex and trial for the number of moves taken to solve the 4-disk ToH.

The above figure shows that right-handed males took fewer moves to solve the 4-disk ToH on the second trial (22.6 moves) than the first trial (30.5 moves). However, females took fewer moves to solve the first trial (23.2 moves) than the second trial (29.8 moves). Males took more moves than females on the first trial but took less moves than females on the second trial.

In order to examine these effects further two one-way between subjects ANOVA's were carried out. The first was carried out on the first 4-disk ToH trial and examined the effect of sex on the number of moves taken to solve the first trial in right-handers F(1, 24) = 3.214, p=0.086. It was found that the difference between male and female right-handers on the number of moves taken to solve the first 4-disk trial of the ToH approached significance with females taking fewer moves to solve it than males. The second ANOVA examined the effect of sex on the number of moves taken to solve the 4-disk ToH second trial in right-handers F(1, 24) = 02.984, p=0.097. It was found that there was no significant difference in the number of moves taken between right-handed males and right-handed females to solve the 4-disk ToH on the second trial.

Therefore on average the number of moves taken by each group to solve the 4-disk Tower of Hanoi on trial 1 and trial 2 revealed that their performance when doing the trial for a second time did not result in a significantly different number of moves (in either direction).

A7.8. First move

Comparison of condition 1 (3-4-disk) v condition 2 (4-4-disk)

Table A7.6: Mean time taken (in seconds) by males and females to move the first disk on the Tower of Hanoi across conditions (first trial)

	Condition 1 3-disk	Condition 2 4-disk
Male	2.85 (2.37)	3.38 (2.75)
Female	5.34 (4.34)	6.26 (7.28)

The above table shows that on average male participants moved the first disk on the 3-disk Tower of Hanoi quicker than females did (average of 2.85 seconds v 5.34 seconds). Males also moved the first disk on the 4-disk Tower of Hanoi quicker than females did (3.38 seconds v 6.26 seconds). Comparing the groups across conditions males moved the first disk quicker on the 3-disk Tower of Hanoi than the 4-disk Tower of Hanoi (2.85 v 3.38 seconds) and females moved the first disk of the 3-disk Tower of Hanoi quicker than they moved the first disk of the 4-disk Tower of Hanoi (5.34 v 6.26 seconds).

Table A7.7: Mean time taken (in seconds) by males and females to move the first disk on the Tower of Hanoi across conditions (second trial)

	Condition 1 4-disk 1st time	Condition 2 4-disk 2nd time
Male	2.25 (2.1)	2.09 (1.3)
Female	3.0 (2.88)	2.1 (1.2)

The above table shows that on average on the second trial of the Tower of Hanoi male participants moved the first disk on the 4-disk Tower of Hanoi (first time) quicker than females did (average of 2.25 seconds v 3.0 seconds). Males and females moved the first disk on the 4-disk Tower of Hanoi (when they completed it for a second time) in the same time (2.09 seconds v 2.1 seconds). Comparing the groups across conditions males moved the first disk quicker in the condition where they were completing the 4-disk Tower of Hanoi for the second time than the males that were completing the 4-disk Tower of Hanoi for the first time (2.09 v 2.25 seconds) and females also took longer to move the first disk of the 4-disk Tower of Hanoi when they did it for the first time than when the other group did the 4-disk Tower of Hanoi for the second time (3.0 v 2.1 seconds).

Table A7.8: Mean time taken (in seconds) by left- and right-handers to move the first disk on the Tower of Hanoi across conditions (first trial)

	Condition 1 3-disk	Condition 2 4-disk
Left	4.72 (3.85)	3.8 (2.7)
Right	3.75 (3.76)	6.0 (7.67)

The above table shows that on average right-handed participants moved the first disk on the 3-disk Tower of Hanoi quicker than left-handers did (average of 3.75 seconds v 4.72 seconds). However, left-handers moved the first disk on the 4-disk Tower of Hanoi quicker than right-handers did (3.8 seconds v 6.0 seconds). Comparing the groups across conditions left-handers moved the first disk quicker on the 4-disk Tower of Hanoi than the 3-disk Tower of Hanoi (3.8 v 4.72 seconds) and right-handers moved the first disk of the 3-disk Tower of Hanoi quicker than they moved the first disk of the 4-disk Tower of Hanoi (3.75 v 6.0 seconds).

Table A7.9: Mean time taken (in seconds) by left- and right-handers to move the first disk on the Tower of Hanoi across conditions (second trial)

	Condition 1 4-disk 1st time	Condition 2 4-disk 2nd time
Left	3.16 (3.13)	2.2 (1.36)
Right	2.11 (1.67)	2.0 (1.04)

Participants were then asked to complete the Tower of Hanoi again. This time the group that completed the 3-disk version in the first trial was asked to complete the 4-disk version. The group that completed the 4-disk version in the first trial was asked to complete this version again.

The above table shows that on average right-handed participants moved the first disk on the 4-disk Tower of Hanoi (when they did it for the first time) quicker than left-handers did (average of 2.11 seconds v 3.16 seconds). Right-handers moved the first disk on the 4-disk Tower of Hanoi (when they did it for a second time) quicker than left-handers did (2.0 seconds v 2.2 seconds). Comparing the groups across conditions left-handers moved the first disk quicker on the 4-disk Tower of Hanoi (second time) than the 4-disk Tower of Hanoi (first time) (2.2 v 3.16 seconds) and right-handers moved the first disk of the 4-disk Tower of Hanoi (second time) quicker than they moved the first disk of the 4-disk Tower of Hanoi (first time) (2.0 v 2.11 seconds).

Table A7.10: Mean time taken (in seconds) overall by participants to move the first disk on the Tower of Hanoi across conditions (trials 1 and 2).

	First trial	Second trial
Condition1	4.25 (3.8) (3-d)	2.67 (2.6) (4-d)
Condition 2	4.88 (5.7) (4-d)	2.1(1.2) (4-d)

The above table shows that overall the group that completed the 3-disk Tower of Hanoi first took less time to make the first move on average than the group that completed the 4-disk Tower of Hanoi first (4.25 v 4.88 seconds). When the groups were asked to complete the 4-disk Tower of Hanoi in trial 2 (for one group this was the second time and for the other it was the first time) the group that was completing it for the first time took longer to make the first move than the group that was completing it for the second time (2.67 v 2.1 seconds on average). The group that did the 3-disk Tower of Hanoi first took more time on average to move the first disk on the 3-disk than when they did the 4-disk version afterwards (4.25 v 2.67 seconds). The group that did the 4-disk Tower of Hanoi first took longer to move the first disk on the first 4-disk trial than the second 4-disk trial (4.88 v 2.1 seconds).

In order to examine these differences a 2 x 2 x 2 between subjects ANOVA (sex x handedness x condition) was carried out on the time taken to move the first disk on the Tower of Hanoi (trial 1 3-disk v 4-disk). The main effect of sex was significant F(1, 92) = 8.005, p<0.01 with females taking significantly longer to move the first disk than males. The main effect of handedness was not significant F(1, 92) = 0.689, p>0.05 nor was the main effect of condition F(1, 92) = 0.756, p>0.05. The two way interaction between sex and handedness failed to reach significance F(1, 92) = 0.001, p>0.05 as did the two way interactions between sex and condition F(1, 92) = 0.097, p>0.05 and hand preference and condition F(1, 92) = 2.431, p>0.05. The three-way interaction between sex, handedness and condition also failed to reach significance F(1, 92) = 1.982, p>0.05.

An additional 2 x 2 x 2 between subjects ANOVA (sex x handedness x condition) was carried out on the time taken to move the first disk on the second trials of the Tower of Hanoi (trial 2 4-disk first time v 4-disk second time). The main effect of sex was not significant F(1, 92) = 0.712, p>0.05. The main effect of handedness was not significant F(1, 92) = 2.365, p>0.05 nor was the main effect of condition F(1, 92) = 1.663, p>0.05. The two way interaction between sex and handedness failed to reach significance F(1, 92) = 0.622, p>0.05 as did the two way interactions between sex and condition F(1, 92) = 0.770, p>0.05 and hand preference and condition F(1, 92) = 1.025, p>0.05. The three-way interaction between sex, handedness and condition also failed to reach significance F(1, 92) = 0.219, p>0.05.

A7.9. Number of moves (2nd trial comparisons only 4-disk condition 1 vs. 4-disk condition 2).

Table A7.11: Mean number of moves taken by males and females to solve the 4-disk Tower of Hanoi across conditions (second trial)

	Mean No of moves to solve 4-disk ToH (1st time trial 2)	Mean No of moves to solve 4-disk ToH (2nd time trial 2)
Male	29.38 (14.1)	23.9 (10.6)
Female	30.3 (14.1)	27.8 (11.7)

The above table shows that on average the males and females completing the 4-disk Tower of Hanoi for the first time took more moves on average to solve it than the males and females who had completed the 4-disk Tower of Hanoi once before. Males took on average 6 more moves to solve the 4-disk Tower of Hanoi the first time than the males who solved it for the second time (29.4 v 23.9 moves) and females who solved it for the first time only took, on average, 3 more moves to solve the 4-disk Tower of Hanoi than the females who were solving it for the second time (this relates to Mataix-Cols & Bartés-Faz (2002) who stated that there was no effect of learning and that this would have to be solved around 5 times before a noticeable improvement in solving it occurred). In the group that solved the 4-disk Tower of Hanoi for the first time males and females solved it in a similar mean number of moves (29.4 v 30.3 moves respectively) and in the group that solved the 4-disk Tower of Hanoi for the second time males solved it on average in less moves than females (23.9 v 27.8 moves respectively).

*Note that the group completing the 4-disk Tower of Hanoi for the first time had already completed the 3-disk Tower of Hanoi and were therefore familiar with the rules.

Table A7.12: Mean number of moves taken by left- and right-handers to solve the 4-disk Tower of Hanoi across conditions (second trial)

	Mean No of moves to solve 4-disk ToH (first time trial 2)	Mean No of moves to solve 4-disk ToH (2nd time trial 2)
Left-handers	27.25 (11.7)	25.6 (11.6)
Right-handers	32.8 (15.8)	26.2 (11.0)

The above table shows that on average left-handers solved the 4-disk Tower of Hanoi in fewer moves than right-handers when the completed it for the first time (after previously completing the 3-disk TOH) (27.3 v 32.8 moves). The left-handers that solved the 4-disk Tower of Hanoi for the second time (after previously completing the same 4-disk problem earlier) completed this in fewer moves than the right-handers in this group (25.6 v 26.2 moves on average). Looking across conditions the left-handers who solved the 4-disk task for the second time solved this in fewer moves than the left-handers that solved this for the first time; however, this difference was only an average of 2 moves. The right-handers that solved the 4-disk Tower of Hanoi for the second time solved this in fewer moves, on average, than the right-handers that solved this for the first time (26.2 v 32.8 moves).

Table A7.13: Mean number of moves taken overall by condition to solve the 4-disk Tower of Hanoi across conditions (second trial)

	Mean No of moves to solve 4-disk ToH (first time trial 2)	Mean No of moves to solve 4-disk ToH (2nd time trial 2)
Overall	29.9 (14.0)	25.9 (11.2)

Overall, the group that completed the 4-disk Tower of Hanoi for the second time took fewer moves, on average, to solve it than the group that completed it for the first time (after completing the 3-disk Tower of Hanoi). However, this difference was only an average of 4 moves and thus does not necessarily indicate a great deal of learning has gone on from the first to the second trial.

In order to examine these differences a 2 x 2 x 2 between subjects ANOVA (sex x handedness x condition) was carried out on the number of moves taken to solve the 4-disk Tower of Hanoi (trial 2 4-disk for the first time v trial 2 4-disk for the second time). The main effect of sex was not significant F(1, 92) = 1.046, p>0.05. The main effect of handedness was not significant F(1, 92) = 1.287, p>0.05 nor was the main effect of condition F(1, 92) = 2.589, p>0.05. The two way interaction between sex and handedness failed to reach significance F(1, 92) = 1.507, p>0.05 as did the two way interactions between sex and condition F(1, 92) = 0.283, p>0.05 and hand preference and condition F(1, 92) = 0.828, p>0.05. The three-way interaction between sex, handedness and condition also failed to reach significance F(1, 92) = 0.001, p>0.05.

A7.10. Completion time – 4-disk condition 1 (first time) vs. 4-disk condition 2 (second time)

Mean time taken to solve the 4-disk ToH (second trial) across conditions

Table A7.14: Mean time (in seconds) taken by males and females to solve the 4-disk Tower of Hanoi across conditions (second trial)

	Mean time to solve 4-disk TOH (first time trial 2)	Mean time to solve 4-disk TOH (2nd time trial 2)
Male	116.5 (127.5)	53.1 (38.7)
Female	107.0 (70.8)	74.7 (46.3)

The above table shows that males, on average took longer than females to solve the 4-disk Tower of Hanoi in the group that did the 3-disk Tower of Hanoi previously and then did the 4-disk version for the first time. In the group that did the 4-disk Tower of Hanoi for the second time males solved it on average 21 seconds quicker than females (53.1 v 74.7 seconds). Examining the performance across the conditions, the males that solved the 4-disk Tower of Hanoi for the first time took on average more than twice the time taken by the males that solved the 4-disk Tower of Hanoi for the second time (116.5 v 53.1 seconds). The females that completed the 4-disk Tower of Hanoi for the first time also took longer than the group of females that completed it for a second time (107 v 74.7 seconds).

Table A7.15: Mean time (in seconds) taken by left- and right-handers to solve the 4-disk Tower of Hanoi (second trial)

	Mean time to solve 4-disk ToH (1st time trial 2)	Mean time to solve 4-disk TOH (2nd time trial 2)
Left-handers	98.9 (85.9)	62.0 (45.3)
Right-handers	124.6 (110.8)	66.8 (42.8)

The above table shows that on average left-handers took longer to solve the 4-disk Tower of Hanoi in the group that did it for the first time (after completing the 3-disk version previously) compared to the left-handers that solved it for a second time with an average difference of around 36 seconds (98.9 v 62 seconds). Right-handers who completed the 4-disk Tower of Hanoi for the first time took almost twice as long to do this than the right-handed group that solved the 4-disk Tower of Hanoi for the second time (124.6 v 66.8 seconds).

Table A7.16: Mean time (in seconds) taken overall by condition to solve the 4-disk Tower of Hanoi (second trial)

	Mean No of moves to solve 4-disk TOH (first time trial 2)	Mean No of moves to solve 4-disk TOH (second time trial 2)
Overall	111.17 *(98.3)*	64.3 *(43.8)*

The above table shows that overall the group that completed the 4-disk Tower of Hanoi for the second time solved the task much quicker than the group who solved the 4-disk task for the first time, even though they had previously solved the 3-disk version.

A 2 x 2 x 2 between subjects ANOVA (sex x handedness x condition) was carried out to examine any differences between conditions on the time taken to complete the 4-disk Tower of Hanoi (in seconds) (trial 2 4-disk first time v 4-disk second time). The main effect of sex was not significant F(1, 92) = 0.200, p>0.05. The main effect of handedness was not significant F(1, 92) = 1.076, p>0.05. However, the main effect of condition was significant F(1, 92) = 9.980, p<0.01 with those solving the 4-disk Tower of Hanoi for the second time solving it significantly faster than those solving it for the first time. The two-way interaction between sex and handedness failed to reach significance F(1, 92) = 0.041, p>0.05 as did the two way interactions between sex and condition F(1, 92) = 1.051, p>0.05 and hand preference and condition F(1, 92) = 0.490, p>0.05. The three-way interaction between sex, handedness and condition also failed to reach significance F(1, 92) = 0.513, p>0.05.

7.11. Comparison of state scores trial 1

Table A7.17: Overall mean first state scores before completing the 3-disk or 4-disk Tower of Hanoi (first trial)

	3-disk	**4-disk**
Mean state score	36.7 *(7.5)*	31.7 *(8.9)*

The above table shows that before completing the first Tower of Hanoi puzzle in the study the group that was given the instructions to and asked to complete the 3-disk Tower of Hanoi had higher state anxiety scores, on average, than the group that were asked to complete the 4-disk Tower of Hanoi first.

Table A7.18: Overall mean second state scores before completing the 4-disk (first time) or 4-disk Tower of Hanoi (second time) (second trial).

	4-disk (1st time)	**4-disk (2nd time)**
Mean state score	34.8 *(8.2)*	30.5 *(8.6)*

The above table shows that before completing the second Tower of Hanoi trial when both groups were asked to solve the 4-disk version the group that had previously solved the 3-disk version and was completing the 4-disk Tower of Hanoi for the first time had a higher mean trait score than the group that was completing the 4-disk Tower of Hanoi for the second time.

Table A7.19: Male and female's mean state scores before completing the 3-disk or 4-disk Tower of Hanoi (first trial).

	3-disk	**4-disk**	**Total**
Male	37.2 *(6.6)*	30.2 *(8.8)*	33.7 *(7.3)*
Female	36.3 *(8.3)*	33.1 *(8.9)*	34.7 *(8.6)*
Total	36.7 *(7.5)*	31.7 *(8.9)*	

The above table shows that before completing the first trial on the Tower of Hanoi, males who completed the 3-disk version first had higher mean state scores than males who completed the 4-disk Tower of Hanoi first (37.2 v 30.2). This pattern was repeated for females as they also had higher mean state scores before completing the 3-disk Tower of Hanoi than before completing the 4-disk Tower of Hanoi (36.7 v 31.7). Overall, state scores were on average higher for those who completed the 3-disk Tower of Hanoi than for those who completed the 4-disk version of the Tower of Hanoi. Overall, females scored slightly higher on state scores irrespective of condition than males but the difference was small (34.7 v 33.7).

Table A7.20: Left- and right-hander's mean state scores before completing the 3-disk or 4-disk Tower of Hanoi (first trial).

	3-disk	**4-disk**	**Total**
Left-handers	39.4 *(5.4)*	30.7 *(7.8)*	35.1 *(6.6)*
Right-handers	33.7 *(8.5)*	32.9 *(10.0)*	32.7 *(9.3)*
Total	36.7 *(7.5)*	31.7 *(8.9)*	

The above table shows that left-handers scored higher overall than right-handers on the state scores before completing the first trial of the Tower of Hanoi. When this was divided into handedness categories left-handers scored higher than right-handers on average before completing the 3-disk Tower of Hanoi but right-handers scored higher than left-handers before completing the 4-disk Tower of Hanoi for the first time. The group of left-handers completing the 3-disk Tower of Hanoi first scored higher on the state questionnaire than the group of left-handers completing the 4-disk Tower of Hanoi first (39.4 v 30.7). This was also the case for the right-handers but the difference in state scores between the two right-handed groups was minimal (33.7 v 32.9). Overall across conditions those in the 3-disk Tower of Hanoi condition had higher state scores than those in the 4-disk Tower of Hanoi condition irrespective of hand preference.

Table A7.21: Male and female's mean state scores before completing the 4-disk Tower of Hanoi – second condition.

	4-disk (1st time)	**4-disk (2nd time)**	**Total**
Male	35.4 (7.5)	28.7 (7.7)	32.1 (7.6)
Female	34.5 (8.9)	32.2 (9.1)	33.4 (9.0)
Total	34.8 (8.2)	30.5 (8.6)	

The above table shows that females scored slightly higher on the state questionnaire than males overall prior to completing the second trial of the Tower of Hanoi (when one group completed the 4-disk version for the first time and the other group completed the 4-disk version for the second time). Overall, those completing the 4-disk Tower of Hanoi for the first time scored higher on the state questionnaire than the group completing the 4-disk Tower of Hanoi for the second time. Within the group that completed the 4-disk Tower of Hanoi for the first time males scored slightly higher on average on the state questionnaire than females (35.4 v 34.5). Within the group that completed the 4-disk Tower of Hanoi for the second time males scored lower on average than females (28.7 v 32.2). Both males and females scored higher in the group that completed the 4-disk Tower of Hanoi for the first time than the males and females in the group that completed the 4-disk Tower of Hanoi for the second time (35.4 v 28.7 for males) and (34.5 v 32.2 for females).

Table A7.22: Left- and right-hander's mean state scores before completing the 4-disk Tower of Hanoi – second condition.

	4-disk (1st trial)	**4-disk (2nd trial)**	**Total**
Left-handers	36.2 (5.7)	29.7 (7.9)	33.0 (6.8)
Right-handers	33.3 (10.2)	31.3 (9.3)	32.3 (9.8)
Total	34.8 (8.2)	30.5 (8.6)	

The above table shows the state scores of left-handers and right-handers who were assigned to the condition where the 4-disk Tower of Hanoi was completed twice. Before completing the 4-disk Tower of Hanoi for the first time left-handers had higher state scores than right-handers (36.2 v 33.3) but before completing the 4-disk Tower of Hanoi for the second time right-handers had higher state scores than left-handers (suggesting some effect of novelty for left-handers?). Overall in this condition left-handers scored marginally higher on state scores than right-handers (33.0 v 32.3) and state scores were higher overall before participants completed the first 4-disk trial than before they completed the second 4-disk trial on the Tower of Hanoi (34.8 v 30.5).

A7.12. First state scores (state 1)

In order to examine these differences a 2 x 2 x 2 between subjects ANOVA (sex x handedness x condition (3-disk ToH first or 4-disk ToH first) was carried out on the self-reported first state scores. The main effect of sex was not significant F(1, 92) =, 0.280, p>0.05. The main effect of handedness was not significant F(1, 92) = 0.874, p>0.05. However, the main effect of condition was significant F(1, 92) = 8.929, p<0.01 with state scores being significantly higher before competing the 3-disk ToH than before completing the 4-disk ToH . The two way interaction between sex and handedness failed to reach significance F(1, 92) = 2.187, p>0.05 as did the two way interaction between sex and condition F(1, 92) = 1.557, p>0.05. However, the two-way interaction between hand preference and condition was significant F(1, 92) = 5.795, p<0.05. The three-way interaction between sex, handedness and condition failed to reach significance F(1, 92) = 0.025, p>0.05.

The significant interaction between condition and handedness for the first state scores was examined further:

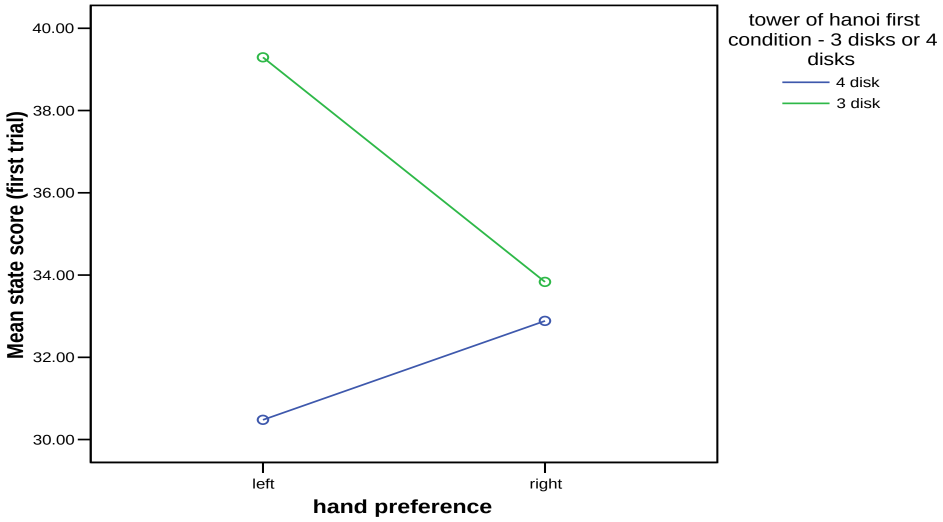


Figure A7.5: Interaction plot between condition (3-disk ToH first or 4-disk ToH first) and handedness for the initial state anxiety scores.

The above plot shows that the state anxiety scores of right-handers did not vastly differ between the two conditions (whether they completed the 3-disk or the 4-disk Tower of Hanoi first). However, the condition did appear to affect the state scores of left-handers. Left-handers who completed the 4-disk Tower of Hanoi first had much lower scores than the left-handers who completed the 3-disk Tower of Hanoi first. When comparing the state scores of left- and right-handers it can be seen that before left-handers completed the 4-disk Tower of Hanoi their mean state score was lower than that of the right-handers, however, left-hander's mean state scores were much higher than right-handers mean state scores before they completed the 3-disk Tower of Hanoi. (Left-hander's high state score contributed to the interaction as the right-handers' scores were flat and the effect of condition was already a significant main effect).

A one-way between subjects ANOVA was carried out on left-handed participants in order to examine the difference between the mean state scores in the 3-disk ToH condition and the 4-disk ToH condition F(1, 50) = 21.194, p<0.01. It was found that left-handers in the 3-disk ToH reported themselves to be significantly more anxious (due to (due state scores of 39.4 and 30.7 respectively) than the left-handers in the 4-disk ToH condition.

A one-way between subjects ANOVA was carried out on right-handed participants to examine the difference between the mean state scores in the 3-disk ToH condition and the 4-disk ToH condition F(1, 46) = 0.087, p>0.05. It was found that there was no significant difference between right-handers' state scores regardless of the condition that they were in (before they completed the 3-disk ToH or the 4-disk ToH).

Thus it seems that the high state score of the left-handed participants before they completed the 3-disk ToH was the main reason for the interaction between condition and handedness

A.7.13. Comparison of trait scores across the two conditions

Table A7.23: Mean overall trait scores for each condition (3-disk TOH first and 4-disk TOH first)

	3-disk first	**4-disk first**
Mean trait score	40.3 (8.9)	38.6 (9.3)

The above table shows that overall trait scores on average are higher for the group that did the 3-disk Tower of Hanoi first than the group that did the 4-disk Tower of Hanoi first (40.3 v 38.6).

Table A7.24: Mean trait anxiety scores of males and female's in each condition (3-disk TOH and 4-disk TOH)

	3-disk condition	**4-disk condition**	**Total**
Male	40.0 (8.8)	37.2 (9.2)	38.6 (9.0)
Female	40.6 (9.3)	40.0 (9.3)	40.3 (9.3)
Total	40.3 (8.9)	38.6 (9.3)	

The above table shows that males and females had similar mean trait scores overall and regardless of the condition that they were in with a range of 37.2 to 40.6.

Table A7.25: Mean trait scores of left- and right-handers in each condition (3-disk TOH and 4-disk TOH)

	3-disk condition	4-disk condition	Total
Left-handers	42.3 (8.3)	37.6 (8.2)	40.0 (8.3)
Right-handers	38.2 (9.3)	39.6 (10.4)	38.9 (9.9)
Total	40.3 (8.9)	38.6 (9.3)	

The above table shows that the group with the highest mean trait anxiety scores was the left-handers in the 3-disk condition. Their trait anxiety scores were higher than the left-handers' trait anxiety scores in the 4-disk condition as well as the two right-handed groups. The right-handed group in the 4-disk condition had higher trait anxiety scores than the left-handers in this condition (39.6 v 37.6). Overall, left-handers had higher mean trait anxiety scores than right-handers and the group in the 3-disk condition had higher trait anxiety scores than the group in the 4-disk condition.

A 2 x 2 x 2 (sex x handedness x condition) between subjects ANOVA was carried out on the trait scores of participants in both conditions. There were no significant main effects of sex F(1, 92) = 0.718, p>0.05 or handedness F(1, 92) = 0.259, p>0.05 or condition F(1, 92) = 0.835, p>0.05. The two-way interaction between sex and handedness failed to reach significance F(1, 92) = 1.069, p>0.05 as did the two way interactions between sex and condition F(1, 92) = 0.345, p>0.05 and hand preference and condition F(1, 99) = 2.929, p<0.05 (although this approached significance p=0.09). The three-way interaction between sex, handedness and condition also failed to reach significance F(1, 92) = 1.333, p>0.05.

When the overall state anxiety scores were examined using a number of different handedness classifications to measure handedness it was found that the strong handedness classifications all supported the initial result that there was a difference between state anxiety scores of left- and right-handers (with left-handers having higher anxiety scores). Again as very few studies have focussed on state anxiety and handedness then it is difficult to back these results up with previous experimental evidence. However, Wienrich *et al's*. study found that there was a difference in trait anxiety scores between left- and right-handers with strong hand preferences compared to those with weak hand preferences. However, they did not distribute the state anxiety questionnaire in relation to strength of hand preference and so no comparisons can be made with the current study (but this might have made a difference).