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The role of visuo-spatial resources in object recognition

Whittaker,, Annalise

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The role of visuo-spatial resources in object recognition

by

Annalise Whittaker

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I would like to thank my family for their never ending and unreserved support of whatever I choose to do.

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Summary

The present study is based on the premise that some sort of normalisation strategy is applied to objects presented at unfamiliar orientations. The strategy employed appears to be that of mental rotation (Jolicoeur, 1985), especially in mono-oriented stimuli (Leek, 1998). The Dorsal stream is suggested to deal with more spatial and motor aspects of vision and it is possible that the inferior parietal lobule is responsible for binding these two sources of information as suggested by Milner (1995). The purpose of these experiments was to further investigate the significance of visuo-spatial normalisation resources in object recognition, particularly mental rotation. It appears that visuo-spatial working memory may deal with visual and spatial information separately, and that the spatial aspect of memory is associated with movement control, especially motor planning (Smyth and Pendleton, 1989). It was decided that the dual tasks employed in these experiments should involve primarily a spatial dual task, and possibly a motor task. A word-picture verification task was adapted from Leek (1998) and various dual tasks were tested concurrently. In each case the spatial dual task had a greater effect on reaction times than the non-spatial dual task, and a motor spatial dual task appeared to have a greater effect than a spatial task. Two experiments tested whether mental rotation resources could be primed by a mental rotation task, previous experiments have shown that it is possible to prime a certain view of an object (Lawson and Humphreys,1996), or to prompt the use of certain resources based on the task used (Takano, 1989). The results of the present experiment, however, suggest that resources can be primed by a previous task and that this improves performance at mental rotation.

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Chapter One

Introduction

Historically in order to study the human visual system it has been necessary to break down its various functions and to study them in laboratory conditions. To this purpose experiments have been conducted by creating very basic stimuli, such as line drawings (Snodgrass and Vanderwart, 1980). In some cases novel stimuli have been created which can be more easily manipulated; an example of this is the 'paperclip objects' of Bulthoff and Edelman (1992). These experiments are useful in order to answer questions such as how much of an object needs to be visible for it to be recognised (Biederman and Blickle, 1985, in Biederman, 1987). But this also begs the question of how much can be generalised from experiments performed with simple stimuli such as 'cube objects' shown on a computer screen (Tarr, 1995). For example, Hamilton (personal communication) has shown that female participants perform significantly better in matching experiments using real models of cube objects than in an identical computer task.

Experiments which use more invasive techniques have been conducted on animal brains. Hubel and Wiesel (1962) performed the first of many experiments that provided a wealth of information about the location of visual resources in the brain, and also about the very basic functions of the visual apparatus such as edge detecting cells (also see Logothetis et al, 1995). Patients with neurological damage can provide invaluable evidence about the location and function of visual resources in the human brain (Goodale et al., 1994; Warrington and Taylor, 1973, 1978;

Warrington and James, 1986; Landis et al., 1988). More recently techniques such as PET and FMRI (e.g. Cohen et al., 1996; Parsons et al., 1995) have added to this body of knowledge and provided an opportunity to observe healthy humans as they perform simple visual tasks.

These separate techniques have provided a wealth of information, but it is probable that the visual system is far too complex, and far too integrated with other systems, for any one model of it to be sufficient. Recently, for example, connections between vision and premotor planning have been shown in mental object rotation (Wohlschlager & Wohlschlager, 1998).

General theories of perception (e.g.,Gregory, 1972, Neisser, 1967) support the theory that in order for objects to be recognised representations of them must be stored in memory, and it is important that these are accessed quickly and accurately when even a degraded view of that object is available. The main opponent of this view has traditionally been Gibson, (1979) who claimed that all of the potential uses of an object are 'afforded' by the object depending on the perceiver's state of mind. It now seems clear that a 'Gibsonian' position is more relevant to the processes of action than object recognition. Gibson apart, these questions of storage and retrieval are central to the study of object recognition (e.g. Palmer, 1975). For example: are objects stored as an entire 'image' as in the classical template matching theories (e.g. Trehub, 1977), or are the parts of the object recognised separately and an image built up by the relative location of the parts to each other (e.g. Poggio and Edelman, 1990, Marr and Nishihara, 1978, Biederman, 1987). Increasingly researchers have been moving towards the view that several routes can be used to achieve object recognition (Jolicoeur, 1985, Tarr and Pinker 1989).

The main focus of this review is object constancy. This is achieved when an object is successfully recognised from any viewpoint. The literature that follows presents a discussion of object constancy from a variety of theoretical standpoints. Marr (1982) provides a model of how object recognition may occur in the visual system. Biederman (1987) takes this theory further and tests object constancy and viewpoint independence. It appears that viewpoint independence can be achieved but only under certain circumstances and with certain objects. Kosslyn (1990) provides a further model of object recognition which includes elements of both these theories. This, however, also fails to account for object constancy across all conditions. Jolicoeur (1985) introduces the idea that mental rotation is used by the visual system when objects are viewed at a novel orientation. The work of Tarr and Pinker (1989) provides a discussion of viewpoint invariance across different objects and orientations. Here a variety of normalisation strategies are discussed.

Many of the models and theories proposed earlier in the review are tested in the computational literature. A computational model of viewpoint invariance is presented by Carpenter and Just (1999). This model was favourably compared to performance in the human visual system during fMRI. Further evidence from the neurological literature is presented and the architecture of the visual system is discussed. Problems of object constancy in patients are presented with a view to locating the relevant resources. Imaging data provides a further analysis of the visual system during object recognition. Finally the Working Memory literature is discussed. This combines neurological evidence with that from cognitive experiments. A model of visual working memory is presented but it appears to fall short of present neurological findings. These suggest far closer connections between motor and visual resources in the brain than is presently accounted for.

Marr

Marr (1982) proposed a model of object recognition that reflects the way in which information appears to be biologically processed by the visual system in the early stages. Marr describes three stages of representation. The first is called the Primal Sketch and is comparable with the earliest stages of vision shown by the edge detection cells described by Hubel and Wiesel (1962); the overall outline of shapes is derived at this stage. The second stage is called the 2.5D sketch and involves the addition of extra information such as shading (e.g. Horn, 1975), texture (Cutting and Millard, 1984, Stevens, 1981), motion (e.g. Ullman, 1979), and binocular disparity (e.g. Marr and Poggio, 1977). This extra information provides higher-level information such as whether the junctions between surfaces are convex or concave. Binocular disparity is caused by the fact that each eye receives slightly different information about a visual scene. It is important in depth perception as it provides information about the relative distances of objects (Marr 1982). Marr and

Poggio (1977) described the complexity involved with the 'correspondence problem' which involves making sure that the information from each eye is matched with the other to avoid one object being perceived as two. Both the primal sketch and the 2.5D sketch use information that is derived from the viewpoint of the observer. Any change in viewpoint will result in surfaces being occluded and may mean that object representations change drastically.

The final stage in processing is described as the 3D model representation. Here an object centred coordinate system is defined and the arrangement of the object parts around this system is compared to similar descriptions in memory. This has the advantage of creating viewpoint invariance and a stable description of individual objects (Marr and Nishihara, 1978).

Marr and Nishihara defined object parts by using generalised cones (Binford, 1971), derived by the convex and concave junction information described by the 2.5D sketch. Unfortunately while this may be suitable for parts such as arms and legs derived from a silhouette, many objects, such as faces, cannot be described in this way (Hoffman and Richards, 1984). The question of exactly how a 3D representation is derived from the 2.5D sketch is the weakest part of the model (Pinker, 1984).

Recognition by Components

Biederman's recognition by components model (1987) is related to Marr's account in that following the extraction of edge information objects are described as consisting of volumes or parts. These volumes are similar to the generalised cones described by Binford (1971) and Marr (1977, 1982); Biederman calls them geons ('geometrical ions') and hypothesises that they should be symmetrical and simple, typically cylinders and blocks. The main difference between the two accounts is that in order for the cones to be derived in Marr's (1982) model a principal axis had to be defined, but in the Biederman model the relation of the geons to each other is what defines the object. The unique arrangement of geons in each object can be compared to the phonemes that make up a language and so only a few geons are necessary to describe all possible objects, probably less than 50 (Biederman, 1987, p118).

This model predicts that representations of objects are stable and invariant to changes in viewpoint. Biederman and Gerhardstein (1993) state that there are three 'conditions for invariance' in human object recognition. The first condition is that it must be possible to decompose an object into parts so that a 'geon structural description' (GSD) of the object can be constructed, secondly the GSD must be unique to that object, and thirdly different viewpoints must produce the same GSD. Using this rule Biederman and Gerhardstein (1993) have shown object representations to be stable across both changes in viewpoint and rotations in depth.

Biederman and Gerhardstein (1993) set out to investigate in more depth the findings of Bartram (1974). Bartram required participants to name black and white photographs of familiar objects from different object classes. Participants were presented with an initial block of objects followed by one of four sets of stimuli. The first stimulus set comprised of the same photographs as the initial set. The second stimulus set consisted of the same objects as the initial set but these were photographed at eight spatial viewpoints which were approximately 45° apart. The third set contained different exemplars of objects from the same object class as the initial photographs, for example a different chair. The final set consisted of different objects from different object classes. Participants were fastest at naming the identical photographs, followed by the different exemplars. Different objects from different classes appeared to slow naming times as much as the rotated objects. This suggests that the rotated objects were treated as novel objects. It has been suggested that this may have been caused by the deletion of object parts during rotation, or by the foreshortening of axes (Palmer, Rosch and Chase, 1981).

Biederman and Gerhardstein (1993) present five experiments which investigate the criticisms of the Bartram (1974) paper. Their first experiment involves a replication of Bartram's experiment using line drawings of familiar objects. During rotation the object views showed the same features whenever possible, and controlled for foreshortened axes. It was shown that the same objects were primed more than the different objects, suggesting that the prime was visual and not one of object class. There was a slight but not significant orientation effect. In experiment two ratings were taken of the different viewpoint images and ones that contained occluded parts were removed from the analysis. This produced a smaller effect of rotation. Experiment Three involved the creation of a set of novel objects that conformed to conditions one and two of the conditions of invariance set out by Biederman and Gerhardstein (1993). A same-different matching task was employed. Objects could be rotated to answer condition three of the conditions of invariance, in that no parts are occluded. Or they could be rotated so that one part was occluded and another came into view. It was found that rotation affected both reaction times and error rates in the part occluded condition. There was little effect of rotation in the no change condition. In experiment four a stimulus set consisting of ten geons was created. Participants saw one geon then were presented with a series of geons. These may or may not match the original and were shown at different orientations. Participants responded when they thought a matching geon was shown. There was no effect of rotation on matching times, but there was an increase in error rates on rotated geons. The final experiment consisted of a replication of Edelman's (1989) experiment that found that participants had great difficulty distinguishing between bent 'paper clip objects' viewed at novel orientations. In this replication a geon was added to the centre of each paper clip object. Participants displayed much reduced difficulty at novel orientations than Edelman's participants. Previously Poggio and Vetter (1992) had found that bilaterally symmetrical objects are more recognisable from all viewpoints. These objects were non-symmetrical but it appears that the addition of a single geon is sufficient to achieve viewpoint invariance (Biederman and Gerhardstein, 1993).

Conversely, other researchers who have designed recognition experiments that satisfy the above conditions have found evidence for viewpoint dependant performance (Hayward and Tarr, 1997; Suzuki et al., 1997; Hayward, 1998; Tarr et al., 1997, 1998). Specifically Tarr et al. (1998) found that if they used the same paradigm as Biederman and Gerhardstein (1993), performance appeared to be viewpoint invariant. However, using the same stimulus set but a different paradigm, such as sequential matching, recognition performance was viewpoint dependent. Indeed small rotation effects were present in all of the Biederman and Gerhardstein (1993) experiments. They suggest that this may be due to the existence of different routes to object recognition. The objects in the stimulus sets were chosen to provide viewpoint invariant information. It is possible that some participants may have used viewpoint specific information such as the global shape of an object. Or some participants may have used a viewpoint specific representation such as the location of particular features. The results can only be taken to suggest that when objects activate distinctive GSD's recognition is largely invariant to rotation in depth (Biederman and Gerhardstein, 1993). The following section discusses a model that combines aspects of both the Marr and the Biederman account.

Kosslyn

Kosslyn et al (1990) produced a model of the later stages of object recognition based on a set of hypotheses created by previous experimentation and neuropsychological findings. A major premise which underlies the model is that information does not flow in only one direction. Visual areas are seen to convey information both upstream and downstream (Van Essen, 1985).

The first major area in the model is the “visual buffer”; low level information about edges, depth etc., is collated here in a similar manner to Marr’s (1982) 2.5D sketch. The next area is the attention window. It is posited that the visual buffer contains more information about the visual scene than can be immediately assessed by high level processes and so the attention window helps to focus on areas of particular importance. Cave and Kosslyn (1989) tested the theory that only certain areas of the visual scene are attended to at any one time by presenting forms which participants had to attend to. On trials where the form to be attended was larger than the previous form evaluation time increased as if an adjustment was being made to the attention window surrounding the form.

Once an object has been attended the next level of processing involves its spatial coordinates. It is important that information about the location of an object in a scene is encoded, and sometimes the relative locations of parts of the object may be encoded and stored separately in memory. This premise is similar to that of Beiderman (1987) discussed earlier in this section. Kosslyn et al. (1990) also state that object orientation should be encoded here because in order to navigate a scene successfully it is useful to know how an object is oriented in space. An important issue when attending to an object is the relation of its parts to each other. The example given is that of a human form where different postures make it impossible to store a generalised representation. To this end a subsystem which encodes categorical relations is suggested. Here rules about how the body parts are connected to each other are encoded. By extending the example of the human form this can be illustrated by specifying 'hinge' relations between the upper and lower arm or upper and lower leg which will always remain constant (Hoffman & Flinchbaugh, 1982).

The next level of processing deals with object properties. Biederman (1987) and Lowe (1987) argue that areas of an image such as where edges intersect can be extracted and used to access stored representations. Kosslyn et al describe these areas as trigger features, Biederman (1987) and Lowe (1987) described similar areas as "nonaccidental" image properties. These areas are important because they tend to remain constant even under changes in viewpoint. From here information can be passed to a pattern activation area which matches the image to a stored representation and also provides an estimate of how good the match is. If the match is good then further analysis of the image is not necessary, but in non-optimal conditions or when a novel object is viewed further processing may be necessary. One possible way in which an object can be more thoroughly analysed is if the visual system analyses object parts separately, for example the eyes of a face (Perret et al, 1985). Further knowledge about an object can be gathered from features such as colour and texture; Kosslyn et al suggest that a subsystem gathers this sort of information and passes is to the next level of processing which is associative memory.

Kosslyn et al (1990) propose that the information about object properties and spatial properties are combined at the level of associative memory. This area also receives information from other systems about an object, such as how it feels or how it sounds. The relevant information is processed and compared to that stored in associative long-term memory in order to match the image being viewed to a known object.

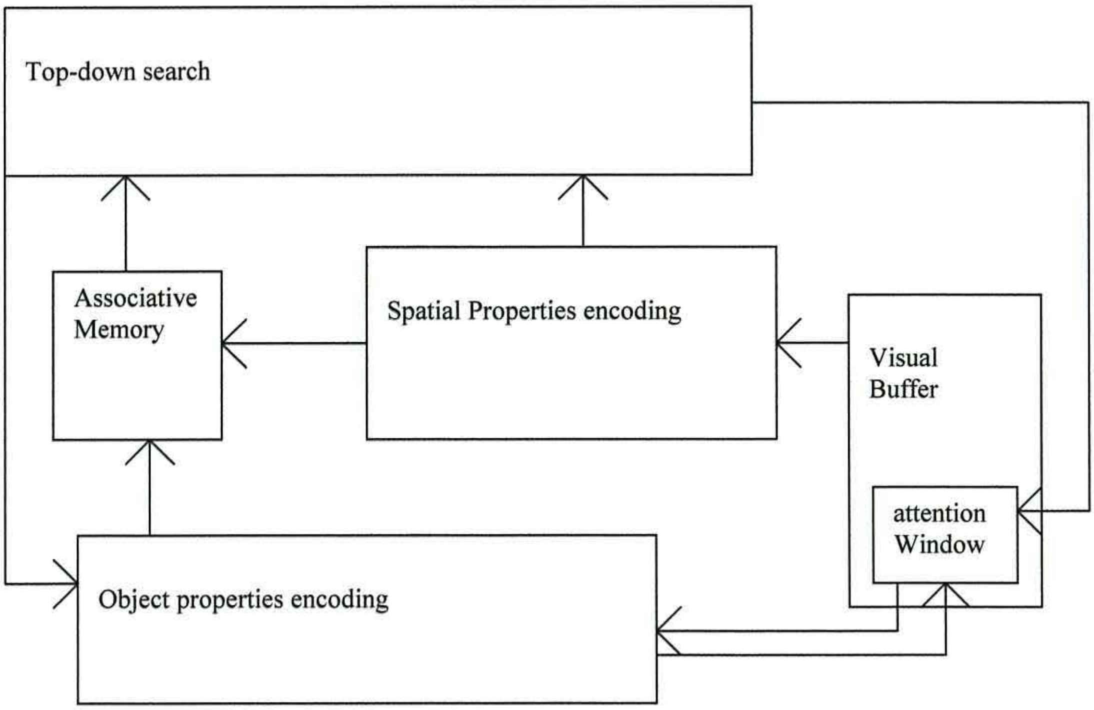

Figure 1. Illustration of the basic model posited by Kosslyn et al. (1990)

It is proposed that each property of an object is assigned a weight by the system in order to deal with different items within a class. The example given is that of a chair where the presence of a seat is highly important and so will be assigned a high weight. Similarly legs and a back are important and assigned medium weights, whereas arms are not very important and so are assigned low weightings. During this analysis information can feed back and forward between the subsystems so that the pattern activation system for example can be primed to activate relevant stored patterns based on the information received. However, as the next section of this review discusses, viewpoint dependency is still a problem in object recognition, and various systems appear to contribute to solving the problem of object constancy.

Mental Rotation

Shepard and Metzler (1971) presented pairs of block objects to participants and asked them to make same/different discriminations. The second object of the pair could be a rotated version of the first one or a rotated version of a mirror image of the first. The rotated mirror images were classed as 'different'. Reaction time was shown to increase linearly with the angular difference in portrayed orientation. Participants reported that this was achieved by mentally rotating one object to the same orientation as the other. For these participants it was necessary for the object orientations to match before a comparison was made, suggesting that viewer centred coordinates are important in object recognition. Shepard and Cooper

(1982) found that mental rotation was also used when matching rotated shapes to those stored in memory.

These findings provided support for the theory that misoriented objects may be recognised following a normalisation process in which a mental image is created and mentally rotated to its natural upright (Jolicoeur, 1985). However the same/different task devised by Shepard and Metzler (1971) does not provide solid enough evidence for object recognition. Object recognition experiments usually require participants to name objects. Several studies (Corballis & Nagournay, 1978; Corballis, Zbrodoff, Shetzer &Butler, 1978; Simion, Bagnara, Roncato & Umlita, 1982; White, 1980) failed to show any relationship between reaction time and orientation. However the stimuli used in these experiments were often simple alphanumeric characters that have often been criticised because they tend to be over learned. Eley (1982) used novel characters in order to avoid the previous problems but still failed to show a slowing in naming time that coincided with an increase in rotation from the canonical upright. From this evidence it was concluded that mental rotation was only used for mirror image discrimination tasks, and that some other strategy was employed for object naming (see Humphreys and Quinlan, 1987).

Jolicoeur and Landau (1984) provided the first real evidence for an effect of orientation on naming of misoriented objects. They moved away from studying reaction time data and used error rate instead. The stimuli were presented briefly and then masked, and using this paradigm there was a subtle effect of increase in orientation. Further experiments performed by Jolicoeur (1985) not only provided an explanation of why previous experiments were flawed but also produced an enlightening theory of object recognition. Jolicoeur (1985, Expt. 1) compared the results of the first exposure to a misoriented stimulus set to those of subsequent exposures. A significant increase in naming time was produced during the first exposure, but this effect decreased (while not completely disappearing) with subsequent exposures. However a block of novel objects had the same effect on reaction times as the first block in the stimulus set. This was taken to mean that familiarity with the new orientations did not cross over to new objects. An example of the first trial effect is shown in Figure 1.2. Jolicoeur (1985, 1990) described this as the 'first trial' effect and suggested that image transformation took place in object naming only on initial exposure to stimuli. Previous experiments in which scores had been averaged over multiple exposures to the same stimulus set would have been compromised by the decrease in reaction time with subsequent exposures (Corballis & Nagournay, 1978; Corballis et al., 1978; Simion et al., 1982; White, 1980; Eley, 1982).

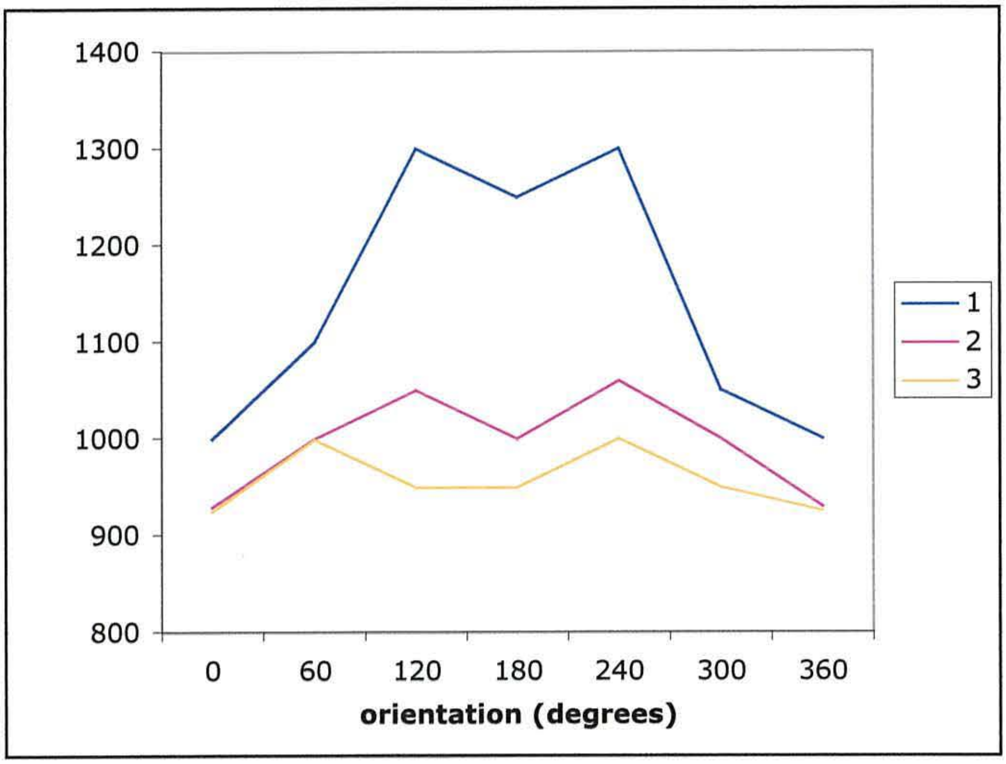

Figure 1.2. Illustration of the first trial effect on mean naming time at first, second and third presentation of the stimuli set

Jolicoeur later attempted to link the 'first trial' effect with the mental rotation findings of Shepard and Metzler (1971) (Jolicoeur, 1985, Expt. 4). In this experiment participants were required to make left/right decisions with rotated objects and the results gained were compared to naming data gathered in a previous experiment using the same stimulus set. The results of the left/right experiment were found to be comparable to those of 'first trial' naming in the previous experiment. However there was no decrease in naming time with repeated exposure to the stimulus set. This was because left/right decisions are considered to always require mental rotation despite repeated presentations. Jolicoeur used this result to suggest that if the left/right task was associated with the use of mental rotation, and since the results were similar, it is also possible that mental rotation is used in the naming of natural objects seen for the first time.

The only difference in the slopes of the two sets of data was at the 180° rotation. In the naming data there is a clear reduction in reaction time at this orientation. And in the left/right data there is a large increase in errors at 180°. This leads to the possible conclusion that participants are ‘flipping’ images of objects shown at 180° over to 0°. Flipping the image would allow much faster recognition than mental rotation in naming trials. It would also account for the large number of errors shown in the left/right discrimination trials as the wrong response would be given as to which way the object was facing (Jolicoeur, 1985). For this reason only data from 0° to 120° was included in the analysis. Jolicoeur concluded from this set of experiments (Jolicoeur, 1985) that while mental rotation may be implicated in the identification of line drawings of natural objects seen for the first time, other processes must account for the recognition of objects subsequently viewed in the same orientations, and for objects viewed at 180°.

The Multiple Views Account

Tarr and Pinker (1989) provided a plausible account of what processes may be responsible for the subsequent trial results shown by Jolicoeur (1985). Participants performed naming experiments with a novel stimulus set in which individual stimuli were always seen at a single orientation. As in Jolicoeur’s (1995) experiments response times were seen to increase when stimuli were presented at novel orientations and to 'equalise' with practice. When the stimuli were presented at surprise orientations response times again increased, but they were only seen to increase as the distance from a previously learned orientation increased. Tarr and Pinker (1989) suggest that participants are using multiple stored representations of objects at the learned orientations. It appears that objects are not simply stored using their canonical upright. Using this process objects seen at novel orientations are mentally rotated to match the nearest previously stored orientation.

This hypothesis has since been challenged by experiments in which familiar stimulus orientations do not always speed identification (Biederman & Gerhardstein, 1993; Murray et al., 1993; Takano, 1989; Tarr & Pinker 1990). It has also been noted that objects can be separated into two classes. Some objects, such as pens and keys, can be described as polyoriented because they are likely to be seen at multiple orientations in the environment (Gibson & Robinson, 1935; Newell & Findlay, 1992). It is possible that representations of mono-oriented objects such as houses, which are generally seen at the same orientation in the environment, could be stored differently from those of polyoriented objects, and that this could account for the difference in experimental findings (Leek, 1998). In a word - picture verification task Leek (1998) found that when mono-oriented stimuli are presented at orientations other than their normal upright response time increases as degree of rotation increases. However no significant variation in response time is found for polyoriented stimuli presented in identical orientations.

Figure 1.3 provides an illustration of this effect. Leek suggests that these results support the hypothesis that multiple representations are encoded at familiar orientations for polyoriented objects.

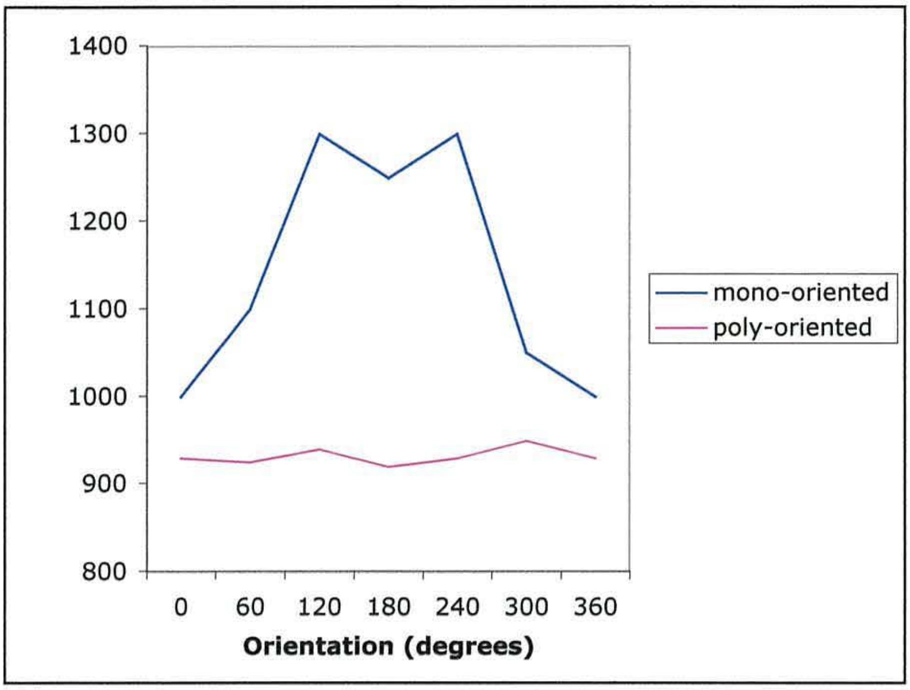

Figure 1.3. An illustration of the mono versus poly oriented object effect

It appears from the evidence above that while recognition by features or components is suitable for familiar objects viewed from familiar orientations, some sort of normalisation strategy is applied to objects presented at unfamiliar orientations. This suggests that viewpoint dependence is important at some level in object recognition. The strategy employed appears to be that of mental rotation (Jolicoeur, 1985), especially in mono-oriented stimuli (Leek, 1998). Once an object has been recognised at a novel orientation however it appears that a representation of it is stored at that level and will be used in future (Tarr & Pinker, 1998).

The computational approach

One way of testing cognitive models of human object recognition is by applying them to object recognition in computers. It is here that view invariant recognition is particularly difficult to achieve. Pattern analysis of face recognition has shown that changes in illumination and orientation of images of the same face can produce larger differences than those produced when images of different faces are shown under more similar viewing conditions (Adini, Moses and Ullman, 1997). This neatly illustrates the difficulties behind the most basic model of view invariant object recognition. Here it is proposed that the visual system stores all known views of an object and compares an image to the stored views in order to achieve recognition (Hopfield, 1982, Kohonen, 1978). Adini et al. showed that this approach does not create a solution to recognising an object under novel viewing conditions.

Attempts to produce structural descriptions of objects, advocated by Biederman (1995) and Marr and Nishihara (1978), have also been unsuccessful. One reason for this is the complexity of deriving structural descriptions from natural images. A second reason is that structural descriptions do now allow for discrimination of similar objects from the same class (Ullman and Bart, 2004).

View invariant features have been proposed as a possible solution to view invariant object recognition. Features that are view invariant under many transformations, or nearly invariant under general transformations, have been successfully derived computationally (Mikolajczyk & Schmid, 2002; Tuytelaars & Gool, 2000).

However Ullman and Bart (2004) point out that it is often difficult to derive enough view invariant features to achieve reliable recognition. It is also problematic that the most useful features for recognition tend not to be view invariant.

Ullman, Vidal-Naquet, & Sali (2002) describe a fragment-based classification scheme for objects. Here shapes can be represented within a class based on structures that are important to that class. A set of structures or fragments can be built up based on previous exposure to objects. Novel images can be compared to the fragment sets in order to identify them as belonging to one class or another. Ullman and Bart (2004) dealt with the problem of view invariance by creating a set of what they described as extended fragments. In these sets multiple views are stored of fragments in order to allow recognition at different viewpoints. For example both front and side views of an eye are important in order to classify an image as a face at various viewpoints. After a training phase on a known set of objects it was possible to introduce novel objects and for a view invariant representation of these objects to be obtained from a single viewing. For this to be successful a motion-tracking algorithm was necessary. The algorithm identified potential extended fragments from video images of shapes. This is echoed by research in human object recognition that shows that view invariant recognition depends heavily on smooth motion perception (Wallis & Bulthoff, 2001).

The fragment-based system described above appears to deal successfully with 'normal' changes in viewpoint. These include changes in depth as a face turns

The fragment-based system described above appears to deal successfully with 'normal' changes in viewpoint. These include changes in depth as a face turns away for example. However it may not fully account for the ability of the human visual system to recognise objects that are rotated to a completely novel orientation in the picture plane. Here only 2D information is available. Just and Carpenter (1985) and Carpenter and Just (1997) present a computational model which attempts to describe the processes involved in such a normalisation strategy.

The model is activation based. When a level or 'element' becomes sufficiently activated to above its threshold it becomes involved in initiating processes within the model. Elements include representations of objects, object parts, and spatial operations. Levels of activation are described as resources that are involved both with the processing and maintenance of representations. Mental rotation is a process within the model. During mental rotation representations of segments of an encoded figure are matched at successive orientations against segments of a target figure until they are similar enough to be compared. Mental rotation increases the activation resources depending on the degree of rotation required. Larger orientations require more activation because more representations are needed. It is suggested (Carpenter et al., 1999) that this can be correlated with increasing activation at the neural level during mental rotation in humans.

An fMRI experiment conducted by Carpenter et al., (1999) showed increasing activation in the areas associated with rotation during increasing mental rotations.

Activation was primarily found in the Parietal lobes. This was proposed as a parallel with the resources in the computational model that deal with processing of representations. Activation in areas associated with object recognition (particularly the inferior temporal regions) was also evident during mental rotation. This did not appear to increase with task difficulty. In the computational model this area was associated with stored representations that are retrieved in order to compare them to target objects. These levels of activation are seen as collaboration between the 'what' and 'where' visual streams during object recognition. These two streams will be discussed in more detail in the following section.

Neurological Literature

It is generally accepted that the complex architecture of mammalian vision is organised into two 'cortical visual systems' (Ungerleider & Mishkin, 1982). This theory separates the areas of extrastriate cortex into two pathways: dorsal and ventral. The dorsal pathway deals with information about spatial location and has been dubbed the 'where' pathway. It runs from occipital to parietal cortex. The ventral stream deals with object identification and has been dubbed the 'what' pathway. It runs from occipital to inferotemporal cortex. This theory stems from primate work. The problem with this is that the monkey visual system does not necessarily map exactly onto the human visual system. However homologues have been suggested, for example that STP (superior temporal polysensory area) in the monkey superior temporal cortex may be the equivalent of the inferior parietal lobule in humans (Morel and Bullier, 1990; Watson et al., 1994; Milner, 1995).

Functions of the two visual streams

Milner and Goodale (1993) have suggested that, in addition to dealing with spatial object location, the dorsal stream also has a role in guiding visuo-motor processes. This has been supported by evidence from the function of both monkey brains (Snyder et al., 1997) and human brains (Kawashima et al., 1996). Based on a review of the behavioural literature, and of their own research, Milner and Goodale (1995) suggest a reinterpretation of the 'what' versus 'where' theory. In their revision information about object features and location are processed by both streams, but for different purposes. The ventral stream combines information about the relation of object features to each other in order to construct long-term object representations, which facilitates recognition and categorisation. The dorsal stream is concerned with processing more on-line information about the spatial location of objects, and for programming appropriate motor interactions. Milner and Goodale stress the importance of coordination between the two streams. The result of a failure here is described by Sirigu, Cohen, Duhamel, Pillion, Dubois, and Agid (1995) who present evidence from a patient who can successfully identify and reach for an object, but who fails to organise the grasp component of the movement in a way that reflects how the object would be used.

Two patients provided most of the evidence for Milner and Goodale's (1995) reinterpretation of the two visual systems theory. Patient DF could reach accurately for objects, and yet was unable to demonstrate their orientation. Patient

RV, in contrast, could accurately describe objects but was unable to reach for them with any real success (Goodale et al., 1994). This has been further supported by evidence from positron emission tomography (PET); Decety et al. (1997) observed the different brain activity produced by passively observing an action in order to copy it or in observing it in order to recognise it. Participants were presented with a video of pantomimed actions and were asked to observe it either with the purpose of subsequently copying the action or of recognising it. It was shown that observation in order to imitate resulted in bilateral activation of the dorsal pathways, while observation in order to recognise activated the ventral pathway. Milner and Goodale (1995, pp.167-170) also cite behavioural evidence from the Titchner illusion where normal participants are fooled visually by the illusion but perform the motor component accurately. It appears that while the ventral stream may have been confused visually by the illusion, the dorsal stream enabled participants to interact successfully with the physical world.

Milner and Goodale have also proposed, based on the evidence presented above, that the two visual systems use different frames of reference, with the ventral stream using an object centred frame, and the dorsal stream using a viewer centred frame (Goodale and Milner, 1992; Milner and Goodale, 1993). This is supported by Kosslyn et al. (1990, 1994) also Biederman (1993). It is suggested that viewpoint dependant recognition is only employed when viewpoint independent processing has proved ineffective and further information about an object is required before it can be matched with a stored representation (Turnbull, Carey and

McCarthy, 1997). This explanation is reflected by neuropsychological evidence from patients with the 'unusual views' deficit. Here patients have few difficulties in identifying objects presented from conventional viewpoints, but fail to recognise objects viewed from more unusual angles (See Warrington and Taylor, 1973, 1978; Warrington and James, 1986; Landis et al., 1988). One possible explanation for this is that patients find it difficult to derive the principal axis of an object if it is foreshortened (Marr and Nishihara, 1978; Marr 1982). A second explanation is that patients find it difficult to identify an object when its critical features have been occluded (Warrington and James, 1986).

Humphreys and Riddoch (1984) described the performance of five visually agnosic patients who appear to support both of the above explanations. Four of the five patients performed poorly when the principal axis of an object was foreshortened, but they were unaffected when critical features were occluded. The final patient performed poorly when critical features were occluded, but was unaffected by foreshortening of principal axes. This evidence led Humphreys and Riddoch to suggest that both axes and features are important in object recognition and that each one represents a separate route to achieving object constancy. If the ventral system is responsible for viewpoint independent axis and features based recognition then the occipitotemporal region should be affected in these patients. However the classic unusual views deficit is associated with inferior parietal lobe lesions (Warrington and Taylor, 1973, 1978; Warrington and James, 1986). This region is usually associated with viewer-centred spatial information. Kosslyn et al. (1990,

1994) suggested a reason why dorsal stream information may be required in order for object recognition to be achieved. It is possible, if feature or axis based analysis fails to identify an object, that spatial information may be used in order to provide a better match between the object and stored representations.

The contribution of the Inferior Parietal Lobule

Further it has been argued by Milner (1995) that the inferior parietal lobule should not be considered as part of the dorsal stream. It is possible that this area is involved in binding information from the dorsal and ventral streams (Friedman-Hill et al., 1995; Morel and Bullier, 1990; McCarthy, 1993; Milner, 1995; Watson et al., 1994). From this it has been suggested that the inferior parietal lobule is used as an 'optional resource' to combine information from the streams when normal object recognition systems have failed in non-optimal circumstances (Turnbull, Carey & McCarthy, 1997). Loss of mental rotation ability is associated with right parietal lobe damage, and this may be a possible reason for the unusual views deficit (Layman and Greene, 1998). If this area is responsible for contributing to object recognition in non-optimal circumstances then damage to it will make unusual views of an object more difficult to decode.

Farah discussed two patients who showed that dissociation can exist between object recognition and mental rotation abilities (Farah et al., 1988; Farah and Hammond, 1988). Patient LK had intact parietal lobes but had bilateral occipitotemporal lesions. This patient showed great difficulty in recognising faces and common objects, and yet when assessed using mental rotation tasks proved to have above average ability (Farah et al., 1998). Patient RT (Farah and Hammond, 1988) had right frontoparietal lesions that extended into the right temporal lobe. This patient showed mental rotation deficits and yet no impairment when recognising faces or objects. From this it can be seen that object recognition can be intact while mental rotation abilities are compromised, and vice versa. It also suggests that mental rotation is just one of the resources employed by the dorsal stream/inferior parietal lobule when recognition is not immediately successful (Turnbull, Carey & McCarthy, 1997).

Turnbull et al., (Turnbull, Beschin & Della Sala, 1997; Turnbull, Laws and McCarthy, 1995) described three patients (LG, NL and SC) who lacked knowledge about the canonical upright orientation of objects while showing preserved object recognition ability. LG for example when asked to copy drawings would spontaneously produce a copy that was at a different rotation from the original, and this applied not only to novel objects such as the Rey Figure but also to familiar objects such as a bicycle (Turnbull et al., 1995). Cooper and Humphreys (2000) reported data from a patient MB who showed a milder orientation agnosia than those described above. When asked to name objects presented at ± 45°, she showed less slowing of reaction times than control participants. However when asked to make left/right decisions about objects she showed a normal pattern of slowing as orientation increased. Cooper and Humphreys suggest that the normal pattern of slowing as objects become increasingly misoriented during object naming could be caused by interference from spatial processes that are sensitive to view position. The left/right performance suggests that orientation information may be used in different ways depending on the task. It is suggested that in a left/right decision matching of object parts may be the most successful strategy and that this strategy is available to MB (Cooper and Humphreys, 2000).

Warrington and Davidoff (2000) present an interesting patient who showed better mirror image detection performance in objects which she could not recognise than in objects which she could recognise. This patient (JBA) had a degenerative condition, possibly Alzheimer's disease, which had bilaterally affected the parietal-occipital regions. By the time of the experiment she could only recognise 18 out of 36 line drawings of objects presented from a conventional viewpoint. For the main task JBA was presented with 24 paired objects and asked to identify them and state whether they were in the identical orientation or whether one was a mirror image of the other. Warrington and Davidoff report that she made significantly more orientation errors for pairs of objects which she could identify correctly than for pairs which she could not. This was tested further by repeating the task using simple geometric designs. In this condition JBA performed above chance level at making correct mirror image judgements. Warrington and Davidoff suggest that when objects are unidentified or novel there is no access to object-centred representations and performance is based on spatial abilities. When JBA could recognise objects she was referring to an object-centred description and at this level, because of her level of brain damage, she was unable to connect to the spatial resources required for correct orientation information. They question whether this is because the products of early spatial processing have been discarded once recognition has been achieved, or whether there is an inhibition of spatial information in recognised objects.

It appears from the evidence presented above that there are two major streams of information in the visual system. One dealing with viewer centred information and one with object centred information. It is possible that the inferior parietal lobule is responsible for binding these two sources of information as suggested by Milner (1995) and that this information is used as an optional resource in non-optimal conditions because there are several routes to achieving object recognition (Turnbull, Carey & McCarthy, 1997). Various patient studies have provided evidence for the two systems by showing that there can be dissociations in visual ability where recognition abilities are preserved while motor or spatial abilities are lacking or vice-versa. Patients who suffer from the ‘unusual views’ deficit tend to show a loss of mental rotation abilities and this condition is associated with right parietal lobe damage, Layman and Greene (1998) state that this is further evidence for the implication of the parietal lobes in providing information in non-optimal conditions.

The role of the parietal cortex in mental rotation has also been investigated using imaging techniques. These techniques allow a detailed analysis of the areas involved. Voyer (1995) showed that activity shifts from left parietal to right as a participant becomes familiar with mental rotation, and with increasing task difficulty. Formisano et al. (2002) used fMRI during an imagery task. Here activity was shown around the left intra parietal sulcus (IPS) during image generation. The area around the right IPS was active during the spatial analysis part of the task. Podzebenko, Egan and Watson (2005) compared performance on discrimination tasks of mentally rotating and real rotating objects during fMRI. Dorsal stream areas showed activation in both conditions. These were primarily the V5/middle temporal complex and the IPS. However during mental rotation the ventrolateral banks of the IPS were activated, and during real rotation the medial bank of the IPS was active. This is further evidence for specialisation within the parietal cortex. It is interesting to note that these areas surround those associated with motor tasks. Binofski et al. (1998) found that the anterior bank of the IPS is active during the performance of motor tasks.

Johnston et al. (2004) further examined the role of motor areas during a mirror image judgement task of 2D objects. This was performed whilst participants underwent fMRI. A 2D task was chosen in order to reduce possible confounds in comparison to 3D image discrimination tasks. Johnston et al. note that during 3D mental rotation of objects there are additional task demands such as foreshortening and occlusion of features. These demands may be reflected in unnecessary additional neuronal activity. Activity during the 2D task was shown primarily in medial premotor cortex. This area has been associated with the planning of internally generated movements (Deiber et al., 1996; Deiber et al., 1999). It is also associated with the processing and maintenance of sensory information (Picard & Strick, 2001). Johnston et al. (2004) conclude that the planning of visually guided movements may be functionally linked to the vector transformations that underlie visuo-spatial transformations.

The imaging literature provides a complex view of the systems associated with visuo-spatial transformation. There is evidence in support of the computational model of Just and Carpenter (1985). This model appears to account for activity in both the 'what' and 'where' streams during normalisation. This may be further linked to left and right parietal specialisation during task. It also appears that motor resources are in some way linked to the resources that deal with visuo-spatial transformation. Theories and models of object recognition have yet to account for this.

Working Memory

It is not always helpful to attempt to map the functions of the brain only on to the known anatomy. The creation of models using the information gained from both cognitive and neuropsychological experiments can more usefully map the various components of brain and behaviour. The Working Memory model is discussed here because it provides an insight into how and where mental rotation may occur, and how it may be investigated further.

Before the Working Memory model proposed by Baddeley and Hitch (1974) memory models had primarily concentrated on levels of processing in memory (eg. Atkinson & Shiffrin, 1968, 1971; Craik & Lockheart, 1972). The Baddeley and Hitch (1974) model was the first to represent memory as a series of specialised systems. The functions of the slave systems were coordinated by the central Executive which was responsible for reasoning and decision making. Following a substantial re-examination of much of the literature and a number of experiments performed themselves, Baddeley and Hitch originally proposed two slave systems; the articulatory loop which served the purpose of providing a temporary store for verbal material; and the visuo-spatial sketch pad (or VSSP) which served as a temporary store for visual or spatial material. The VSSP is similar to the visual buffer discussed by Kosslyn (1980, 1991) in that it is proposed that an image can be generated and manipulated here. However the VSSP is seen to be one of several systems involved in temporary storage and processing whereas the visual buffer is discussed mainly in terms of perception and long-term processing (Della Sala and Logie, 1993). Kosslyn (1991) suggested that working memory could be included in his model as a system which is involved with retrieving long-term memory information and placing it in the visual buffer.

The function of the slave systems has since been updated following further experimentation and data from neuropsychology. Baddeley (1986) made a distinction between phonological (speech based) and articulatory processes in the articulatory loop. The articulatory loop was described as consisting of a phonological store dedicated to speech perception, and an articulatory process dedicated to speech production. Similarly, following work conducted by Baddeley and Lieberman (1980), the VSSP (now the Visuo-Spatial Scratch Pad) was explored and described as an area where an image is held and manipulated in order to aid visual problem solving. During many visuo-spatial tasks spatial coding appeared to play a larger contribution that visual coding. For example a concurrent spatial tracking task had a disruptive effect on performance of the Brooks' matrix (Brooks, 1968) while a visual task did not (Baddeley and Lieberman, 1980). This prompted Baddeley and Lieberman (1980) to conclude that spatial information is of more importance in the VSSP than visual information. Logie (1986) suggested that perhaps the spatial nature of the Brooks' matrix itself may have affected this outcome. In a task where participants completed a visual imagery task performance was affected by a visual concurrent task involving the presentation of irrelevant patterns (Logie, 1986).

One of the important aspects of the VSSP is that information is held on a temporary basis once it is received from the senses or retrieved from long term storage, but that there must be some way of extending this retention interval if further analysis of an image is necessary (Della Sala and Logie, 1993). It appears that retention is achieved by both verbal and visual codes; this has been tested by investigations into whether verbal or visual confusions occur in memory for similar objects. Hitch et al. (1988) found that 5-year old children show more confusion errors when remembering a set of pictures that are visually similar such as pen and rake, than when remembering a set which are not similar such as pen and pig. However Hitch et al. (1989) showed that this effect disappears in older children and can only be replicated by concurrent articulatory suppression. This suggests that visual codes are used before verbal codes have developed, or with items which are novel or difficult to name (Della Sala and Logie, 1993).

The issue of whether visuo-spatial working memory is composed of two systems involved with visual codes and spatial codes is partly answered by its association with movement control. Logie and Marchetti (1991) found that when participants were required to retain information from a visual task following a retention interval filled by a concurrent movement task or the presentation of irrelevant pictures, memory was disrupted by the irrelevant pictures but not the movement task. Similarly if the information to be retained was spatial in nature the movement task disrupted memory but the irrelevant pictures did not. It appears from this evidence that both visual and spatial codes are used in working memory, and that they selectively affect visual and spatial memory. It is not clear from this evidence whether visuo-spatial working memory is composed of two separate systems.

Dual Task methodology

Mental Rotation is described as the act of imagining an object turning around (Corballis & Corballis, 1993). This description in some ways echoes the function of the VSSP as described above and it is sensible to conclude that this is where such manipulations will occur. All parts of the working memory are perceived to possess a finite level of resources during problem solving. Consequently dual task experiments are often utilised as a way of exploring the limitations of each part of the Model (e.g. Baddeley & Lieberman, 1980). Kahneman (1973) described dual task interference as the stage when the capacity of available resources is exhausted by the total mental effort. Pashler (1998) states that the two main assumptions of such capacity theories are that the two tasks can be performed in parallel but that performance will be constrained by the amount of mental resources allocated to each task, and that individuals are able to exercise control over allocation of mental resources. If this is the case it is important that equal weighting is given to each task by the experimenter as they instruct the participant.

Another type of theory about dual task interference is the bottleneck theory. Here it is proposed that not all kinds of mental resources can occur in parallel, and that a bottleneck of resources is created at various stages such as response selection (Welford, 1952, 1967; Van Selst & Jolicoeur, 1994). If this is the case it is important to ensure that the chosen dual task affects performance at the stage of perceptual encoding by being closely matched with the primary task and that stimulus onset is matched in both cases. It appears that visuo-spatial working memory deals with visual and spatial information separately, and that the spatial aspect of memory is associated with movement control, especially motor planning (Smyth and Pendleton, 1989). Any attempt to tax the spatial aspects of visuo-spatial memory therefore should involve primarily a spatial dual task, and possibly a motor task.

Summary

It appears from the evidence presented above that there are two major streams of information in the visual system, one dealing with viewer centred information and one with object centred information. Recognition by features or components is suitable for familiar objects viewed from familiar orientations and the neurological literature places recognition at this level in the Ventral system. However some sort of normalisation strategy is applied to objects presented at unfamiliar orientations. The strategy employed appears to be that of mental rotation (Jolicoeur, 1985), especially in mono-oriented stimuli (Leek, 1998). The Dorsal stream is suggested to deal with more spatial and motor aspects of vision and it is possible that the inferior parietal lobule is responsible for binding these two sources of information as suggested by Milner (1995). Various patient studies have provided evidence for the two systems by showing that there can be dissociations in visual ability where recognition abilities are preserved while motor or spatial abilities are lacking or vice-versa. Patients who suffer from the 'unusual views' deficit tend to show a loss of mental rotation abilities and this condition is associated with right parietal lobe damage. Layman and Greene (1998) state that this is further evidence for the implication of the parietal lobes in providing information in non-optimal conditions. Once an object has been recognised at a novel orientation it appears that a representation of it is stored at that level and will be used in the future (Tarr & Pinker, 1989).

Aims of the present study

The purpose of the following experiments is to investigate the role of visuo-spatial resources in object constancy. One way of investigating this would be to find a successful test of object constancy, and then to apply the appropriate dual tasks. Experiments One and Two represent an attempt to find and adapt a suitable primary task in which mental rotation appears to contribute to object recognition, and which is suitable to a dual task paradigm. A typical mental rotation trend is produced when reaction times increase linearly with increasing misorientation of an object from its normal upright (Shepard and Metzler, 1971).

A dual task is introduced in Experiment Three. It is important that the primary task can be conducted alongside a simultaneous dual task. In this case a primary task that requires visual imput and motor output is matched with a dual task that requires audio input and verbal output. It is predicted from the working memory literature (eg Baddeley and Lieberman, 1980) that spatial resources contribute towards mental rotation. A suitable dual task will therefore test only spatial resources. It is expected that the effect of the dual task will be to further slow reaction times when objects are misoriented from their usual upright. Increasing misorientations should be increasingly slowed. This is because the spatial resources that are allocated to performing mental rotation will be taxed by the addition of a spatial dual task (Kahneman, 1973). It is not expected that reaction times will increase when an object is presented at its usual upright position because this requires only a match to a previously stored representation (Tarr & Pinker, 1998). Spatial resources are not implicated at this level.

If the expected increase in reaction times is not evident there are two possible avenues of investigation. The first is to review and refine the application of the dual task. The task may not be testing spatial resources accurately enough. One method of ensuring the dual task is appropriate is to choose one which has been tested previously in the literature. Conversely it may be appropriate to create a new and more focussed dual task. A second possible reason for a failure of the spatial dual task is that the resources involved in mental rotation are not purely spatial in nature. It has been proposed that visuo-spatial working memory deals with visual and spatial information separately, and that the spatial aspect of memory is associated with movement control (Smyth & Pendleton, 1989). It is possible that the current working memory model, with its emphasis on visuo-spatial resources, is too simplistic. In addition it is proposed in the neurological literature that the parietal lobes are responsible for binding spatial and motor information (Milner 1995). It is possible that motor as well as spatial resources are implicated in mental rotation. If this is so it will be necessary to compare a spatial with a motor dual task.

Experiments Four to Six represent an attempt to test the dual task methodology further. A non-spatial dual task is created in Experiment Four in order to compare the general load of a dual task with the spatial load of the dual task in Experiment Three. It is predicted that the spatial dual task will have a greater effect on reaction times than the non-spatial dual task. Experiments Five and Six represent an attempt to create novel dual tasks which more accurately test mental rotation resources.

Experiment Seven takes the idea of manipulating spatial resources further by attempting to prime them. A comparison is made between performance of a repetition of the primary task following practice at object matching in one condition and mental rotation in another condition. It is expected that participants will not need to use mental rotation in a repetition of the primary task because they have been previously exposed to the pictures and will have stored representations of them at the novel orientations (Tarr & Pinker, 1998). If participants continue to show a mental rotation trend following mental rotation practice this suggests that participants can be primed to use resources even when other resources are available to them. Experiment Ten represents an attempt to refine the paradigm used in Experiment Seven.

Experiments Eight and Nine add specific motor-spatial aspects to the dual task procedure in order to test current theories that motor resources play a large part in spatial transformations. If the motor-spatial tasks have a greater or similar effect on object recognition than the spatial tasks this will suggest that current theories of object recognition are too simplistic. A role for motor resources will have to be found in the working memory model. This will add to the growing body of literature that suggests that visual and motor resources are linked.

Chapter 2

Introduction

It is probable that the time taken to recognise misorientated objects in the world around us is influenced by stored knowledge about them. Objects that are almost always seen at the same orientation (e.g. Wardrobes) are described as mono-oriented. The time taken to recognise these objects has been shown to increase as the angle at which the stimulus is viewed increases from that of its familiar upright position (e.g. Jolicoeur, 1985; Leek, 1998; McMullen and Farah, 1991). In particular Leek showed that although this is true of mono-oriented objects, recognition of poly-oriented objects, such as keys, does not appear to be affected by degree of orientation. Leek suggested that the most plausible explanation for this is to be found in the multiple views hypothesis (e.g. Tarr, 1995; Tarr and Bulthoff, 1995; Tarr and Pinker, 1989). This hypothesis states that the long-term memory template of an object is stored at the orientation it is familiarly seen at. Therefore a wardrobe will have a fixed upright position in memory because that is how it is usually viewed, whereas a representation of a key may be stored at many orientations because it is usually viewed from many different angles (eg. Tarr, 1995; Tarr and Pinker, 1989; Ullman, 1989). Leek suggests that if recognition of a misoriented object involves a mental rotation of the stimulus to match the stored representation, then the time taken to do this with a poly-oriented stimulus will be smaller than with a mono-oriented stimulus because there are several representations in memory, each at a different orientation.

The following experiment is a replication of Leek's (1998). The only changes that have been made to the original study are the translation of stimulus names from French to English, and the reduction of possible orientations from eight to five. The main reason for the change in number of orientations was that the two experiments have different aims. Leek's experiment was designed to investigate the different ways in which mono-oriented and poly-oriented stimuli are stored in memory. Stimuli were chosen from the Snodgrass and Vanderwart (1980) Standardized Set of 260 pictures, this provided a measure of control in the experimental design. The groundwork has already been carried out here for potential researchers in that the pictures are standardised on name agreement, image agreement, familiarity, and visual complexity (Snodgrass and Vanderwart, 1980). In the case of Leek's experiment both mono and poly-oriented pictures were used in the set of stimuli to be tested, this increased the number of possible picture choices from the Standardized Set. However in the proposed experiment the stimulus set must contain only mono-oriented stimuli, this narrows the available choices. Both experiments rely on an equation based on the number of participants who see pictures at each orientation. In Leek's experiment there were 48 pictures in each condition, each picture was shown only once at one of 8 orientations to any one participant. For a picture to be seen in each orientation by 12 participants there had to be 96 participants. In the planned set of experiments participants would also see each stimulus only once and would be eligible to take part in just one experiment in order to avoid practice effects (see Jolicoeur, 1985). For reasons of practicality over design therefore it was important to be able to reduce both the number of stimuli and the number of orientations in order not to exhaust the available participant panel and stimulus list. In addition to this a dual task will increase the experimental load on participants and it is prudent to reduce task length. Before the dual task paradigm can be implemented it is important to find a suitable 'starting point' experiment. This replication is an attempt to test the suitability of this particular experiment at reduced participant levels and orientations.

It is predicted that the time taken to recognise objects in the mono-oriented condition will increase linearly as they are presented at orientations further from their normal upright. This pattern of results is not expected in the poly-oriented condition. If the findings of similar experiments are replicated it is probable that this pattern will also not be shown in the 180° orientation because it is generally accepted that something other than mental rotation occurs here.

Method

Participants: Thirty participants from University of Wales, Bangor, participated in this experiment (24 female, 6 male). All participants were right handed, and received a course credit for their participation.

Materials: The stimuli were 96 black and white line drawings of common objects previously used by Leek (1998). A full list of the stimuli can be found in Appendix A. These were presented in a 12 x 12 cm frame on a 17-inch Apple Macintosh monitor. Each drawing could be presented in each of the following orientations in the picture plane: 0°, 45°, 90°, 135°, and 180°. For mono-oriented objects the zero degree orientation was taken to be their 'normal' orientation in the environment. For poly-oriented objects the zero degree orientation was taken to be when the principal axis of orientation was parallel with the vertical axis of the monitor. The experiment was run using Psychlab version 0.91, on a Macintosh Power PC and responses were collected using a Macintosh keyboard. A chin and headrest was provided to prevent participants from making head movements.

Design: There were 14 practice trials followed by 96 experimental trials. In each trial the name of an object was presented on the screen and then replaced by a picture. There were two types of trial: 'yes' response trials and 'no' response trials. In a 'yes' response trial the name was correct for the object presented. In a 'no' response trial the name was not correct for the object presented. In these trials the object was as similar as possible to the name both visually and semantically, for example a picture of a mouse followed the name 'hamster'. This ensured that participants studied the images and could not make accurate judgements based on basic shape features or global outlines. Figure 2.1 illustrates the sequence of events.

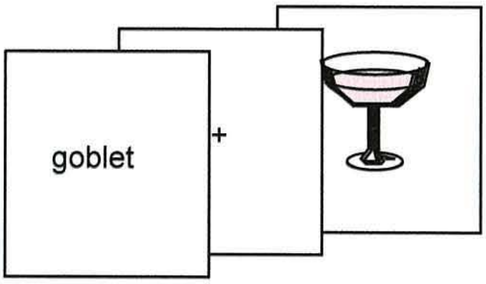

Figure 2.1. Illustration showing sequence of events in stimulus presentation

In total there were 48 stimuli in the 'yes' condition (24 polyoriented and 24 mono-oriented) and 48 in the 'no' condition. The stimuli in the 'no' condition were made up of randomly selected common objects and could be mono or poly-oriented. Appendix A contains the list of stimuli in each condition. In order to avoid practice effects each stimulus was presented only once to each participant. This involved creating Five stimulus lists, the first one showing 'chair' at 0° and 'lamp' at 45° orientation for example, the next showing 'chair' at 45° and 'lamp' at 90° and so on. Each participant was randomly assigned to one of the five lists and this resulted in each stimulus being seen at each orientation by 6 different participants.

Procedure: Each trial began with the prompt "Ready?" which was presented in the centre of the screen and remained until the participant pressed the spacebar. When the spacebar had been pressed, and after an interval of 500ms, the name of an object was presented in the same location as the prompt. The name remained for 750ms. A blank interval of 500ms followed, and then a line drawing of an object was presented in the centre of the screen at one of the five orientations in the picture plane. Participants were instructed to respond by pressing the key marked 'YES' if the name matched the picture presented, or by pressing the key marked 'NO' if the picture and name did not match. The 'O' and 'E' keys were chosen on the computer keyboard to represent 'yes' and 'no' respectively. Participants responded by using the index finger of their preferred hand. Responses were to be made as quickly and accurately as possible following presentation of the picture. If no response was recorded within 2500ms an error tone was sounded and the next stimulus set was presented. In all trials after a response was made the stimulus disappeared from the screen and there was a delay of 3000ms before the next trial.

Participants completed a written consent form before being given verbal instructions to explain the task. These were similar to those provided in Appendix C. They were seated at a distance of 36cm from the monitor and rested their heads on a chinrest for the duration of the experiment. They were asked to avoid any head movements. The experiment lasted for approximately 10 minutes. Participants were verbally debriefed, again this was similar to that provided in Appendix C.

Results

For each participant mean reaction times (RTs) were obtained for each orientation in the 'YES' condition. A standard deviation was calculated for each participant at each orientation and scores of more than two standard deviations above or below the norm were rejected. A mean participant RT for each orientation was then obtained. Participant RTs were then further collapsed to provide mean group RTs for each orientation. These are provided in Table 2.1

Table 2.1. Table showing group means, standard errors and standard deviations in the mono- and poly-oriented conditions

	Mono-oriented			Poly-oriented		
Orientation (°)	Mean	SE	SD	Mean	SE	SD
0	684	41.0	161	721	36.2	211
45	788	40.0	250	740	42.2	222
90	808	48.5	227	694	28.6	160
135	898	51.4	286	740	33.7	234
180	797	34.2	185	706	28.9	157

As can be seen in the table and is illustrated by Figure 2.2 there is a clear trend in the Mono-oriented condition with reaction times increasing as rotation from the upright increases, no such trend is apparent in the poly-oriented condition. The mean scores were entered into a 2x5 ANOVA with stimulus orientation and object type (Mono versus Poly) as factors. A mauchly sphericity test was non-significant $p=.642$, so there was no evidence of heterogeneity of covariance. A boxplot of the data showed no evidence of skewness in either condition. A significant main effect of object type [$F(1, 58)=4.41$, $MSE=160677$, $p<.05$] was found, and a significant interaction [$F(4,232)=2.70$, $MSE=68090$, $p<.05$]. An analysis of simple effects showed that there was a significant effect of orientation in the mono-oriented condition [$F(4,116)=3.47$, $MSE=31878$, $p<.01$, Mauchly =0.589], but not in the poly-oriented condition.

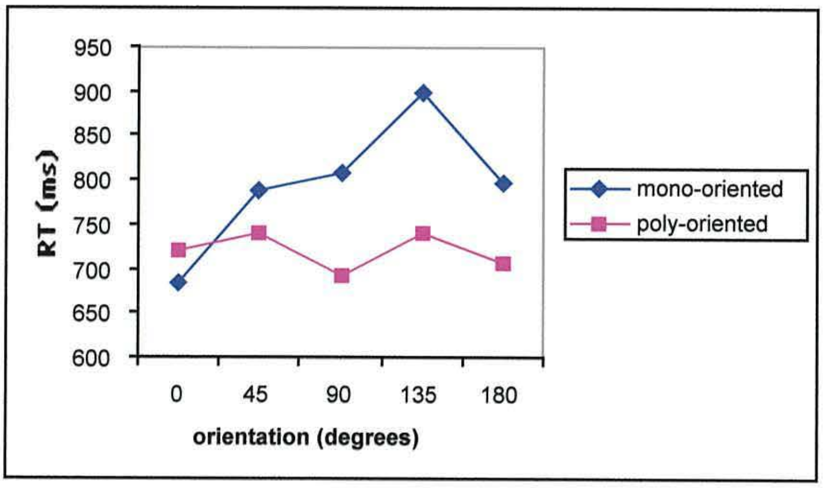

Figure 2.2. Mean reaction times (RT) as a function of stimulus orientation in the mono- and poly-oriented conditions

Analysis of Error Rates

An analysis of error rates showed that participants made 10.2% errors on No response trials and 4.8% errors on Yes response trials. A Wilcoxan test showed that this difference was significant [Z corr = -2.1861, p<.01]. In the Yes responses, the participants made 4% errors in the mono-oriented object trials and 2.6% errors in the poly-oriented object trials. This difference was not significant. A two-way ANOVA on error rates for the Yes response trials with stimulus orientation and object type as factors showed that there were no main effects of either factor, and no significant interaction. This allows us to discount the possibility that differences between mono- and poly-oriented RT's are a result of a speed-accuracy tradeoff.

Discussion

The results gained from this are an encouraging replication of those obtained by Leek (1998), with misorientation having a strong effect on RT's for mono-oriented objects but not for poly-oriented objects. It is possible to propose that mental rotation is being performed by participants in the mono-oriented condition but not in the poly-oriented condition. It appears from the evidence that this paradigm is robust enough to form the primary Mental Rotation task to be used in further experiments. Reducing the number of orientations does not appear to have weakened the effect in comparison to Leek's original study.

Chapter 3

Introduction

During Experiment One it became apparent that some changes had to be made to the design in order to make it more suitable for dual task methodology. The poly-oriented stimuli were removed because they were not needed in the dual task paradigm; all 'Yes' stimuli in the new experiment were mono-oriented because only they produce an orientation effect. Removal of poly-oriented stimuli allowed an increase in the number of mono-oriented stimuli that could be used before participants became tired during dual task load, resulting in a decrease in the number of participants required for each experiment.

Orientations were also altered. It was decided to adopt the six orientations previously used by Jolicoeur (1985) rather than continuing to use the 0-180° orientations from Experiment One. A full range of orientations through 360° illustrates the interesting 'M' shaped dip in reaction times caused by the 180° orientation. A new experiment was programmed in order to address these factors. The removal of poly-oriented stimuli allowed an increase in the number of mono-oriented stimuli that could be used in the 'Yes' condition from 48 to 72, while still reducing the overall number of experimental stimuli. The additional pictures were also taken from the Snodgrass and Vanderwart Standardized Set (1980) as a measure of control. Pictures in the 'No' condition consisted of poly-oriented stimuli and also mono-oriented stimuli that were deemed less suitable for the Yes condition (for reasons such as being presented at a foreshortened view). In order for each picture to be presented only once to each participant, while also being presented at all 6 orientations for the purposes of the experiment, it was necessary to create 6 stimuli lists as described in the previous experiment. In the lists, for example, 'aeroplane' was presented at 0° in list one, 60° in list two, and so on. Before a dual task could be performed it was important to collect baseline measurements. This experiment will provide control group data for subsequent dual task experiments.

Method

Participants: Twenty-four participants from University of Wales, Bangor, participated in this experiment (17 Female, 7 Male). All participants were right handed. They received a course credit, or payment, for their participation.

Materials: The stimuli were 144 black and white line drawings of common objects taken from the Snodgrass and Vanderwart set (1980). A full list of the stimuli can be found in appendix B. These were presented in a 12 x 12 cm frame on a 17-inch Apple Macintosh monitor. Each drawing could be presented in each of the following orientations in the picture plane: 0°, 60°, 120°, 180°, 240°, and 300°. The zero degree orientation was taken to be the 'normal' orientation in the environment for mono-oriented stimuli. The experiment was run using PsyScope version 1.2.4.PPC, on a Macintosh Power PC and responses were collected using a Macintosh keyboard. Instruction and debriefing screens were shown at the beginning and end of the experiment and are provided in appendix C. A chin and headrest was provided to prevent participants from making head movements.

Design: There were 10 practice trials followed by 144 experimental trials. On each trial the name of an object was presented on the screen and then replaced by a picture. There were two types of trial: 'yes' response trials and 'no' response trials. In a 'yes' response trial the name was correct for the object presented. In a 'no' response trial the name was not correct for the object presented. In these trials the object was as similar as possible to the name both visually and semantically, for example a picture of a mouse followed the name 'hamster'. This ensured that participants studied the images and could not make accurate judgements based on basic shape features or global outlines. In total there were 72 stimuli in the 'yes condition and 72 in the 'no' condition. The stimuli in the 'yes' condition were all mono-oriented, the stimuli in the 'no' condition were made up of randomly selected common objects and could be mono or poly-oriented. Participants saw each stimulus only once to avoid practice effects. This was achieved by creating 6 stimuli lists, which contained one each of the 144 stimuli (List One can be seen in Appendix D), and assigning participants randomly to one of the lists. In total 4 different participants saw each object at each stimulus orientation. The stimuli lists were randomised for each participant.

Procedure: Each trial began with the prompt "Ready?" which was presented in the centre of the screen and remained until the participant pressed the spacebar. When the spacebar had been pressed, and after an interval of 500ms, the name of an object was presented in the same location as the prompt, this remained for 750ms. A blank interval of 500ms followed, and then a line drawing of an object was presented in the centre of the screen at one of the six orientations in the picture plane. Participants were instructed to respond by pressing the key marked 'YES' if the name matched the picture presented, or by pressing the key marked 'NO' if the picture and name did not match. The 'N' key on the keyboard was labelled 'YES' and the 'M' key was labelled 'NO'. Responses were made with the index finger of the preferred hand. Responses were to be made as quickly and accurately as possible following presentation of the picture. In all trials after a response was made the stimulus disappeared from the screen and there was a delay of 3000ms before the next trial.

Participants completed a written consent form before reading an instruction screen on the computer monitor. They were seated at a distance of 36cm from the monitor and rested their heads on a chinrest for the duration of the experiment. They were asked to avoid any head movements. The experiment lasted for approximately 15 minutes.

Results

For each participant mean reaction times (RTs) were obtained for each orientation in the 'YES' condition. A standard deviation was calculated for each participant at each orientation and scores of more than two standard deviations above or below the norm were rejected. A mean participant RT for each orientation was then obtained. Participant RTs were then further collapsed to provide mean group RTs for each orientation. This produced the set of data that is illustrated in Figure 3.1 and which demonstrates the typical 'M-shaped' graph associated with mental rotation experiments where a dip in reaction times occurs at 180°. Means and Standard Deviations are presented in Table 3.1

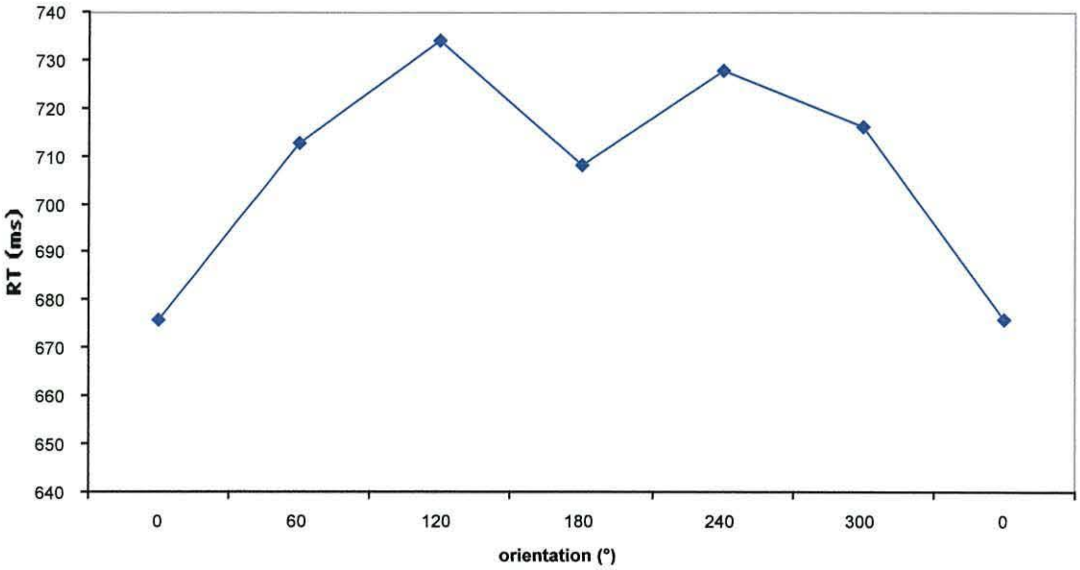

Figure.3.1. Mean reaction times (RT) as a function of stimulus orientation showing the typical 'M' shaped graph

Table 3.1. Means, standard deviations and standard error at the 6 orientations

Orientation (°)	Mean	SD	SE
0	676	106	20.3
60	713	93	17.9
120	734	105	20.2
180	708	116	22.4
240	728	130	22.2
300	716	105	24.7

The mean scores were entered into an ANOVA. A boxplot showed that the data was skewed and marked one participant as an outlier, this data set was removed from the analysis in order to correct the skewness. A Mauchly Sphericity test was significant ($p>0.05$). However the orientation effect was so significant that a more conservative Greenhouse Geisser was not necessary [$F(5,120)=4.01$, $MSE=11165$, $p<.001$] as this is only recommended if the F with unadjusted degrees of freedom is barely significant beyond the 0.05 level (Kinnear & Gray, 2000).

Analysis of Error Rates

An analysis of error rates showed that participants made 14.6% errors on No response trials and 2.6% errors on Yes response trials. A Wilcoxan test showed that this difference was significant [Z corr = -3.0594, p<.01]. An ANOVA of error rates for the Yes response trials with stimulus orientation as a factor showed that there were no main effects of orientation. This allows us to discount the possibility that differences in RT's are a result of a speed-accuracy tradeoff.

Summary

These results show that the amended stimulus set replicates the effect seen in the mono-oriented condition of Experiment one, suggesting that mental rotation is taking place. RT's can be seen to increase linearly as misorientation increases. Making use of a range of orientations from 0-360° provides a useful illustration of the Mental Rotation effect at all orientations. The dip in reaction times at 180° suggests that some participants are not using mental rotation at this orientation. Jolicoeur (1985) suggests that the visuo-spatial transformation of 'flipping' the image over to 0° probably occurs here. This would be faster than mental rotation based on the Carpenter and Just (1985) model. This is because fewer activation resources are required. Only one tentative representation needs to be created in order to achieve a match. Following this successful replication it is possible to go on to test the effect of a dual task on object recognition.

Chapter 4

Introduction

For the purposes of this experiment a dual task paradigm was devised. Based on the theory discussed earlier that the visual system uses two streams in object recognition, with a spatial stream providing extra information when an object is misoriented (Turnbull, Carey and McCarthy, 1996), it is hypothesised that this spatial stream can be occupied with a dual task. If the pattern of reaction times produced in the previous experiment are affected by a spatial dual task this will indicate that spatial resources do contribute to Mental Rotation. The Just and Carpenter model (1985) states that increasing levels of activation resources are allocated to increasing orientations in order to create tentative matches. The Working Memory Model places these resources in the Visuo-Spatial Scratchpad and implicates spatial resources (Baddeley and Lieberman, 1980). It is expected that reaction times will not be disrupted when an object is presented in its normal upright position because Mental Rotation is not needed here. A slowing of reaction times at increasing levels of misorientation is predicted as the spatial task interferes with spatial resources.

Smyth and Scholey (1994) showed that an auditory spatial dual task interferes with spatial memory. In one condition they required participants to make a left-right distinction between tones sounded to the right and left of the body's midline and found that this significantly interfered with spatial span recall. Interference was evident even when no response was required, but a verbal or manual response increased interference (Smyth and Scholey (1994). A version of this paradigm has been adopted here. While participants are performing the dual task, their reaction times should increase if they are unable to access the problem solving spatial store. In order to test how the dual task should be applied a pilot study was carried out.

Pilot Study

Six participants from the University of Wales, Bangor participated in the experiment. The materials were identical to those described in Experiment Two, except for the use of an animal training clicker. The dual task experiment required subjects to make a verbal response to clicks made in a 'square' pattern behind them. They were asked to say which corner of the square the sound came from: 'top left', 'bottom right' etc. Figure 4.1 illustrates the arrangement of the experimenter and participant.

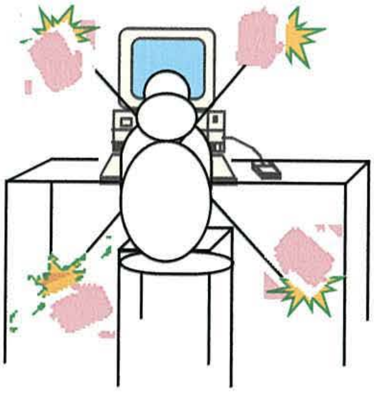

Fig 4.1. Approximate arrangement of experiment. Experimenter seated behind the participant. Clicks made in a square pattern around the participant

It was found that participants performed best when the clicks were produced approximately 20 cm above the head or floor level, and approximately 45cm from the midline of the body. If the clicks were closer to the midline of the body participants had difficulty in distinguishing right from left, and if they were too close together on the vertical plane subjects had difficulty in distinguishing top from bottom. The experimenter sat approximately 45cm behind the subject. All measurements are approximate because it was necessary to find the appropriate distances for each participant in a trial session before the experiment began. Each participant was allowed to repeat the task until they were happy with their performance and until they were making reliably correct responses. At this point participants completed the task described in Experiment One with two different dual task conditions: half of the participants heard a click when the stimulus name appeared on the screen; and half of the participants heard a click when the stimulus itself appeared on the screen.

It appears from the pilot study that the dual task affects RT's more when it coincides with the stimulus appearing on the screen. Reaction times ranged from 900 -1000ms in the stimulus name condition, and from 1000 - 1400 in the stimulus condition. This suggests that the dual task condition causes an increase in reaction time overall during the stimulus name condition, but that a true dual task interference effect can be seen in the stimulus condition as shown by the further increase in reaction times.

Main Experiment

Method

Participants: Twenty-four participants from University of Wales, Bangor, participated in this experiment (16 females, 8 males). All participants were right handed. They received a course credit, or payment, for their participation.

Materials: The stimuli were 144 black and white line drawings of common objects taken from the Snodgrass and Vanderwart set (1980). A full list of the stimuli can be found in Appendix B. These were presented in a 12 x 12 cm frame on a 17-inch Apple Macintosh monitor. Each drawing could be presented in each of the following orientations in the picture plane: 0°, 60°, 120°, 180°, 240°, and 300°. The zero degree orientation was taken to be the 'normal' orientation in the environment for mono-oriented stimuli. The experiment was run using PsyScope version 1.2.4.PPC, on a Macintosh Power PC and responses were collected using a Macintosh keyboard. Instruction and debriefing screens were shown at the beginning and end of the experiment and are provided in Appendix C. A chin and headrest was provided to prevent participants from making head movements. An animal training clicker was used during the dual task described in the pilot study.

Design: There were 10 practice trials followed by 144 experimental trials. On each trial the name of an object was presented on the screen and then replaced by a picture. There were two types of trial: 'yes' response trials and 'no' response trials. In a 'yes' response trial the name was correct for the object presented. In a 'no' response trial the name was not correct for the object presented. In these trials the object was as similar as possible to the name both visually and semantically, for example a picture of a mouse followed the name 'hamster'. This ensured that participants studied the images and could not make accurate judgements based on basic shape features or global outlines. In total there were 72 stimuli in the 'yes condition and 72 in the 'no' condition. The stimuli in the 'yes' condition were all mono-oriented, the stimuli in the 'no' condition were made up of randomly selected common objects and could be mono or poly-oriented. Participants saw each stimulus only once and in total 4 different participants saw each object at each stimulus orientation. The trials were randomised.

Procedure: Each trial began with the prompt "Ready?" which was presented in the centre of the screen and remained until the participant pressed the spacebar. When the spacebar had been pressed, and after an interval of 500ms, the name of an object was presented in the same location as the prompt, this remained for 750ms. A blank interval of 500ms followed, and then a line drawing of an object was presented in the centre of the screen at one of the six orientations in the picture plane. A click was produced at the same time as the line drawing appeared on the screen. Participants were asked to make a verbal response to the click and a key press response to the drawing. Participants were instructed to respond by pressing the key marked 'YES' if the name matched the picture presented, or by pressing the key marked 'NO' if the picture and name did not match. Again the 'N' key on the keyboard was labelled 'YES' and the 'M' key was labelled 'NO', responses were made with the index finger of the preferred hand. Responses were to be made as quickly and accurately as possible following presentation of the picture. In all trials after a response was made the stimulus disappeared from the screen and there was a delay of 3000ms before the next trial. Participants completed a written consent form before reading an instruction screen on the computer monitor. They were seated at a distance of 36cm from the monitor and rested their heads on a chinrest for the duration of the experiment, they were asked to avoid any head movements. The experiment lasted for approximately 20 minutes.

Results

Data were collapsed as described in Experiment Two. Group means and standard deviations are shown in Table 4.1.

Table.4.1. Group means, standard deviations and standard errors

Orientation (°)	Mean	SD	SE
0	991	281	41.9
60	1066	362	56.3
120	1106	345	41.7
180	1043	281	30.5
240	1076	253	48.6
300	1029	295	39.9

A boxplot showed evidence of skewness in the data and marked one participant as an outlier; this data set was removed in order to correct the skewness. The data was entered into an ANOVA, a Mauchly's test was non-significant $p=0.414$. A significant effect of orientation was shown $F(5,110)=2.51, MSE=36952, p<0.05$

Figure 4.1 shows that reaction times increase as misorientation increases in both Experiments Two and Three, but that the dual task in Experiment Three increases RT's at all orientations

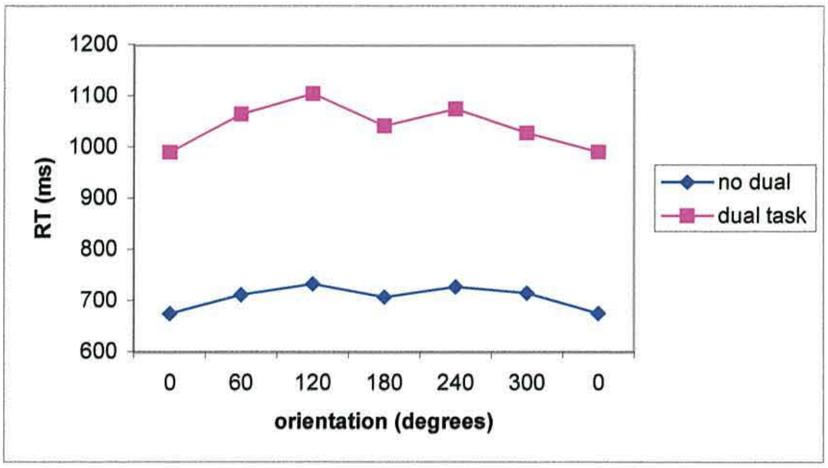

Figure 4.1 Mean reaction times (RT) as a function of stimulus orientation in experiments 2&3

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A between subjects ANOVA including data from Experiment 2 was performed. A boxplot showed no evidence of skewness and a Mauchly Sphericity test was non-significant *p*=0.208. The ANOVA showed a significant effect of orientation *F*(5,220)=5.18,*MSE*=45981 *p*>0.001, and a significant effect of condition *F*(1,44)=28.16,*MSE*=7862906 *p*>0.001. However there was no significant interaction between the groups. The reason for this is suggested in a Bonferroni Comparison which shows that there is a significant difference in RT's between conditions at all orientations including zero *t*(22)=5.21 p>0.008.

However the most important factor for comparison between the groups here is not the size of reaction times but the trend of the data in each condition. Consequently a t-test between trend lines was performed. Figure 4.1 shows that during mental rotation the M shaped curve produced by the data in the first presentation is fairly symmetrical. By combining the 60° and 300° and 120° and 240° orientation RT's together and applying the relevant contrast weights an increasing trend is shown in the data. Effectively the M is folded back on itself. An increasing trend indicates that mental rotation is taking place; a flat trend would indicate that other resources are contributing to recognition. The 180° data was not included in the analysis because it does not appear that mental rotation takes place at this orientation. This was performed for each participant, creating three data points, which is the minimum required to show the trend of a data set. The trend of the data for each participant was plotted on a scatter graph and recorded. This was combined into an average score for each group. Following this a trend line analysis between the groups from Experiments 2 and 3 was performed and showed a significant difference in slopes $t(46) = 4.48$; $p<0.001$.

Figure 4.2 shows the trend and standard error in each of the conditions. Both conditions produced a positive trend in the data but it is clear that the trend was much steeper in Experiment 2.

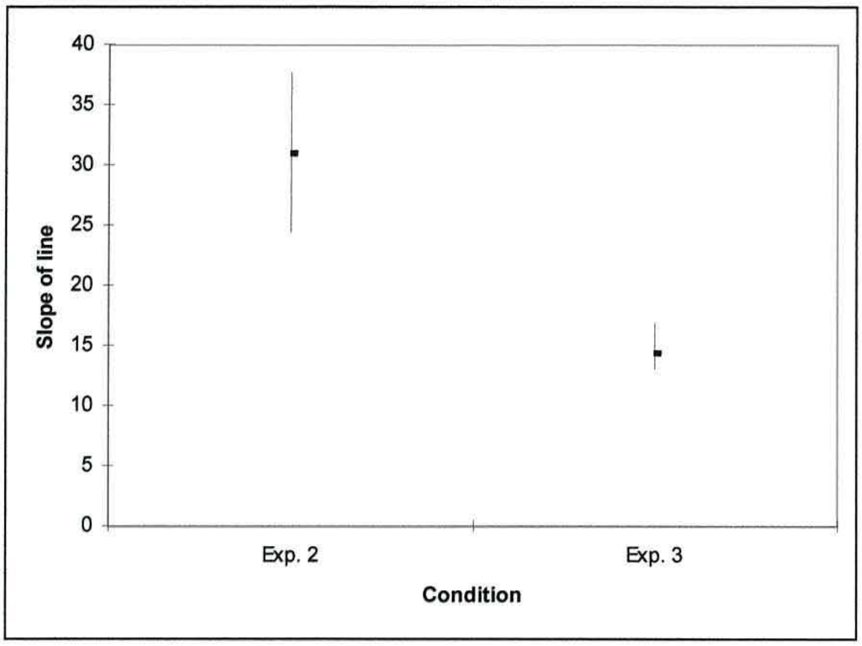


Figure 4.2. Mean trend and standard error of data for Experiments 2 and 3.

An analysis of error rates showed that participants made on average 1.83/72 (2.5%) errors in Experiment Two, and 3.54/72 (4.91%) errors in Experiment three. A Mann Whitney U test showed that this increase was not significant [$z=2.30$; $p>0.05$] and this can be taken to suggest that participants were attending to the main task in both conditions.

Summary

Intuitively one would expect a dual task to have the effect of increasing reaction times if it is having an effect on the primary task. In this particular case it was expected that the spatial dual task would have little effect on RT's at the 0° orientation but that it would slow RT's at increasing orientations. This is because the spatial task should only interfere with spatial resources. There is no suggestion in the literature that spatial resources are needed when an object is viewed at a familiar orientation. In the present experiment, the effect of the dual task has been to increase RT's at the 0° orientation in addition to the rest of the orientations. It is important to consider what is happening while working memory is processing both tasks.

Van Selst and Jolicoeur (1994) separated processing into 3 levels, namely perceptual encoding, response selection and response execution. They state that that when two tasks of similar difficulty are performed simultaneously there is a bottleneck of resources at the level of response selection. In this case, when a participant is required to respond to both a click and to an object viewed at 0° orientation, both of which are simple tasks, there is an increase in reaction time because of the response selection bottleneck. However, when an object is viewed at 120° for example, the primary task has become more difficult while the clicker task remains the same. In this case there is no bottleneck, resulting in faster response selection time which makes it appear that the dual task makes the primary task easier and producing a shallower slope between 0° and 120°.

Because of this it will be necessary in subsequent experiments to use closely matched dual tasks. The difference in RT's at the Zero orientation in experiments Two and Three could be caused by the fact that no dual task is taking place in Experiment Two. Any increase in slope between 0° and 300° will be indicative of slowed resources at the perceptual encoding stage of working memory processing. Based on the Van Selst and Jolicoeur (1994) model, if the bottleneck in resources occurs only at response selection the line produced should be fairly flat.

It is also worth remembering that at the 180° orientation it appears that a different visuo-spatial transformation occurs because the mental rotation trend is disturbed and recognition times generally become much faster here. This suggests that other routes to object constancy are available to participants (Tarr and Pinker, 1989).

From the trend line data it appears that the spatial dual task has reduced the average trend in the data. This is consistent with the discussion above in that the slope of reaction times has become much shallower during dual task. However it is possible to quantify and compare the difference in trend produced by the dual task. It can be seen here that an increasing slope in the data indicates that mental rotation is still taking place. Comparison of trend lines during dual task will be important in future experiments.

Chapter 5

Introduction

In the previous experiment it was shown that the spatial dual task did have an effect on reaction times during the object recognition task. It is important to test the effects of a non-spatial dual task on reaction times as well as a spatial dual task, in order to separate out the basic dual task effect. In experiment Four a non-spatial control task was devised for the spatial clicker task. Again the constraints of the task were that it had to have audible input and verbal output. Previously a tone discrimination task has been used in similar experiments (Van Selst & Jolicoeur, 1994), and this appeared to be the most suitable task in this situation. Experiment 4 will also have a within subjects design; both dual tasks will be completed by each participant.

It is predicted that the spatial dual task will have a greater effect on reaction times than the non-spatial dual task. This is because spatial resources are implicated in mental rotation and it appears, from the pattern of RT's produced in previous experiments, that mental rotation is being used in order to facilitate recognition of misoriented objects.

Method

Participants: Twenty-four participants from University of Wales, Bangor, participated in each experiment (15 Females, 9 Males). All participants were right handed. They received a course credit, or payment, for their participation.

Materials: The stimuli were 144 black and white line drawings of common objects taken from the Snodgrass and Vanderwart set (1980). A full list of the stimuli can be found in appendix B. These were presented in a 12 x 12 cm frame on a 17-inch Apple Macintosh monitor. Each drawing could be presented in each of the following orientations in the picture plane: 0°, 60°, 120°, 180°, 240°, and 300°. The zero degree orientation was taken to be the 'normal' orientation in the environment for mono-oriented stimuli. The experiment was run using PsyScope version 1.2.4.PPC, on a Macintosh Power PC and responses were collected using a Macintosh keyboard. Instruction and debriefing screens were shown at the beginning and end of the experiment and are provided in appendix C. A chin and headrest was provided to prevent participants from making head movements. An animal training clicker described in Experiment Three was used in the spatial dual task component of this experiment. Two keys from a xylophone, both C, an octave apart were used in the non-spatial dual task component.

Design: There were 10 practice trials followed by 144 experimental trials. On each trial the name of an object was presented on the screen and then replaced by a picture. There were two types of trial: 'yes' response trials and 'no' response trials. In a 'yes' response trial the name was correct for the object presented. In a 'no' response trial the name was not correct for the object presented. In these trials the object was as similar as possible to the name both visually and semantically, for example a picture of a mouse followed the name 'hamster'. This ensured that participants studied the images and could not make accurate judgements based on basic shape features or global outlines. In total there were 72 stimuli in the ‘yes condition and 72 in the ‘no’ condition, the stimuli in the ‘yes’ condition were all mono-oriented, the stimuli in the ‘no’ condition were made up of randomly selected common objects and could be mono or poly-oriented. Participants saw each stimulus only once to avoid practice effects. This was achieved by creating 6 stimuli lists, which contained one each of the 144 stimuli (List One can be seen in Appendix D), and assigning participants randomly to one of the lists. In total 4 different participants saw each object at each stimulus orientation. The trials were randomised.

Participants randomly participated in either dual task first; half performed the spatial task first and half the non-spatial task. The spatial dual task experiment required participants to make a verbal response to clicks made in a ‘square’ pattern behind them; they were asked to say which corner of the square the sound came from. Clicks were produced approximately 20 cm above the head or floor level, and approximately 45cm from the midline of the body. In the non-spatial dual task one of the xylophone keys was sounded and participants were required to state whether they heard a high or a low note. The tone task was chosen because, like the clicker task, it has been used in previous experiments and this offers some measure of control. It relies on auditory input and verbal output, this matches the requirements of the clicker task, and there is no reason to suppose that it taxes spatial resources. Both tasks are easily learned and fairly simple to perform on their own. Any difference in task difficulty will be shown in increased error rates on one task compared to the other. In order to reduce practice effects participants were presented with different stimuli lists each time they completed the main experiment. Participant One would have been presented with stimuli from List One during the spatial condition for example, and with stimuli from List Two in the non-spatial condition.

Procedure: Each trial began with the prompt "Ready?" which was presented in the centre of the screen and remained until the participant pressed the spacebar. When the spacebar had been pressed, and after an interval of 500ms, the name of an object was presented in the same location as the prompt, which remained for 750ms. A blank interval of 500ms followed, and then a line drawing of an object was presented in the centre of the screen at one of the six orientations in the picture plane. Participants were instructed to respond by pressing the key marked 'YES' if the name matched the picture presented, or by pressing the key marked 'NO' if the picture and name did not match. The 'N' key on the computer keyboard was labelled 'YES' and the 'M' key was labelled 'NO'. Responses were made with the index finger of the preferred hand. Responses were to be made as quickly and accurately as possible following presentation of the picture. In all trials after a response was made the stimulus disappeared from the screen and there was a delay of 3000ms before the next trial.

In the dual task condition a sound was produced when the object appeared on the screen. The spatial dual task experiment required participants to make a verbal response to clicks made in a 'square' pattern behind them; they were asked to say which corner of the square the sound came from. In the non-spatial dual task one of the xylophone keys was sounded and participants were required to state whether they heard a high or a low note. In each condition participants performed practice trials of just the dual task until they were comfortable with them.

Participants completed a written consent form before reading an instruction screen on the computer monitor. They were seated at a distance of 36cm from the monitor and rested their heads on a chinrest for the duration of the experiment, they were asked to avoid any head movements. The experiment lasted for approximately 45 minutes.

Results

Data were collapsed as described in Experiment Two. Means and standard deviations are shown in Table 5.1. Figure.5.1 shows the slopes gained.

Table. 5.1. Means, standard deviations and standard errors in the click and tone conditions

	Click			Tone		
Orientation (°)	Mean	SD	SE	Mean	SD	SE
0	953	307	42.3	831	310	33.0
60	984	362	49.1	867	252	38.0
120	1054	340	56.1	879	270	43.2
180	959	308	51.4	855	257	40.7
240	1039	344	45.5	874	241	45.4
300	977	341	48.5	880	307	42.0

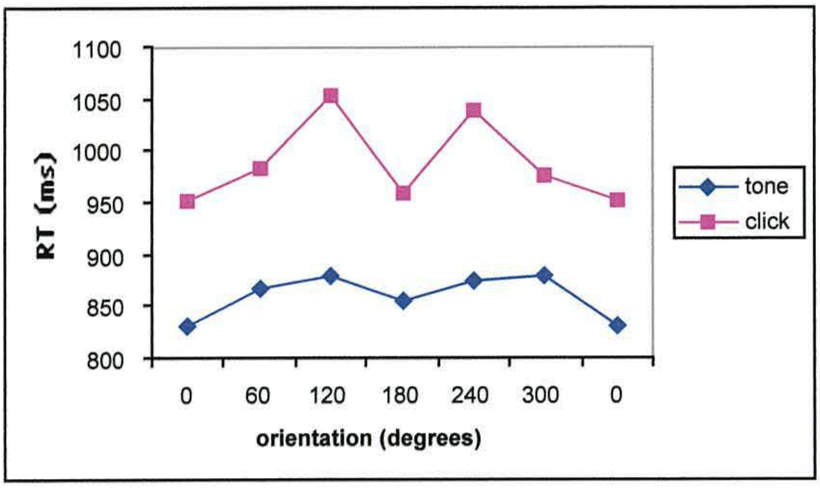


Figure.5.1 Mean reaction times (RT) as a function of stimulus orientation in the click and tone conditions

The data was entered into a 2x5 ANOVA, here boxplots showed no evidence of skewness and a Mauchly Sphericity test was non-significant p=0.518. A significant main effect of orientation was shown $F(5,115)=3.58, MSE=38357$ $p>0.005$ but not of condition $F(1,23)=2.69, MSE=1213032$ $p>0.114$. Again there was no significant interaction; this is because there was a large difference in reaction times at the zero degree orientations.

Data was collapsed as in Experiment Three and a trend line analysis showed a significant difference between the conditions $t(32) = 4.169$ $p<0.001$. It can be seen in Figure 5.2 that an increasing trend is shown in the Click data, this indicates that mental rotation is still taking place despite the dual task load. However, although the trend in the Tone condition is positive, it is very shallow and suggests that resources other than mental rotation are being used.

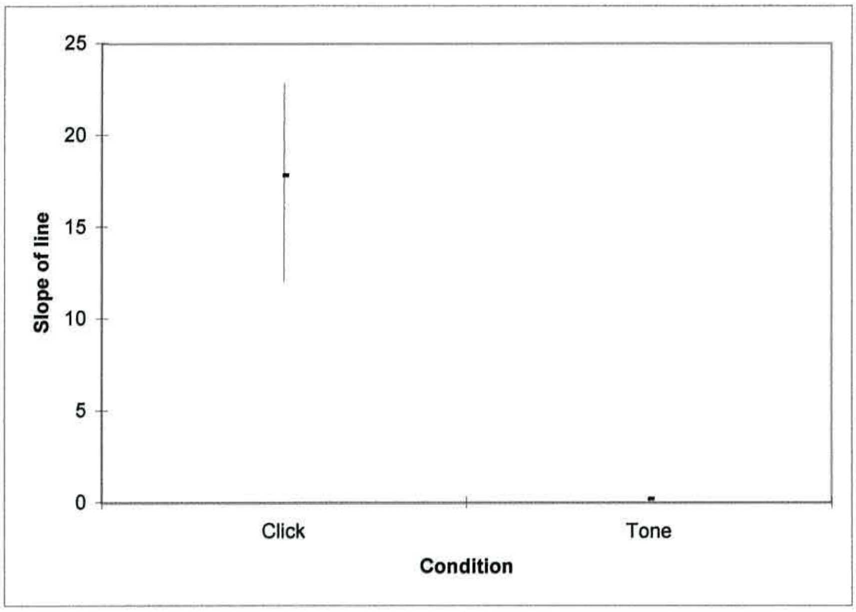


Figure 5.2. Trend and standard error of data in each condition

An analysis of error rates showed that the participants made an average of 3.91/72 (5.43%) errors in the click condition and 1.62/72 (2.2%) errors in the tone condition. A Wilcoxan test showed that this difference was not significant [z=2.5; p>0.05) and again leads us to conclude that participants attended to both conditions.

Summary

The higher reaction times overall in the click condition, shown in Figure 5.1, indicate increasing task difficulty compared to the tone condition. This suggests that the spatial dual task is successfully interfering at the level of perceptual encoding in the spatial condition, but perhaps at the level of response selection in the non-spatial condition. Spatial resources are being taxed by the clicker task and it appears that this is affecting reaction times. The typical M shaped curve has been produced in both conditions but it is much more pronounced in the clicker condition. The dip in reaction times at 180° shows that other visuo-spatial transformations are available to participants but that mental rotation is still taking place.

Despite the trend in the data shown in Figure. 5.1, there is no significant difference between the two conditions in an ANOVA. The lack of interaction in the ANOVA also suggests that perhaps the tasks were not equally matched. There was still a greater effect of dual task in the click condition at the Zero degree orientation. This suggests that future experiments will need more closely matched conditions.

However the trend line analysis showed a significant difference in the mean trend of the data between conditions. Figure 5.2 illustrates this difference and demonstrates that the trend of the data in the Tone condition is almost flat, while there is an increasing trend in the Click condition. This suggests that the dual task in the Tone condition is creating a resource bottleneck at response selection throughout the trial, whereas it is creating a bottleneck at the perceptual encoding stage of processing (Van Selst and Jolicoeur, 1994). From this we can conclude that only the spatial Click dual task is interfering with mental rotation resources.

Chapter 6

Introduction

The previous experiments have provided evidence that a spatial dual task does appear to affect performance on an object recognition task by increasing reaction times overall compared to a non-spatial dual task. Experiment 5 represents an attempt to produce a novel dual task that more accurately affects the spatial resource of interest. Here participants were required to mentally rotate letters in order to perform the dual task component.

Experiment 6 represents the creation of a suitable non-spatial dual task to allow comparison with experiment 5. Here participants were presented with pairs of letters and were required to state the letter which would appear between the pair in the alphabet. Both tasks answer the initial requirements of a suitable dual task for these experiments in that input is auditory and output is verbal. In addition they are matched in that both involve manipulating letter pairs.

It is predicted that a greater increase in reaction times will be shown in Experiment 5 than in Experiment 6 if the novel dual task affects mental rotation performance.

Method

Participants: Forty-Eight participants from University of Wales, Bangor, participated in the experiments. There were Twenty-Four participants in each experiment (7 males and 17 females in Experiment Five, 9 males and 15

Females in Experiment Six). All participants were right handed. They received a course credit for their participation.

Materials: The stimuli were 144 black and white line drawings of common objects taken from the Snodgrass and Vanderwart set (1980). A full list of the stimuli can be found in appendix B. These were presented in a 12 x 12 cm frame on a 17-inch Apple Macintosh monitor. Each drawing could be presented in each of the following orientations in the picture plane: 0°, 60°, 120°, 180°, 240°, and 300°. The zero degree orientation was taken to be the 'normal' orientation in the environment for mono-oriented stimuli. The experiment was run using PsyScope version 1.2.4.PPC, on a Macintosh Power PC and responses were collected using a Macintosh keyboard. Instruction and debriefing screens were shown at the beginning and end of the experiment and are provided in appendix C. A chin and headrest was provided to prevent participants from making head movements. Two task sheets were created with the appropriate letter pairs for each experiment from which the experimenter read.

Design: There were 10 practice trials followed by 144 experimental trials. On each trial the name of an object was presented on the screen and then replaced by a picture. There were two types of trial: 'yes' response trials and 'no' response trials. In a 'yes' response trial the name was correct for the object presented. In a 'no' response trial the name was not correct for the object presented. In these trials the object was as similar as possible to the name both visually and semantically, for example a picture of a mouse followed the name 'hamster'. This ensured that participants studied the images and could not make accurate judgements based on basic shape features or global outlines. In total there were 72 stimuli in the 'yes condition and 72 in the 'no' condition, the stimuli in the 'yes' condition were all mono-oriented, and the stimuli in the 'no' condition were made up of randomly selected common objects and could be mono or poly-oriented. Participants saw each stimulus only once and in total 4 different participants saw each object at each stimulus orientation. The trials were randomised.

In Experiment Five participants were verbally presented with a pair of letters taken from the set 'p,d,b,q'. From this set 'p' can be rotated to make 'd', and 'b' can be rotated to make 'q'. Participants had to make a 'yes' or 'no' response depending on whether the letter pair presented to them could be combined in this way. In Experiment Six participants were presented with pairs of letters and were required to state the letter which would appear between the pair in the alphabet, for example the letter pair 'jl' would elicit the response 'k'. Pairs were arranged pseudorandomly so that the same pair never appeared twice in two trials and each pair appeared the same number of times during the experiment. These tasks appear not to have been used previously in similar experiments and so there is no formal evidence that they are equivalent.

Procedure: Each trial began with the prompt "Ready?" which was presented in the centre of the screen and remained until the subject pressed the spacebar. When the spacebar had been pressed, and after an interval of 500ms, the name of an object was presented in the same location as the prompt. This remained for 750ms. A blank interval of 500ms followed, and then a line drawing of an object was presented in the centre of the screen at one of the six orientations in the picture plane. Participants were instructed to respond by pressing the key marked 'YES' if the name matched the picture presented, or by pressing the key marked 'NO' if the picture and name did not match. The 'N' key on the keyboard was labelled 'YES' and the 'M' key was labelled 'NO'. Responses were made with the index finger of the preferred hand. Responses were to be made as quickly and accurately as possible following presentation of the picture. In all trials after a response was made the stimulus disappeared from the screen and there was a delay of 3000ms before the next trial.

The experimenter read from a sheet of 144 letter pairs in each experiment. When an object name appeared on the screen a letter pair was read out and the participant had to make the appropriate verbal response, either 'yes' or 'no' in experiment 5 or the appropriate letter in experiment 6. Each experiment lasted for approximately 20 minutes.

Participants completed a written consent form before reading an instruction screen on the computer monitor. They were seated at a distance of 36cm from the monitor and rested their heads on a chinrest for the duration of the experiment, they were asked to avoid any head movements.

Results

Data were collapsed as described in Experiment Two. Pre-ANOVA boxplots indicated 4 sets of participant data in each condition that skewed the data set.

These data points were removed during analysis. Table 6.1 shows means and standard deviations in each condition.

Table. 6.1. Means, standard deviations and standard errors in Experiments Five and Six

	Exp Five			Exp Six		
Orientation (°)	Mean	SD	SE	Mean	SD	SE
0	1000	327	52.8	1185	508	99.4
60	1069	398	59.6	1255	488	110
120	1174	478	55.2	1152	358	98.4
180	1178	553	48.4	1250	497	97.6
240	1083	385	45.6	1173	315	96.0
300	1088	437	54.3	1346	674	102

A between subjects ANOVA was performed on the remaining data set. A Mauchly Sphericity test was significant p=0.001. There were no significant main effects of condition $F(1,38)=1.08, MSE=988166$ $p=0.306$, or orientation $F(5,190)=1.27, MSE=93306$ $p=0.280$, and no interaction was found $F(5,190)=1.37, MSE=101311$ $p=0.238$. Figure. 6.1 shows the trend of the data in each experiment.

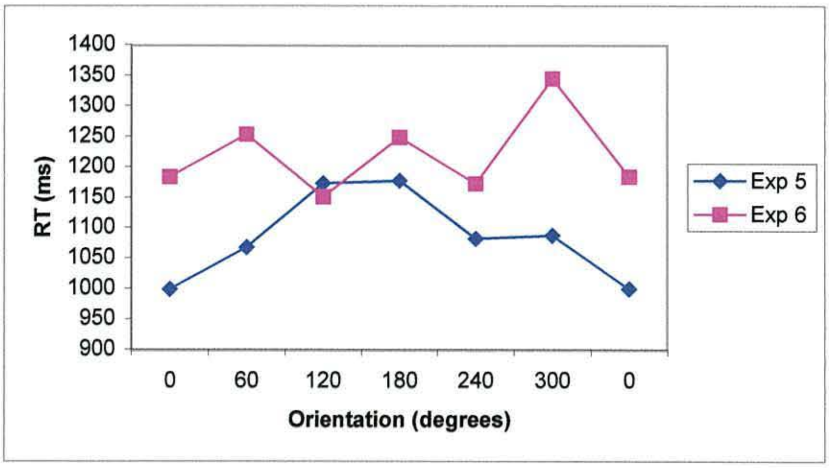


Figure.6.1 Mean reaction times (RT) as a function of stimulus orientation in experiments Five and Six

A trend of increasing RT's as misorientation increases can be seen in Experiment Five, but no such trend is apparent in Experiment Six. A Repeated Measures ANOVA was performed on data from Experiment Five (Mauchly Sphericity non-significant $p=0.497$). This showed no significant main effect of orientation $F(5,95)=1.47, MSE= 91742$ $p=0.142$. A repeated measures ANOVA performed on the data from Experiment Six showed no significant trends in the data.

Data was further collapsed as described in Experiment Three and a trend line analysis also showed no significant difference in line slope t(46)=0.61; p=0.27. Figure 6.2 shows that both data sets show steep trends in the data in comparison to previous experiments.

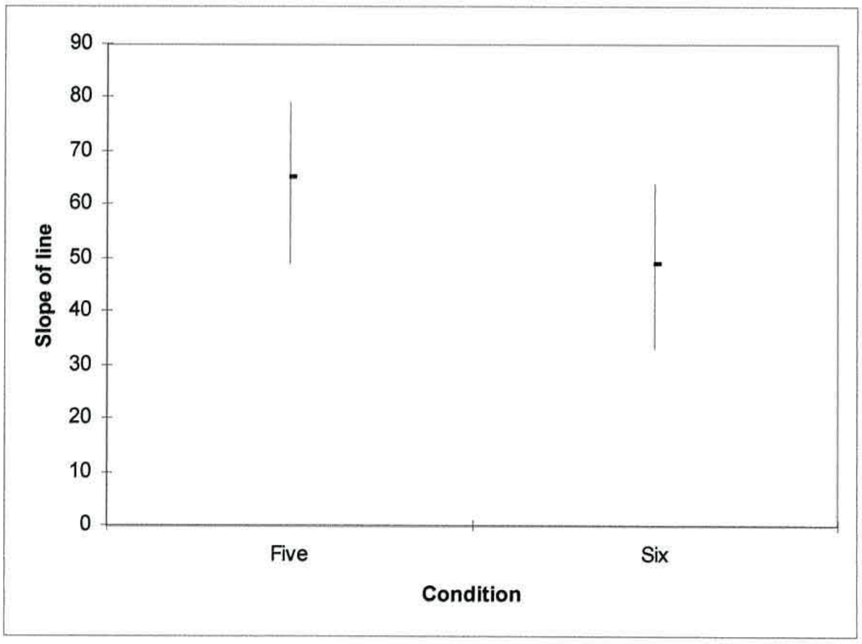


Figure 6.2 Mean slope of line and standard error for Experiments Five and Six

An analysis of error rates in the main task showed that the participants made an average of 2.6/72 (3.7%) errors in the click condition and 3.0/72 (4.2%) errors in the tone condition. A Mann Whitney U test showed that this difference was not significant [z=0.58; p> 0.05] and again leads us to conclude that participants attended to both conditions. In these experiments it was also possible to accurately record errors in the dual task conditions. In Experiment Five participants made an average of 9.6/144 (6.7%) errors, in Experiment Six they made an average of 7.4/144 (7.4%) errors. A Mann Whitney U test showed that this difference was not significant [z=0.81; p> 0.05].

Summary

It appears again that the spatial condition has produced a trend in reaction times that is associated with mental rotation. However, no significant difference was produced between the two data sets. Perhaps both experiments required overly complex processing and this has interfered with the results gained. It is quite possible that resources from other areas of working memory were involved due to the letter recognition aspect of the tasks and consequently that not only spatial resources were being tapped

Task difficulty could also have been a factor in these experiments. Although there was no significant difference in errors between the dual task conditions there was a difference in participant reactions to these errors. The alphabet is something that is usually learned in childhood and participants appeared to be embarrassed when they were unsure of a response. In contrast participants appeared to be largely unaware of, or at least unaffected by, errors in

Experiment Five. In consequence many participants appeared not to 'settle in' to the tasks in Experiment Six as well as participants in other experiments. This may possibly have led in some part to the random variation in RT's in Experiment Six. This effect may have been attenuated if participants were alone in the test room. This could have been achieved by software that linked to the stimulus onset of the main task and caused a pre-recorded letter pair to be vocalised by speakers, responses could have been recorded by microphone. Unfortunately this was beyond the current programming experience of the experimenter.

In conclusion it appears that, as in previous experiments, the more spatial of the dual tasks had the most robust effect on reaction time trends in the data. However this effect was not shown to be significantly different to that produced when participants performed a less spatial dual task. It is interesting to note that the typical dip in reaction times that is usually evident at 180° was not produced in Experiment Five. It is possible that the mental rotation dual task has in some way caused mental rotation to take place here despite faster visuo-spatial transformations being available. Experiment Seven investigates this theory in more detail.

Chapter 7

Introduction

Experiments 1 to 6 represent an attempt to investigate the contribution of mental rotation and spatial resources to object recognition using the dual task methodology. The difficulties encountered in creating more focussed dual tasks are that they become increasingly complex and may implicate more than just spatial resources. The results have shown that spatial resources, in particular mental rotation, do appear to contribute towards object recognition in non-optimal circumstances.

The purpose of experiment 7 is to investigate whether priming of mental rotation can affect object recognition. In the previous experiments a mental rotation trend has been noted in all the spatial conditions but not in the non-spatial conditions. One possible reason for this is that only the spatial dual task taxes the VSSP enough to push past the dual task bottleneck discussed in Chapter Four (Van Selst and Jolicoeur, 1994). Another possible explanation could be that of resources. It is possible that there are several routes to achieving object recognition (Turnbull, Carey & McCarthy, 1997) and that mental rotation is generally the fastest route in non-optimal circumstances. This suggests that all the visual system's resources begin the task of object recognition and that the fastest route varies depending on conditions. The 180° effect discussed earlier is an example of this. It appears that at this orientation an image can be 'flipped' in order for it to be matched with a target image (Jolicoeur, 1985). In Experiments One to Four the pattern of results supported this theory. However in Experiment Five a mental rotation dual task appeared to facilitate a mental rotation transformation instead of a 'flip' transformation at this orientation. This hypothesis can be explored by answering the following question: if mental rotation is contributing to object recognition when objects are not observed in their normal upright condition then is it possible to prime mental rotation and influence object recognition in these circumstances?

Lawson and Humphreys (1996, 1998) have performed priming experiments in depth rotation and shown that view-specific priming can occur. In Lawson and Humphreys (1998) they showed that a priming of a foreshortened view of a line drawing could result in it being named faster than a more usual view in subsequent trials. And in Lawson and Humphreys (1996) they showed the same effect in picture-picture matching experiments. It is worth noting that in the 1998 experiments there was a gap of several minutes between the prime and the presentation of the object, and in the 1996 experiment a mask was presented between prime and object, so this effect has been tested in both 'long term' and 'short term' conditions. Hayward and Tarr (1997) produced similar results in an experiment using novel 3D objects.

These studies have shown that object recognition can be primed for objects presented at certain orientations both over a period of seconds and of minutes. The present experiment aims to test whether the mental rotation processes that underlie object recognition in non-optimal circumstances can be primed. For this purpose a block of prime novel objects was created and participants completed a picture-picture matching task of the novel objects in between two blocks of the object recognition experiment used in Experiments Two to Six. It is predicted that reaction times in the prime condition will be faster than those in non-prime conditions.

Method

Participants: Seventy-two participants from University of Wales, Bangor, participated in the experiment (12 males, 60 females). All participants were right handed. They received a course credit, or payment, for their participation.

Materials: The stimuli were 144 black and white line drawings of common objects taken from the Snodgrass and Vanderwart set (1980). A full list of the stimuli can be found in appendix B. These were presented in a 12 x 12 cm frame on a 17-inch Apple Macintosh monitor. Each drawing could be presented in each of the following orientations in the picture plane: 0°, 60°, 120°, 180°, 240°, and 300°. The zero degree orientation was taken to be the 'normal' orientation in the environment for mono-oriented stimuli. The experiment was run using PsyScope version 1.2.4.PPC, on a Macintosh Power PC and responses were collected using a Macintosh keyboard. Instruction and debriefing screens were shown at the beginning and end of the experiment and are provided in appendix C. For the Prime component of the experiment the stimuli consisted of 72 novel shapes adapted from the Tarr and Pinker (1989) set. This set can be found in appendix E. The shapes were presented in 36 pairs. In the prime condition each stimulus in a pair was presented at one of the following orientations: 0°, 60°, 120°, 180°, 240°, and 300°. In the control prime condition the shapes were presented at the same orientation. A chin and head rest was provided to prevent participants from making head movements

Design: In this experiment there were three conditions, each completed by 24 participants. In each condition participants completed the basic task described in experiment two and following a five-minute break repeated the experiment. In the control condition participants did nothing during the five-minute break. In the prime condition participants completed a mental rotation picture-picture matching task during the break. In the control prime condition participants performed a picture-picture matching task during the break. The task followed an identical format to that of the main experiment except that instead of matching a name and a picture participants matched two pictures. In both prime conditions there were 5 practice trials followed by 36 experimental trials. There were two types of trial: 'yes' response trials and 'no' response trials. In a 'yes' response trial the shapes matched. In a 'no' response trial the shapes did not match.

Procedure: Each trial began with the prompt "Ready?" which was presented in the centre of the screen and remained until the subject pressed the spacebar. When the spacebar had been pressed, and after an interval of 500ms, the name of an object was presented in the same location as the prompt, this remained for 750ms. A blank interval of 500ms followed, and then a line drawing of an object was presented in the centre of the screen at one of the six orientations in the picture plane. Participants were instructed to respond by pressing the key marked 'YES' if the name matched the picture presented, or by pressing the key marked 'NO' if the picture and name did not match. The 'N' key on the keyboard was labelled 'YES' and the 'M' key was labelled 'NO'. Responses were made with the index finger of the preferred hand. Responses were to be made as quickly and accurately as possible following presentation of the picture. In all trials after a response was made the stimulus disappeared from the screen and there was a delay of 3000ms before the next trial.

After completing the experiment participants in the control condition took a five minute break during which they did nothing. Following this break they repeated the experiment. In the prime condition each trial began with the prompt "Ready?" which was presented in the centre of the screen and remained until the subject pressed the spacebar. When the spacebar had been pressed, and after an interval of 500ms, a novel shape was presented in the centre of the screen, this remained for 750ms and could be at any one of the five orientations in the picture plane. A blank interval of 500ms followed, and then a second novel shape was presented in the centre of the screen again at one of the five orientations in the picture plane. The shapes were always presented at different orientations. Participants were instructed to respond by pressing the key marked 'YES' if the shapes matched, or by pressing the key marked 'NO' if the shapes did not match. Responses were to be made as quickly and accurately as possible following presentation of the picture. In all trials after a response was made the stimulus disappeared from the screen and there was a delay of 3000ms before the next trial.

In the control prime condition each trial began with the prompt "Ready?" which was presented in the centre of the screen and remained until the subject pressed the spacebar. When the spacebar had been pressed, and after an interval of 500ms, a novel shape was presented in the centre of the screen, this remained for 750ms and could be at any one of the five orientations in the picture plane. A blank interval of 500ms followed, and then a second novel shape was presented in the centre of the screen again at one of the five orientations in the picture plane. The shapes were always presented at the same orientation. Participants were instructed to respond by pressing the key marked 'YES' if the shapes matched, or by pressing the key marked 'NO' if the shapes did not match. Responses were to be made as quickly and accurately as possible following presentation of the picture. In all trials after a response was made the stimulus disappeared from the screen and there was a delay of 3000ms before the next trial.

Participants completed a written consent form before reading an instruction screen on the computer monitor. They were seated at a distance of 36cm from the monitor and rested their heads on a chinrest for the duration of the experiment, they were asked to avoid any head movements. The experiment lasted for approximately 45 minutes.

Results

Data were collapsed as described in Experiment Two. Tables. 7.1 to 7.3 show means, standard deviations and standard errors in each pair of conditions. there was no evidence of skewness in the data and no participants were removed from the analysis. As can be seen there is a large difference in reaction times between the first and second presentation of the stimulus set because learning has occurred. An ANOVA would simply illustrate this difference. For the purposes of this experiment only a trendline analysis was performed. Data was collapsed as in Experiment Three.

Table 7.1. Means, standard errors and standard deviations in the pre-control and control conditions

	pc			c		
Orientation (°)	Mean	SD	SE	Mean	SD	SE
0	630	82	20	425	73	18.4
60	656	97	24.3	451	65	15.8
120	685	93	22.6	451	75	18.3
180	655	88	21.5	464	82	19.9
240	665	93	22.7	437	64	15.6
300	692	75	18.9	458	76	19.1

Table. 7.2. Means, standard errors and standard deviations in the pre-upright and upright conditions

	pu			u		
Orientation (°)	Mean	SD	SE	Mean	SD	SE
0	665	89	18.6	447	117	23.8
60	687	111	22.7	462	109	22.3
120	698	108	22.2	467	123	25.1
180	686	106	21.9	478	115	22.7
240	700	93	19.1	453	111	23.5
300	705	108	22.1	471	124	25.3

Table 7.3. Means, standard errors and standard deviations in the pre-rotate and rotate conditions

	pr			r		
Orientation (°)	Mean	SD	SE	Mean	SD	SE
0	682	108	23	499	118	24.6
60	708	93	19.9	503	100	20.5
120	725	113	23.7	529	107	21.6
180	701	109	22.8	494	120	26.3
240	738	111	23.2	521	99	19.3
300	718	116	24.5	505	107	20.9

The first comparisons compared trendlines in the pre intervention condition to ensure that there was no significant difference between them. Conditions pre control and pre prime were compared and produced a negative result t(23) = 0.754; p=0.458, and conditions pre control and pre control prime similarly produced a negative result t(23) = 1.03; p=0.314. Comparisons between pre and post intervention trendlines were then made in each condition. As was expected there was no significant difference between trendlines in the control condition t(46) = 1.36; p=0.09. Figure 7.1 shows that in the control condition the typical mental rotation slope is lost, perhaps suggesting that participants are using some other method of recognition during the second presentation of the stimuli

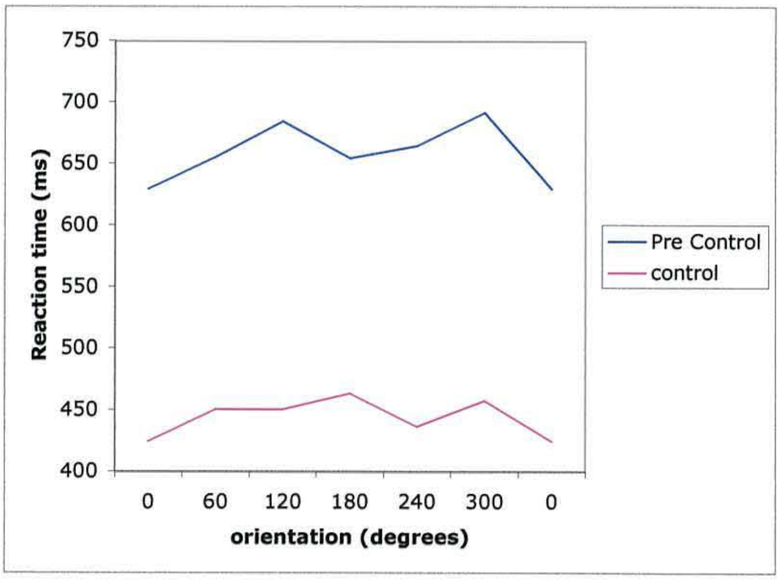


Figure7.1 Mean reaction times (RT) as a function of stimulus orientation in the control condition

No significant difference was shown in the upright prime condition t(46) =1.26; p=0.11. Again it can be seen from Fig 7.2 that the typical mental rotation slope is missing during the second presentation of the stimuli.

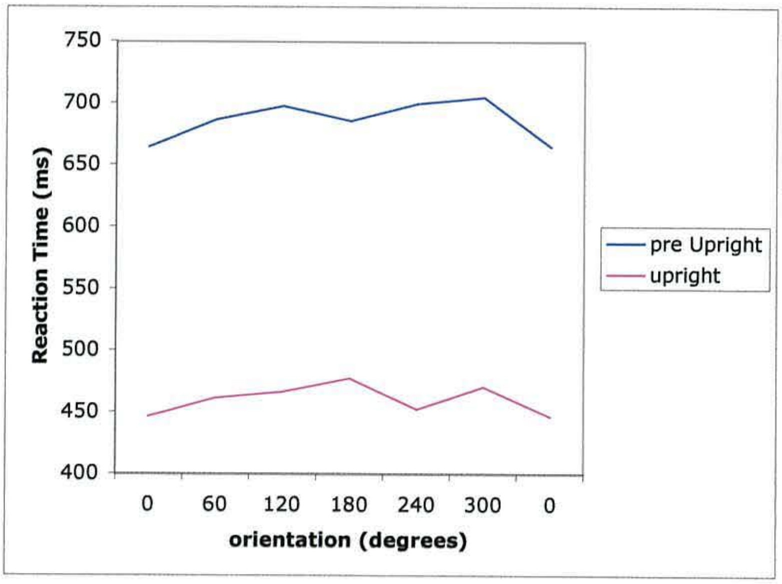


Figure.7.2 Mean reaction times (RT) as a function of stimulus orientation in the upright prime condition

However a significant difference was shown in the prime condition t(46) =1.72; p<0.05. Fig 7.6 shows that a similar trend is maintained in the data in both pre and post rotate prime conditions.

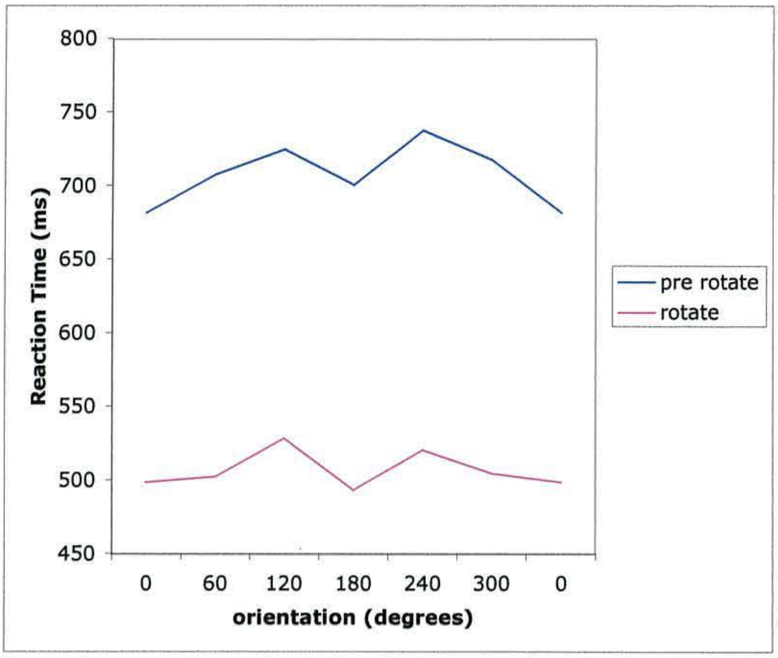


Figure.7.3 Mean reaction times (RT) as a function of stimulus orientation in the rotate prime condition

An analysis of error rates showed that the participants made an average of 2.4/72 (3.3%) errors in the pre control condition and 1.7/72 (2.35%) errors in the control condition. Participants in the pre control prime condition made an average of 1.9/72 (2.6%) errors and 1.2/72 (1.7%) errors in the control prime condition. In the pre prime condition an average of 2/72 (2.7%) errors were made, this fell to 1/72 (1.4%) in the prime condition. A Wilcoxan test showed that this difference was not significant in the control condition [$z=0.80$; $p>0.05$] or the control prime condition [$z=1.47$; $p>0.05$], however there was a significant difference in errors in the prime condition [$z=3.34$; $p<0.01$]

Summary

It appears from the results gained that mental rotation can be primed and that this can speed up object recognition in non-optimal circumstances. If a repeated presentation of the experiment were enough to speed reaction times significantly this would have been shown in the control condition, if practice at object matching were enough to affect reaction times this would have been shown by the control prime condition. It is only in the prime condition that reaction times are seen to reduce significantly. And it is only here that errors are significantly reduced, suggesting that accuracy has also been improved by the mental rotation prime. A mental rotation slope is seen during the second presentation of the stimulus set in the rotate condition but not in the other conditions. This suggests that, as found by Jolicoeur (1985), mental rotation is not always necessary during presentation of an object at a previously viewed orientation. It appears that the rotating practice in between the two presentations has in some way facilitated mental rotation in the rotate condition.

The increase in accuracy suggests that mental rotation transformations are more accurate than faster transformations. It is possible that the visual system employs mental rotation during novel viewing conditions where errors are more likely. The results of this experiment are tentative. The collapsing of orientations from five to three in the analysis is not ideal. But it can be seen from the relevant figures that the collapsed orientations are symmetrical. Any lack of symmetry is indicative of other visuo-spatial transformations than mental rotation taking place. This lack of symmetry in reaction times would result in a flattened or negative trendline being produced. This effectively highlights participants who used mental rotation in all conditions. The results here therefore compare the participants who continued to use mental rotation during the second presentation of the stimuli. The Figures show that the trend in the control and upright conditions was against mental rotation on second presentation of the stimuli. And the trend line analysis shows that of those who continued to use mental rotation, the participants in the rotate condition were fastest.

Chapter 8

Introduction

Mental rotation has previously been regarded as a primarily visuo-spatial process (See Shepard and Metzler, 1971). The aim of the dual tasks employed so far in these experiments has been to affect object recognition by interfering with mental rotation on a visuo-spatial level. However there is increasing evidence for the contribution of motor-spatial resources in mental rotation and this experiment represents an attempt to compare the effects of a visuo-spatial versus a motor-spatial task on object recognition.

The involvement of the superior parietal lobule in mental rotation has been supported by a large body of research (e.g. Tagaris et al, 1996; Tagaris et al, 1997, 1998; Alivisaros and Petrides, 1996; Cohen et al, 1996). However recent neuroimaging experiments have implicated other areas which are also active during mental object rotation; including premotor areas during mental rotation of human hand stimuli (Bonda, Petrides, Frey, and Evans, 1995; Parsons et al, 1995), and the supplementary motor area and lateral premotor areas which were found to be active during mental rotation of Shepard and Metzler stimuli (Richter et al, 2000).

It is now also accepted that a significant number of premotor neurons are visuo-motor neurons (Jackson and Hussain, 1997; Wise, DiPellegrino and Boussaud, 1996) and it has long been proposed that some parietal neurons appear to be motor-dependant (Mountcastle, Lynch, Georgeopolus, Sakata, & Acuna, 1975.).

It has been suggested that these areas together form a system for visually guided, object-oriented actions (Gallese et al, 1996; Grazziano et al 1994).

Wohlschlager & Wohlschlager (1998) demonstrated that the mental rotation of Shepard and Metzler (1971) cube figures could be affected by a simultaneous hand movement. Reaction times on mental rotation performance were slowed if hand movements were made in the opposite direction to the rotation; later experiments suggested that merely planning of hand movements could slow reaction times (Wohlschlager, 2001).

The aim here is to apply a similar paradigm to that of Wohlschlager (2001) to the task of object recognition. As discussed previously mental rotation is one of the resources that are thought to contribute to object recognition, and the present experiment will attempt to discover whether visuo-spatial or motor-spatial resources are of more importance to the process. The clicker task, which has provided successful results in previous experiments, will be modified in one condition of this experiment so that responses are made physically via a knob on a dial. It is expected that reaction times will be slowed to a greater extent in the condition that is taxed most by the concurrent task.

Method

Participants: Eighteen participants from University of Wales, Bangor, participated in each experiment. All participants were right handed. They received a course credit, or payment, for their participation.

Materials: The stimuli were 144 black and white line drawings of common objects taken from the Snodgrass and Vanderwart set (1980). A full list of the stimuli can be found in appendix B. These were presented in a 12 x 12 cm frame on a 17-inch Apple Macintosh monitor. Each drawing could be presented in each of the following orientations in the picture plane: 0°, 60°, 120°, 180°, 240°, and 300°. The zero degree orientation was taken to be the 'normal' orientation in the environment for mono-oriented stimuli. The experiment was run using PsyScope version 1.2.4.PPC, on a Macintosh Power PC and responses were collected using a Macintosh keyboard. For the motor task a wheel with a handle was mounted on a board and placed next to the participant. In both dual tasks an animal training clicker was used. Instruction and debriefing screens were shown at the beginning and end of the experiment and are provided in appendix C. A chin and headrest was provided to prevent participants from making head movements.

Design: Eighteen participants completed both conditions in a within subjects design, being randomly assigned to each condition so that half completed the spatial condition first and half completed the motor condition first. In the main experiment there were 10 practice trials followed by 144 experimental trials. On each trial the name of an object was presented on the screen and then replaced by a picture. There were two types of trial: 'yes' response trials and 'no' response trials. In a 'yes' response trial the name was correct for the object presented. In a 'no' response trial the name was not correct for the object presented. In these trials the object was as similar as possible to the name both visually and semantically, for example a picture of a mouse followed the name 'hamster'. This ensured that participants studied the images and could not make accurate judgements based on basic shape features or global outlines. In total there were 72 stimuli in the 'yes condition and 72 in the 'no' condition. The stimuli in the 'yes' condition were all mono-oriented, and the stimuli in the 'no' condition were made up of randomly selected common objects and could be mono or poly-oriented. Participants saw each stimulus only once to avoid practice effects. This was achieved by creating 6 stimuli lists, which contained one each of the 144 stimuli (List One can be seen in Appendix D), and assigning participants randomly to one of the lists. In total 4 different participants saw each object at each stimulus orientation. The trials were randomised.

Procedure: Each trial began with the prompt "Ready?" which was presented in the centre of the screen and remained until the participant pressed the spacebar. When the spacebar had been pressed, and after an interval of 500ms, the name of an object was presented in the same location as the prompt, this remained for 750ms. A blank interval of 500ms followed, and then a line drawing of an object was presented in the centre of the screen at one of the six orientations in the picture plane. A click was produced at the same time as the line drawing appeared on the screen, and participants were asked to make a verbal or spatial response to the click and a key press response to the drawing. Participants were instructed to respond by pressing the key marked 'YES' if the name matched the picture presented, or by pressing the key marked 'NO' if the picture and name did not match. The 'N' key on the keyboard was labelled 'YES' and the

'M' key was labelled 'NO'. Responses were made with the index finger of the preferred hand. Responses were to be made as quickly and accurately as possible following presentation of the picture. In all trials after a response was made the stimulus disappeared from the screen and there was a delay of 3000ms before the next trial.

In the motor condition instead of making a key press response participants made a motor response. The participant was instructed to use the handle to respond. The handle was returned to the upright position (at 12o'clock) between trials and was rotated to indicate the position of the clicks produced during each trial. In this way using a clock as a reference a 'top left' click would elicit a rotation to roughly 10 o'clock, a 'bottom right' click would be roughly 4 o'clock etc.

Participants completed a written consent form before reading an instruction screen on the computer monitor. They were seated at a distance of 36cm from the monitor and rested their heads on a chinrest for the duration of the experiment, they were asked to avoid any head movements. The experiment lasted for approximately 45 minutes.

Results

Data were collapsed as in Experiment Two. Group means and standard deviations are shown in Table 8.1. A 2X6 ANOVA was carried out, boxplots had shown no sign of skewness in the data and a Mauchly Sphericity test was non-significant $p=0.068$. It was not necessary to remove any participants from the analysis. Figure 8.1 shows the slope of the data in each condition.

Table 8.1. Means , standard errors and standard deviations in the Spatial and Motor conditions

	Motor			Spatial		
Orientation (°)	Mean	SD	SE	Mean	SD	SE
0	892	278	36.5	858	225	30.6
60	1069	440	36.5	911	204	32.3
120	1080	353	49.2	952	268	39.1
180	1040	427	40.1	953	261	34.9
240	1079	363	55.9	975	253	40.4
300	992	308	40.1	981	286	34.5

A significant main effect of orientation was shown $F(5,85)=15.12, MSE=98946$ $p<0.001$ and a significant main effect of condition $F(1,17)=5.33, MSE=951220$ $p<0.05$. A significant interaction was also shown in the data $F(5,85)=2.65, MSE=32843$ $p<0.05$. Data were collapsed as in Experiment Three and a trend line analysis showed a significant difference between the conditions $t(32) = 4.169$ $p<0.001$. Figure 8.2 shows the average trend of the data in each condition.

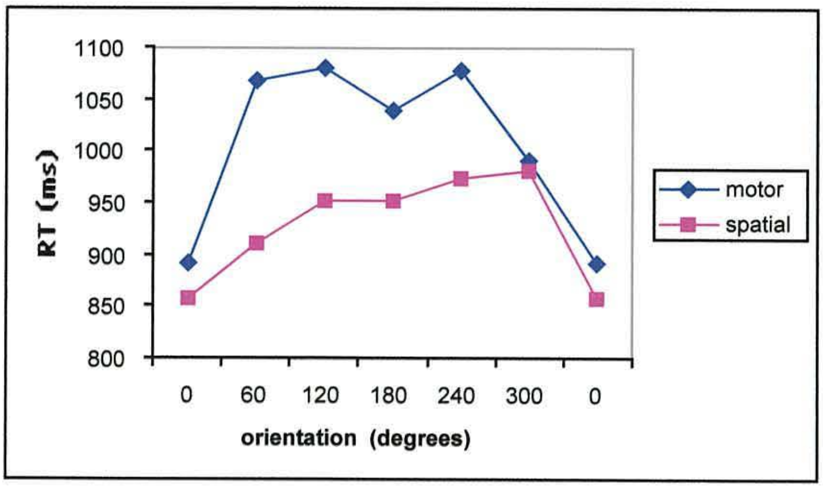


Figure.8.1 Mean reaction times (RT) as a function of stimulus orientation in the motor and spatial conditions

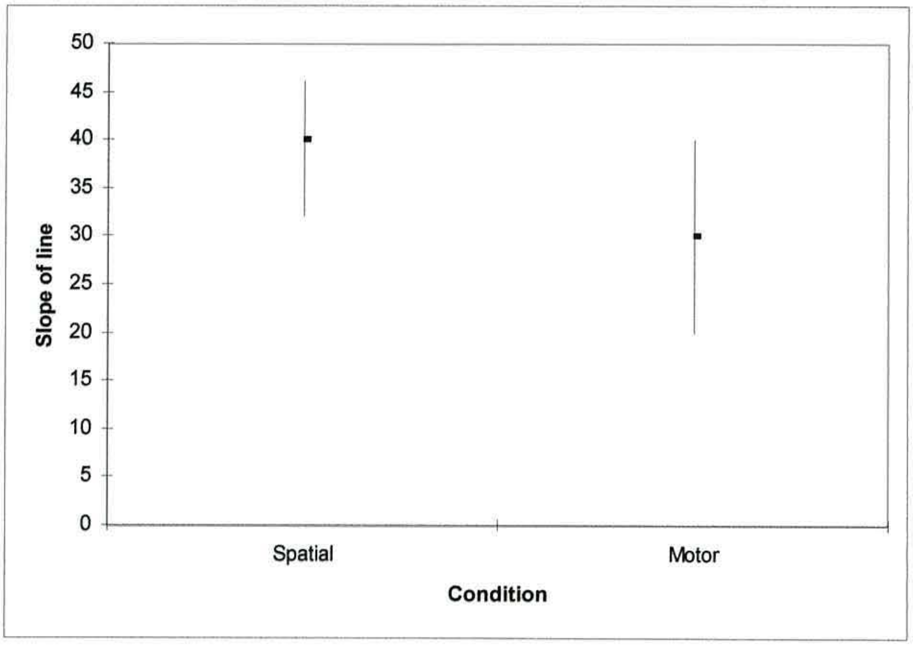


Figure 8.2. Mean trend of data and standard error in each condition

An analysis of error rates showed that participants made on average 3/72 (4%) errors in the Motor condition, and 4/72 (5.5%) errors in the Spatial condition. A Wilcoxan test showed that this difference was not significant [z=2.54; p>0.05].

Summary

The initial reaction time data from both conditions suggests that the dual tasks are interfering at the level of processing and not just at response selection, the M-shaped mental rotation curve is apparent in both conditions. The larger increase in reaction times in the motor condition appears to suggest that there is more interference in this condition. Overall this provides more evidence for both motor and spatial contributions to mental rotation. It would seem that the resources responsible for mental rotation are being taxed in both conditions but more so by the motor-spatial dual task than by the spatial dual task alone. The error rate information suggests that participants were attending to the main task and that the data isn't representative of a time/accuracy trade off.

The trend line analysis shows that participants in the Motor condition overall produce a shallower trend in their data than those in the Spatial condition. There is also a greater spread of data here as shown by the larger standard error. It is worth noting at this point that some of the motor rotations in the dual task will have been made counter to the mental rotation used by participants, and some of the motor rotations will have matched the mental rotations. It is probable that this will have affected the overall trend of the data.

These results imply that present models of object recognition and visuo-spatial transformation are failing to account for the contribution of motor resources. Evidence for this effect in mental rotation is provided by the work of Wohlschlager & Wohlschlager (1998), and Wohlschlager (2001). Support also comes from the stimulus compatibility literature. Tucker and Ellis (1998) presented images of real-world objects, such as aerosol cans and frying pans, and asked participants to make key presses and wrist movements in response to their orientation. Stimulus response compatibility was shown between object orientation and hand. Tucker and Ellis concluded that the actions afforded by an object are intrinsically linked to its representation. This suggests that any visuo-spatial transformation of a graspable object also involves a visuo-motor transformation. It is not clear whether these resources are also implicated in the transformation of non-graspable objects. But the presence of motor cortex activity during rotation of novel shapes suggests that they are (Johnston et al., 2004)

Chapter 9

Introduction

The aim of Experiment Eight was to compare the effects of a spatial and a motor-spatial dual task on recognition of misorientated objects. The results suggested that the motor-spatial dual task affected reaction time performance more than the spatial dual task alone. However a trend line analysis showed that the overall trend of the data was stronger in the Spatial condition, it also showed that there was a larger spread of data in the Motor condition. It was suggested that this may be because some of the hand rotations matched the mental rotation being made by the participant and some would be counter to the mental rotation. From the mental rotation data presented by Wohlschlager & Wohlschlager (1998), and Wohlschlager (2001) it appears that hand rotations counter to the mental rotation create slower reaction times while those in the same direction as the mental rotation may help to speed up reaction times. This would create a greater spread of data in the trend line condition.

Experiment Nine represents an attempt to further investigate the effect of hand movements on object recognition. Two major changes were made here. Firstly the orientations used in the experiment were changed. The trend line analysis in these experiments so far has been performed on collapsed data from 5 data points, this has provided 3 data points for the analysis which is the minimum required in order to show a trend in data. The orientations used so far were chosen in order to reflect ones previously used in similar experiments, they also produced the M-shaped data curve produced in mental rotation experiments.

This has been useful in showing when mental rotation is occurring in order to achieve object recognition. However for the purposes of the final two experiments in this thesis a new set of orientations was created. These allow 5 data points to be included in the trend line analysis; this analysis has become increasingly useful in picking out the nuances of the data and it was felt that a change of orientations was justified in order to strengthen this. In the new data set the 240° orientation was replaced with a 210° orientation, similarly the 300° orientation was replaced with a 270° orientation. On a compass 210° is opposite 150° and 270° is opposite 90°. In previous experiments the compass was collapsed across in order to perform the trend line analysis creating the 3 data points of 0°, 60° (300° and 60°), and 120 (240° and 120°). With the new data set collapsing the compass produces 0°, 60°, 90°(270°), 120° and 150°(210°), 180° was also included as in the previous experiments but again was not included in any analysis because it does not appear that mental rotation resources are reliably used at this orientation.

The second change in this experiment was made in order to investigate the effect of hand movements in more detail. Instead of the hand rotations being made in response to a click controlled by the experimenter, they were made in response to an arrow appearing on the computer screen prior to the main task. This meant that the hand rotations were continued throughout each trial because there was no end point for them as in Experiment Eight. This ensured that both tasks took place simultaneously. It was also possible to separate out hand movements at the data processing stage into those that counter mental rotation and those in the same direction as mental rotation.

It is expected that hand movements made in the opposite direction to mental rotation will slow reaction times, and possibly increase errors, in comparison to those in the same direction as mental rotation. This is based on the previously discussed mental rotation experiments of Wohlschlager & Wohlschlager (1998), and Wohlschlager (2001). If the same effect is seen in this object recognition experiment it will show that mental rotation is taking place in order to facilitate object recognition, and also that motor resources are contributing to mental rotation.

Method

Participants: Twenty-four participants from University of Lancaster participated in each experiment. All participants were right handed. They received a course credit for their participation.

Materials: The stimuli were 144 black and white line drawings of common objects taken from the Snodgrass and Vanderwart set (1980). A full list of the stimuli can be found in appendix B. These were presented in a 12 x 12 cm frame on a 17-inch Apple Macintosh monitor. Each drawing could be presented in each of the following orientations in the picture plane: 0°, 60°, 120°, 180°, 210°, and 270°. The zero degree orientation was taken to be the 'normal' orientation in the environment for mono-oriented stimuli. The experiment was run using PsyScope version 1.2.4.PPC, on a Macintosh Power PC and responses were collected using a Macintosh keyboard. For the motor task participants used the computer mouse. Instruction and debriefing screens were shown at the beginning and end of the experiment and are similar to those in Appendix C.

Design: Twenty-four participants completed both conditions in a within subjects design, being randomly assigned to each condition so that half completed the baseline condition first and half completed the motor condition first. In the main experiment there were 10 practice trials followed by 144 experimental trials. On each trial the name of an object was presented on the screen and then replaced by a picture. There were two types of trial: ‘yes’ response trials and ‘no’ response trials. In a ‘yes’ response trial the name was correct for the object presented. In a ‘no’ response trial the name was not correct for the object presented. In these trials the object was as similar as possible to the name both visually and semantically, for example a picture of a mouse followed the name ‘hamster’. This ensured that participants studied the images and could not make accurate judgements based on basic shape features or global outlines. In total there were 72 stimuli in the ‘yes condition and 72 in the ‘no’ condition. The stimuli in the ‘yes’ condition were all mono-oriented, and the stimuli in the ‘no’ condition were made up of randomly selected common objects and could be mono or poly-oriented. Participants saw each stimulus only once. This was achieved by creating 6 stimuli lists, which contained one each of the 144 stimuli (List One can be seen in Appendix D), and assigning participants randomly to one of the lists. In total 4 different participants saw each object at each stimulus orientation. The trials were randomised.

Procedure: Each trial began with the prompt “Ready?” which was presented in the centre of the screen and remained until the subject pressed the spacebar. When the spacebar had been pressed, and after an interval of 500ms, the name of an object was presented in the same location as the prompt, this remained for 750ms. A blank interval of 500ms followed, and then a line drawing of an object was presented in the centre of the screen at one of the six orientations in the picture plane. Participants were instructed to respond by pressing the key marked ‘YES’ if the name matched the picture presented, or by pressing the key marked ‘NO’ if the picture and name did not match. The ‘N’ key on the keyboard was labelled ‘YES’ and the ‘M’ key was labelled ‘NO’, responses were made with the index finger of the left hand. Responses were to be made as quickly and accurately as possible following presentation of the picture. In all trials after a response was made the stimulus disappeared from the screen and there was a delay of 3000ms before the next trial.

In the motor condition an arrow appeared on the computer screen after the participant pressed the spacebar in response to the prompt ‘Ready?’. The arrow remained on the screen for 500ms and participants were instructed to move the computer mouse in a circle with their right hand in the direction that the arrow was pointing, and to continue moving the mouse throughout the trial. In half of the trials the arrow pointed in the same direction that the picture would be mentally rotated in order to be upright. In half of the trials the arrow pointed in a direction counter to mental rotation. Participants then completed the trial as described above.

Participants completed a written consent form before reading an instruction screen on the computer monitor. They were seated at a distance of 36cm from the monitor and were asked to avoid any head movements. The experiment lasted for approximately 45 minutes.

Results

Data were collapsed as in Experiment Two. Group means and standard deviations are shown in Table 9.1. An ANOVA showed no significant difference between the three conditions. A trend line analysis was carried out using the five data points from 0° to 150° for each participant. Here a significant difference was shown between the Control and Counter Rotate conditions t(23)=1.88, p=0.036, but not between the other conditions. Figure 9.1 shows the slope of the data in each condition and Figure 9.2 illustrates the trend of the data in each condition.

Table 9.1. Means, standard errors and standard deviations in the Control and Motor conditions

	Control			Rotate			Counter Rotate		
Orientation (°)	M	SD	SE	M	SD	SE	M	SD	SE
0	593	99	20	674	154	31	680	164	33
60	600	107	22	662	155	31	708	143	29
270 (90)	627	138	28	662	169	34	685	160	32
120	625	131	26	670	144	29	703	162	33
210 (150)	629	116	23	692	172	35	662	181	37
180	625	118	24	684	156	32	689	152	31

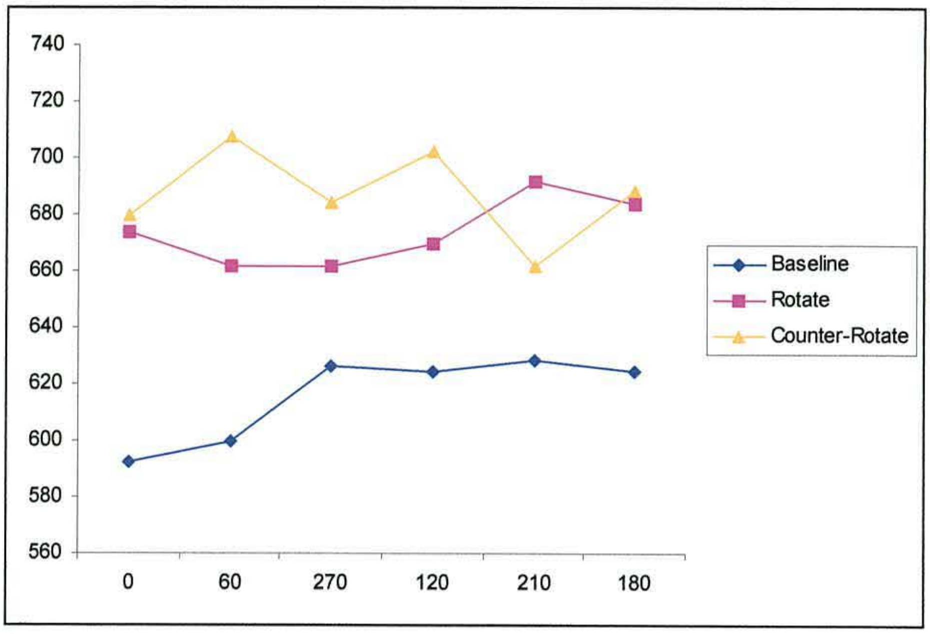


Figure.9.1 Mean reaction times (RT) as a function of stimulus orientation in the Baseline, Rotate and Counter-Rotate conditions

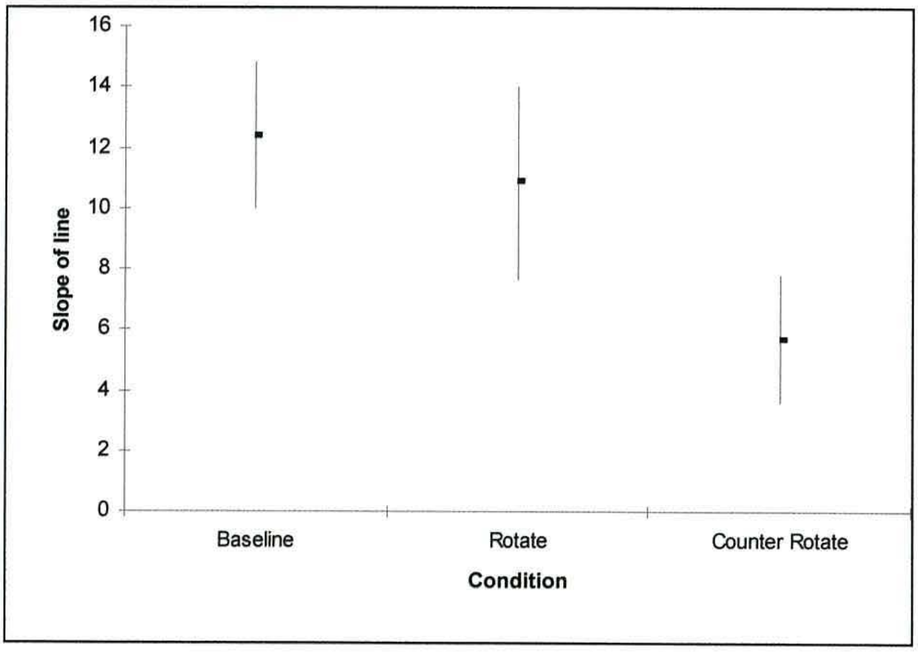


Figure 9.2. Mean trend of data and standard error in each condition

An analysis of error rates showed that participants made on average 2.4% errors in the Baseline condition, 2.13% errors in the Counter Rotate condition and 0.8% errors in the Rotate condition. A Wilcoxan test showed that this difference was not significant in the Baseline versus Counter Rotate Condition [z=0.16; p>0.05]. However it was significant in the Rotate versus Counter Rotate conditions [z= 2.49; p=0.013] and just significant in the Baseline versus Rotate Condition [z=1.99; p=0.046].

The error rates here are very low and it would be difficult to argue that a speed/accuracy trade-off was occurring between the main and dual task in any of the conditions. They also compare favourably with the rates shown in the previous experiments. So the significant difference in error rates here seems to be due to the very low rate of errors in the Rotate condition. It appears that a hand rotation in the same direction as mental rotation can improve response accuracy as well as reducing reaction times.

Summary

As in previous experiments the dual task has had the effect of increasing reaction times across all orientations including zero. This means that the Baseline condition cannot be compared to the dual task conditions using an ANOVA. However a trend line analysis showed that there was a significant difference between the Baseline condition and the Counter Rotate condition. From the initial RT data it can be seen that reaction times are faster in the Rotate condition as compared to the Counter Rotate condition. The trend line data shows that there is a much lower overall trend in the Counter Rotate condition, suggesting that mental rotation is not being used consistently here.

These results support those from Experiment 8 in that a motor dual task has had the effect of increasing reaction times in an object recognition task. In the Rotate condition a trend line analysis shows an increasing trend in the data that closely matches that in the baseline condition. This suggests that mental rotation is occurring in both of these conditions but not in the Counter Rotate condition. The reduced error rates in the Rotate condition suggest that making hand rotations in the same direction as mental rotation has increased recognition accuracy.

Effectively the results from both Experiment Eight and Experiment Nine combine to support the evidence from Wohlschlager & Wohlschlager (1998), and Wohlschlager (2001) in that hand movements can affect speed and accuracy in mental rotation. This suggests that mental rotation is not purely a visuo-spatial process. However in the present experiments this was tested during an object recognition task, so this moves the evidence further in that it shows that participants use mental rotation in order to recognise misoriented objects, and that this can be affected by both spatial and motor dual tasks.

The trend line analysis presented throughout the experiments here so far also provides evidence that mental rotation is used more in some circumstances than in others. In some conditions the increasing trend in the data shows that mental rotation is taking place, however the shallow or flat slope in other conditions indicates that other resources are being used in order to recognise the objects being presented. It has not been possible to show whether mental rotation is used more by some participants than others in these experiments, or whether mental rotation is used to a greater or lesser degree by all participants depending on the task.

Chapter 10

Introduction

Experiment Seven in the present set of experiments provided a tantalising suggestion that it may be possible to prime the mental resources that underlie object recognition. The design was thorough yet cumbersome and unfortunately the stimulus set only provided the minimum number of data points for analysis. The revised stimulus set, which was created for Experiment Nine, lends itself to running a re-designed version of Experiment Seven.

The baseline condition data in many of the experiments in this set has been of very little use when used as a comparison for the dual task data. This is because the dual tasks have increased reaction times across all orientations including zero. This means that the baseline reaction time data appears to be unrelated to the dual task data at the analysis stage. In Experiment Seven it was necessary to collect the baseline data in each of the three conditions first so the data in each of the test conditions suffered from being collected during a second run of the experiment. The main conditions of interest were Upright Prime and Rotate Prime. It was interesting to have the data for the Control condition but this was mainly to allow a comparison between participant performance at first and second run of the experiment without a prime task. The decision not to collect baseline data here allows the creation of a much tighter experimental design.

In Experiment Ten the Upright Prime and Prime conditions were compared in a within subjects paradigm using the new stimulus set. The aim of the experiment was to investigate whether the resources that underlie object recognition can be primed. It is expected, based on the tentative data from Experiment Seven, that a stronger mental rotation trend will be shown in the data following the Rotate Prime task than following the Upright Prime task.

Method

Participants: Twenty-four participants from University of Lancaster participated in each experiment. All participants were right handed. They received a course credit for their participation.

Materials: The stimuli were 144 black and white line drawings of common objects taken from the Snodgrass and Vanderwart set (1980). A full list of the stimuli can be found in appendix B. These were presented in a 12 x 12 cm frame on a 17-inch Apple Macintosh monitor. Each drawing could be presented in each of the following orientations in the picture plane: 0°, 60°, 120°, 180°, 210°, and 270°. The zero degree orientation was taken to be the 'normal' orientation in the environment for mono-oriented stimuli. The experiment was run using PsyScope version 1.2.4.PPC, on a Macintosh Power PC and responses were collected using a Macintosh keyboard. Instruction and debriefing screens were shown at the beginning and end of the experiment and are provided in appendix C.

For the Prime component of the experiment the stimuli consisted of 72 novel shapes adapted from the Tarr and Pinker (1989) set. This set can be found in appendix E. The shapes were presented in 36 pairs. In the prime condition each stimulus in a pair was presented at one of the following orientations: 0°, 60°, 120°, 180°, 240°, and 300°. In the control prime condition the shapes were presented at the same orientation.

Design: Twenty-four participants completed both conditions in a within subjects design, being randomly assigned to each condition so that half completed the Upright Prime condition first and half completed the Rotate Prime condition first. In the main experiment there were 10 practice trials followed by 144 experimental trials. On each trial the name of an object was presented on the screen and then replaced by a picture. There were two types of trial: 'yes' response trials and 'no' response trials. In a 'yes' response trial the name was correct for the object presented. In a 'no' response trial the name was not correct for the object presented. In these trials the object was as similar as possible to the name both visually and semantically, for example a picture of a mouse followed the name 'hamster'. This ensured that participants studied the images and could not make accurate judgements based on basic shape features or global outlines. In total there were 72 stimuli in the 'yes condition and 72 in the 'no' condition. The stimuli in the 'yes' condition were all mono-oriented, and the stimuli in the 'no' condition were made up of randomly selected common objects and could be mono or poly-oriented. Participants saw each stimulus only once and in total 4 different participants saw each object at each stimulus orientation. The trials were randomised.

In the Rotate Prime condition participants completed a mental rotation picture-picture matching task before the main experiment. In the Upright Prime condition participants performed a picture-picture matching task before the main experiment. The task followed an identical format to that of the main experiment except that instead of matching a name and a picture participants matched two novel pictures. In both prime conditions there were 5 practice trials followed by 36 experimental trials. There were two types of trial: 'yes' response trials and 'no' response trials. In a 'yes' response trial the shapes matched. In a 'no' response trial the shapes did not match.

Procedure: Each trial began with the prompt "Ready?" which was presented in the centre of the screen and remained until the participant pressed the spacebar. When the spacebar had been pressed, and after an interval of 500ms, the name of an object was presented in the same location as the prompt, this remained for 750ms. A blank interval of 500ms followed, and then a line drawing of an object was presented in the centre of the screen at one of the six orientations in the picture plane. Participants were instructed to respond by pressing the key marked 'YES' if the name matched the picture presented, or by pressing the key marked 'NO' if the picture and name did not match. The 'N' key on the keyboard was labelled 'YES' and the 'M' key was labelled 'NO', responses were made with the index finger of the left hand. Responses were to be made as quickly and accurately as possible following presentation of the picture. In all trials after a response was made the stimulus disappeared from the screen and there was a delay of 3000ms before the next trial.

In the Rotate Prime condition each trial began with the prompt “Ready?” which was presented in the centre of the screen and remained until the subject pressed the spacebar. When the spacebar had been pressed, and after an interval of 500ms, a novel shape was presented in the centre of the screen, this remained for 750ms and could be at any one of the six orientations in the picture plane. A blank interval of 500ms followed, and then a second novel shape was presented in the centre of the screen again at one of the six orientations in the picture plane. The shapes were always presented at different orientations. Participants were instructed to respond by pressing the key marked ‘YES’ if the shapes matched, or by pressing the key marked ‘NO’ if the shapes did not match. Responses were to be made as quickly and accurately as possible following presentation of the picture. In all trials after a response was made the stimulus disappeared from the screen and there was a delay of 3000ms before the next trial.

In the Upright Prime condition each trial began with the prompt “Ready?” which was presented in the centre of the screen and remained until the subject pressed the spacebar. When the spacebar had been pressed, and after an interval of 500ms, a novel shape was presented in the centre of the screen, this remained for 750ms and could be at any one of the six orientations in the picture plane. A blank interval of 500ms followed, and then a second novel shape was presented in the centre of the screen again at one of the six orientations in the picture plane. The shapes were always presented at the same orientation. Participants were instructed to respond by pressing the key marked ‘YES’ if the shapes matched, or by pressing the key marked ‘NO’ if the shapes did not match.

Responses were to be made as quickly and accurately as possible following presentation of the picture. In all trials after a response was made the stimulus disappeared from the screen and there was a delay of 3000ms before the next trial.

Participants completed a written consent form before reading an instruction screen on the computer monitor. They were seated at a distance of 36cm from the monitor and were asked to avoid any head movements. The experiment lasted for approximately 45 minutes.

Results

Data were collapsed as in Experiment Two. Group means and standard deviations are shown in Table 10.1. The data was entered into a 2x5 ANOVA, here boxplots showed no evidence of skewness and a Mauchly Sphericity test was non-significant p=0.555. A significant main effect of orientation was shown $F(4,92)=7.63, MSE=2732$ p=0.005 and a significant interaction $F(4,92)=3.65, MSE=2208$ p=0.008 A trend line analysis was carried out using the five data points from 0° to 150° for each participant. A significant difference was shown between the Rotate and Upright conditions t(23)=2.89, p=0.036. Figure 10.1 shows the slope of the data in each condition and Figure 10.2 shows the trend of the data in each condition.

Table 10.1. Means , standard errors and standard deviations in the Control and Motor conditions

	Rotate			Upright		
Orientation (°)	Mean	SD	SE	Mean	SD	SE
0	587	176	36	590	129	26
60	595	196	40	626	101	20
270	617	190	38	664	130	26
120	620	201	41	635	132	26
210	642	190	38	619	121	24
180	620	187	37	651	114	21

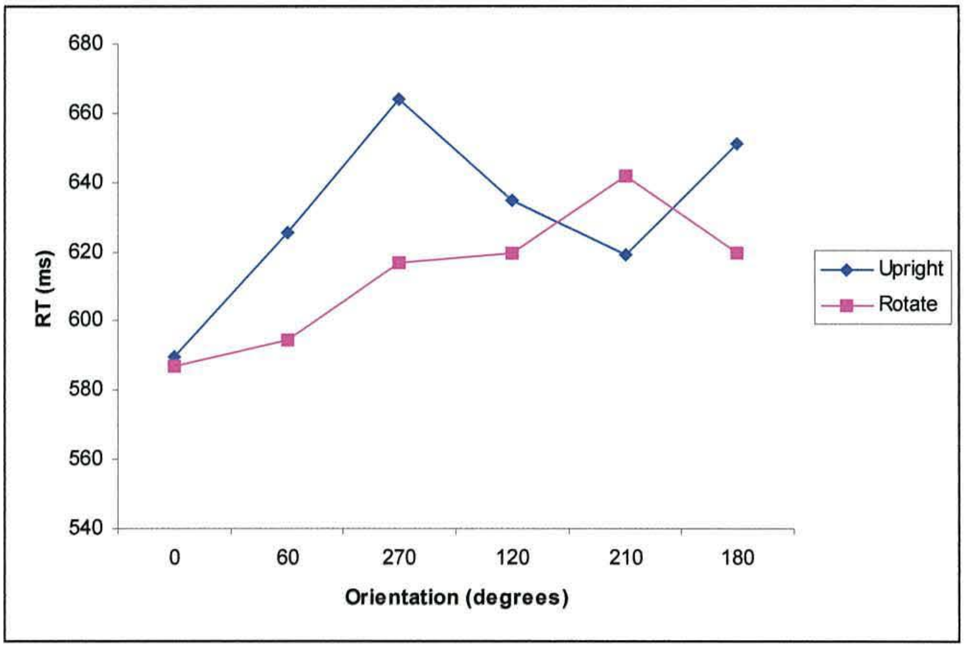


Figure.10.1 Mean reaction times (RT) as a function of stimulus orientation in the upright and rotate prime conditions

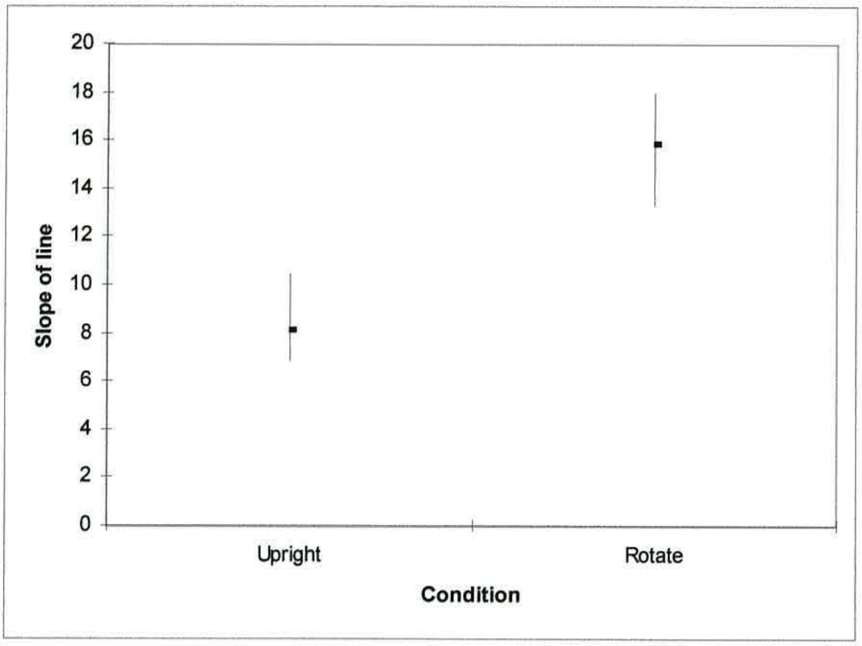


Figure 10.2. Mean trend of data and standard error in each condition

An analysis of error rates showed that participants made on average 1.6/72 (2.1%) errors in the Rotate Prime condition, and 1.4/72 (1.9%) errors in the Upright Prime condition. A Wilcoxan test showed that this difference was not significant [z=0.79; p>0.05].

Summary

The design of this experiment allowed an ANOVA to be performed on the data and this showed a significant effect of orientation and an interaction between the conditions. The trend line analysis also showed a significant difference between the trend of the data in each condition. It can be seen that the reaction times in the Upright Prime condition are much messier than those in the Rotate Prime condition. Those in the Rotate Prime condition show a gradual increase as orientation increases and a typical mental-rotation drop in reaction time at

180°. The trend line analysis further supports the evidence that more mental rotation is occurring in the Rotate Prime condition because the slope of the data is much lower in the Upright Prime condition. These results suggest that mental resources can be primed by experimental tasks. It appears that mental rotation resources have been primed here in the Rotate Prime condition and that some other forms of recognition resources have been primed in the Upright Prime condition.

These results support those in Experiment Seven but the tighter design and changed orientations have allowed a more detailed and convincing analysis. These experiments combine to support the priming experiments of Lawson and Humphreys (1996,1998) and Haward and Tarr (1997) while taking the evidence further in that the aim of the present experiment was to prime mental rotation resources during object recognition. Again it is unclear whether some participants have been primed to use one resource more than other participants, or whether all participants have been primed to favour one resource most of the time. In order to investigate this matter further it will be necessary to plan a future series of experiments to test individual differences between participants.

Discussion

The basic premise behind the experiments conducted in this thesis was that some sort of normalisation strategy is applied to objects presented at unfamiliar orientations. The purpose of the experiments was to further investigate the significance of visuo-spatial normalisation resources in object recognition, particularly mental rotation. This thesis represents an attempt to find a successful test of object recognition, and then to apply the appropriate dual tasks. All parts of the working memory are perceived to possess a finite level of resources during problem solving, consequently dual task experiments are often utilised as a way of exploring the limitations of each part of the Model (e.g. Baddeley & Lieberman, 1980). It appears that visuo-spatial working memory may deal with visual and spatial information separately, and that the spatial aspect of memory is associated with movement control, especially motor planning (Smyth and Pendleton, 1989). It was decided that the dual tasks employed in these experiments should involve primarily a spatial dual task, and possibly a motor task.

Summary of thesis experimental work

Experiment One represented an attempt to replicate the results of Leek (1998). This was successful and increases in orientation were shown to have a strong effect on reaction times on presentation of mono-oriented objects but not of poly-oriented objects. The effect of increasing orientation on reaction time suggested that participants in the mono-oriented condition were using mental rotation. A modified task was devised in Experiment Two, using only the sensitive mono-oriented stimuli, and the results showed that the amended stimulus set replicated the effect seen in the previous experiment suggesting that mental rotation is taking place. Following this successful replication it was possible to go on to test the effect of a spatial dual task on object recognition

In Experiment Three a dual task paradigm was devised. This was based on that of Smyth and Scholey (1994) who used an auditory clicker task to interfere with spatial performance. Reaction times were expected to increase as task difficulty increased, producing a steeper effect than in the non dual-task condition. However, overall reaction times were affected and a shallower effect was produced than in the non-dual task condition. As discussed in Chapter four this effect was described in a paper by Van Selst and Jolicoeur (1994), which stated that that when two tasks of similar difficulty are performed simultaneously there is a bottleneck of resources at the level of response selection. In this case when a participant was required to respond to both a click and to an object viewed at 0° orientation, both of which were simple tasks, there was an increase in reaction time because of the response selection bottleneck. However when an object was viewed at 120° for example the primary task became more difficult while the clicker task remained the same, so in this case there was no bottleneck, resulting in faster response selection time. This made it appear that the dual task made the primary task easier and produced a shallower slope between 0° and 120°.

Experiment Four allowed a comparison between the spatial dual task and a similar non-spatial tone discrimination task. Increases in orientation only produced increasing reaction times in the click condition. However there was no significant difference between reaction times or error rates in the two conditions. It appeared that the spatial dual task was successfully interfering at the level of perceptual encoding in the spatial condition and perhaps at the level of response selection in the non-spatial condition. Similar error rates in both conditions made it unlikely that a time/accuracy trade-off was taking place in the tone condition.

Experiment 5 represented an attempt to produce a novel dual task that more accurately taxed mental rotation. This experiment required participants to mentally rotate letters in order to perform the dual task component. Experiment 6 represented the creation of a suitable non-spatial dual task to allow comparison with experiment 5. Here participants were presented with pairs of letters and were required to state the letter which would appear between the pair in the alphabet. Both tasks answered the initial requirements of a suitable dual task for these experiments in that input was auditory and output was verbal, in addition they are matched in that both involve manipulating letter pairs. The results from Experiment Five produced an increase in reaction times at increasing object orientations. However no significant difference was found between the two data sets. It was considered that both experiments may have required overly complex processing in that perhaps resources from other areas of working memory were involved due to the letter recognition aspect of the task and so not only spatial resources were being tapped.

Experiment Seven was prompted by the analyses of the previous experiments. Biederman and Gerhardstein (1993) suggest that not all participants choose the same route to object constancy. It has also been suggested by Tarr et al. (1998) that experimental paradigms may influence whether participants make use of viewpoint invariant or viewpoint dependant information. Participants in Experiment Five were also seen to use mental rotation at the 180° rotation, which is not normally associated with mental rotation responses. It is possible that the mental rotation dual task in some way facilitated mental rotation transformations. The aim in Experiment Seven was to investigate whether priming of mental rotation can affect visuo-spatial transformations. The relevant factors here were reaction time and error rate. In all conditions there was a decrease in overall reaction time on the second presentation of each stimulus. However it was only in the Rotate Prime condition that reaction times and errors were seen to reduce significantly, suggesting that accuracy had also been improved by the mental rotation prime. If the reduction in reaction times had been due to the second presentation of the stimuli then it would be expected that a significant effect would have been produced in the Control condition. If it were due to matching practice then a significant effect would have been produced in the Control Prime condition. Neither of these conditions produced a significant effect, which suggests that the mental rotation prime was responsible for the significant reduction in reaction times and errors.

The aim of Experiment Eight was to attempt to discover whether visuo-spatial or motor-spatial resources are of more importance in mental rotation. The role of motor resources in mental rotation has been suggested in previous papers (e.g. Banda, Petrides, Frey, and Evans, 1995; Parsons et al, 1995) and this was tested here by a comparison of the spatial clicker task and a motor-spatial version of it. It was expected that reaction times would be slowed to a greater extent in the condition that is taxed most by the concurrent task. The data from both conditions suggested that the dual tasks were interfering at the level of processing and not just at response selection. However the larger increase in reaction times in the motor condition may be taken to suggest that there was more interference in this condition and that it provides more evidence for both motor and spatial contributions to mental rotation as suggested by Wohlschlager & Wohlschlager (1998), and Wohlschlager (2001). However a trend line analysis of the data showed that a steeper overall trend was shown in the Spatial condition. This may have been because some of the hand movements in the Motor condition were in the direction of mental rotation used by the participants, and some was in the opposite direction.

Experiment Nine represented and attempt to further investigate the motor effects shown in Experiment Eight. The orientations used in the stimulus set were changed in order to provide more data points for trend line analysis. This analysis had proved to be very useful so far in showing the changing trend in mental rotation use between experimental conditions. Participants were required to make some hand movements in the same direction as they would be mentally rotating the presented objects, and some hand movements in the other direction. As in the mental rotation experiments of Wohlschlager & Wohlschlager (1998), and Wohlschlager (2001), manual rotations in the same direction as mental rotations were seen to speed up reaction times. Manual rotations counter to mental rotation were seen to increase reaction times. The fact that this was shown in an object recognition experiment can be taken as evidence that mental rotation is taking place during object recognition, and also that motor resources are contributing to the process.

In Experiment Ten the new stimulus set was used in order to run a revised version of Experiment Seven. The paradigm in Experiment Seven was very thorough but very cumbersome. This was simplified in order to investigate the two main conditions of interest, which were Rotate Prime and Upright Prime. Participants completed both conditions in a within subjects design. A stronger mental rotation trend was shown in the Rotate Prime condition and a significant difference in trends was produced between the two conditions. This can be taken to suggest that object recognition resources can be primed. In particular that mental rotation resources were primed in the Rotate condition in comparison to the Upright condition. It is unclear whether some participants had been primed to use one resource more than other participants, or whether all participants had been primed to favour one resource most of the time. In order to investigate this matter further it will be necessary to plan a future series of experiments to test individual differences between participants

The main experimental outcomes and their implications

These results as a whole support the theory that mental rotation contributes to object recognition when mono-oriented objects are viewed at non-cannonical orientations (see Leek, 1998; Jolicoeur, 1995). Neuropsychological evidence has been taken to suggest that the parietal lobes contribute to this process (Layman and Greene, 1998) and that this region is usually associated with viewer-centred spatial information (Kosslyn et al., 1990, 1994). This is consistent with the results gained here where a spatial dual task can have a greater affect on mental rotation trends than a non-spatial dual task. It also appears that motor resources are important in mental rotation. It is now accepted that a significant number of premotor neurons are visuo-motor neurons (Jackson and Hussain, 1997; Wise, DiPellegrino and Boussaud, 1996) and it has long been proposed that some parietal neurons appear to be motor-dependant (Mountcastle, Lynch, Georgeopolus, Sakata, & Acuna, 1975). Recent experiments have shown that simultaneous hand movements can affect mental rotation (Wohlschlager & Wohlschlager, 1998; Wohlschlager 2001). The results of Experiments Eight and Nine also support this theory in that motor-spatial dual tasks have a greater affect on reaction times than a purely spatial task

The greater effect of a motor dual task supports the computational evidence of Ullman and Bart (2004). Here motion tracking is essential to creating a view invariant representation of an object. They report that Wallis and Bulthoff (2001) have similar evidence of the importance of movement perception in human object recognition. The first trial effect described by Jolicoeur (1985, 1990) suggests that once mental rotation has assisted object recognition a view invariant representation of that object can be held in memory. It is possible that motor resources and mental rotation are associated with the first trial effect. The stimulus compatibility evidence of Tucker and Ellis (1998) also supports this theory in that the actions afforded by an object are intrinsic to any representation of that object. Therefore a motor-spatial dual task will tax resources more than a purely spatial dual task.

The importance of motor resources in these object recognition tasks also suggests that the working memory model (Baddeley and Hitch, 1974; Baddeley and Lieberman, 1980) is incomplete. The model in its present state does not account for motor contributions to visuo-spatial performance. Again this leads back to the comment by Milner and Goodale (1995) that the purpose of vision is to allow us to interact with the world. Motor and Visual systems are likely to be closely interlinked and any account of vision that does not include motor resources is likely to be incomplete.

In conclusion the results of these experiments provide further support for the theory that mental rotation contributes to object recognition, and that spatial resources contribute to mental rotation. In particular motor-spatial resources are implicated here in mental rotation, and this affects reaction times for object recognition. Of particular interest is the possibility that these resources can be primed which leads to improved performance at object recognition.

Limitations of this research and future directions

The experiments presented here represent a journey based on an initial question rather than a planned piece of research. As each new finding emerged it was used as a base to prompt the next experiment and so the limitations of each experiment have been discussed along the way and an attempt has been made to address them in the following experiment.

One limitation, which is always present in this type of paradigm, is that of object type and information. The objects used in these experiments were simple 2D line drawings of everyday objects, and although the results are more generalisable than in experiments where only block or stick figures are used, they cannot be generalised to 3D objects in the environment. This could be addressed in future experiments by the creation of a set of 3D objects, ideally using virtual reality technology to emulate real objects in the environment. It may be an artefact of the 2D stimuli that prompts the mental rotation response. 3D depth rotations are problematic (see Johnston et al., 2004) and so it is still sensible to continue using 2D rotations within the picture plane. The creation of a more realistic set of objects also appears sensible based on the work of Tucker and Ellis (1998). It is probable that the actions afforded by objects become stronger as the object becomes more realistic. This may account for why motor-resources have yet to be considered in many cognitive experiments. The use of line drawings and novel objects in stimulus sets may not fully engage all the resources that a real-world object engages.

Another limitation of this type of experiment is the method by which participants make their responses. Here the responses were collected by keypresses, and this means that the recognition response time includes a motor response selection process. This is especially important when Experiments Eight and Nine are considered because the dual task responses were not delivered verbally. It is possible that the delay in reaction times in the motor conditions are due here to a conflict of resources at the response selection or response execution stage of processing. However two sources of evidence are available to support the present results. The first is discussed in Chapter Four and comes from Van Selst and Jolicoeur (1994), where it is stated that if the bottleneck of resources occurs at response selection a fairly flat trend of data is produced, it can be seen from the trend of the data that the motor response data reflects a steep increase in reaction times here. The second type of evidence comes from neuroimaging experiments where keypress motor activity can be separated from rotation induced motor activity. Experiments have shown that there is still motor activity during mental rotation, which cannot be associated with a keypress response (Richter et al, 2000).

The priming data is especially interesting and deserves further investigation. It appears that rotation practice primes rotation performance in a subsequent task. It would be interesting to investigate this further by assessing to what extent each participant uses mental rotation in order to achieve object recognition prior to the experiment. It is not known whether some participants use mental rotation more than others, or whether all of the participants use mental rotation to some extent in addition to other recognition resources.

The affordance evidence from Tucker and Ellis (1998) provides the ideal starting point for future research. As stated earlier the creation of a new stimulus set of photographs of real world objects, or ideally a virtual reality stimulus set, would be useful. Of particular interest would be the comparison of graspable versus non-graspable objects from novel viewpoints. It is possible that graspable objects are more likely to be affected by a motor-spatial dual task if they automatically afford action representations. This would be especially evident if the motor-spatial task interferes with imagined performance of those actions. If however no difference is found between the two sets of objects this will support the neuroimaging literature that shows motor cortex activity even with novel stimuli (Johnston et al., 2004). Experiments could include making congruent versus incongruent grasping shapes with the hand. A comparison of more real-world stimuli with the present line drawing stimuli, and a set of novel stimuli, would also be informative in order to assess whether motor resources are allocated more to transformations involving to be manipulated objects.

Appendix A: Experiment One Stimuli

Mono-oriented stimuli

1. chair
2. lamp
3. computer
4. truck
5. television
6. motorcycle
7. stool
8. tree
9. car
10. table
11. fridge
12. bench
13. sailboat
14. washing machine
15. desk
16. wardrobe
17. dresser
18. clock
19. crane
20. church
21. bed
22. house
23. skyscraper
24. signpost

Polyoriented stimuli

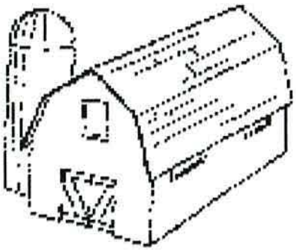
25. pencil
26. lighter
27. razor
28. clothes peg
29. scissors
30. banana
31. tennis
32. comb
33. carrot
34. pen
35. match
36. nail
37. hammer
38. knife
39. axe
40. toothbrush
41. key
42. screwdriver
43. pear
44. flashlight
45. lipstick
46. paintbrush
47. cigarette
48. screw

Appendix B: Revised stimuli in the yes condition

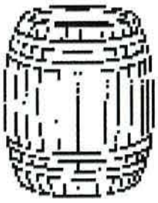
(Picture quality has been degraded by size reduction in this Appendix)

Aeroplane

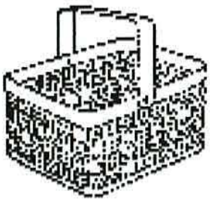
Barn



Barrel



Basket



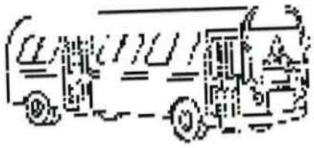
Bear

Bicycle

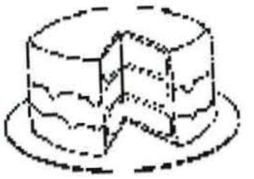
Boat

Bread

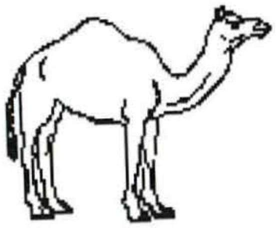
Bus



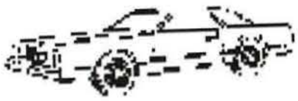
Cake



Camel

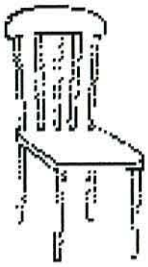


Car

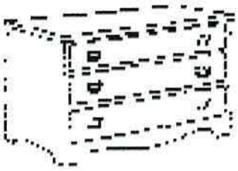


Cat

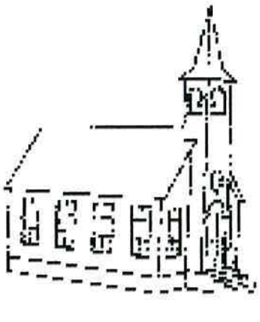
Chair



chest of drawers



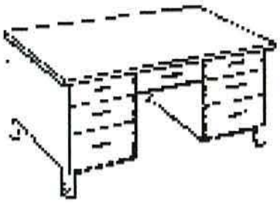
church



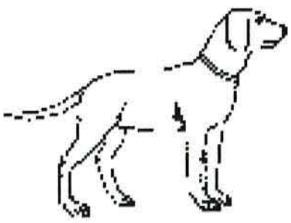
cow

crown

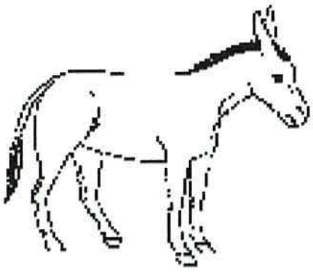
desk



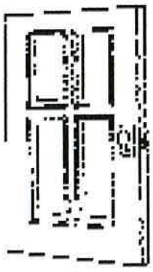
dog



donkey



door

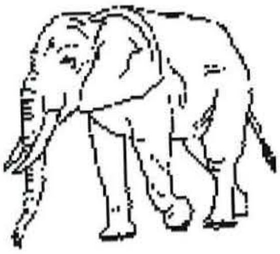


Duck

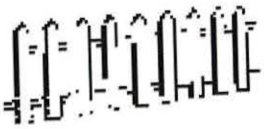
Dustbin

eagle

elephant

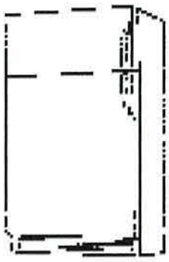


fence

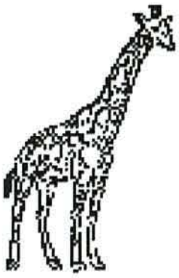


Fox

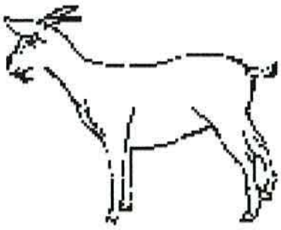
Fridge



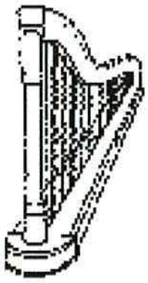
Giraffe



Goat

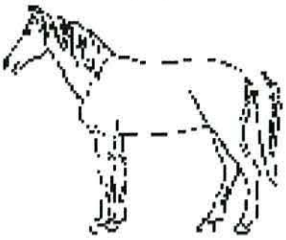


Harp

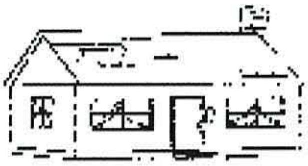


Hen

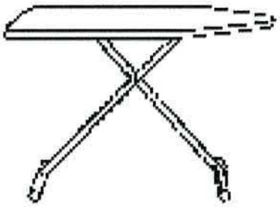
Horse



House

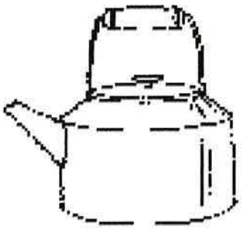


ironing board



kangaroo

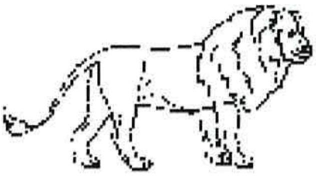
kettle



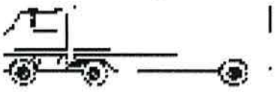
lamp

leopard

lion

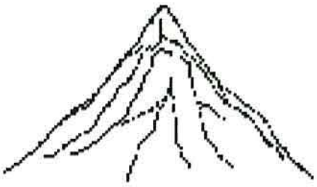


lorry



motor-bike

mountain



ostrich

oven

owl

peacock

penguin

piano

pig

pram

rabbit

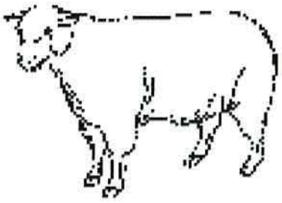
Racoon

Rhinoceros

rocking-chair

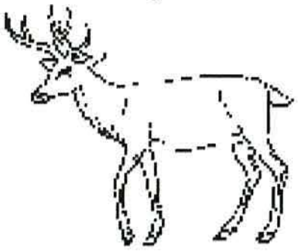
seal

sheep



snowman

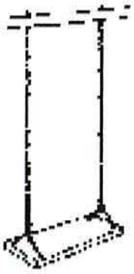
stag



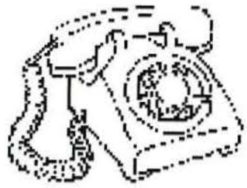
stool

swan

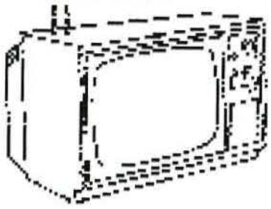
swing



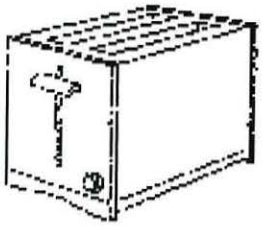
Telephone



Television



Toaster

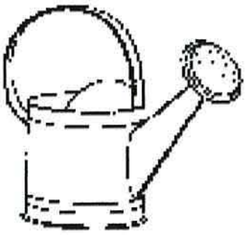


Train

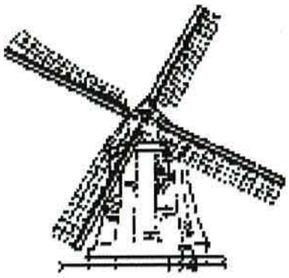
Tree

Vase

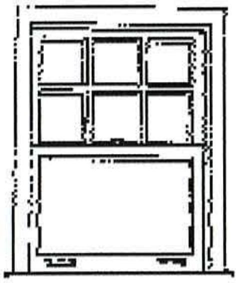
watering can



windmill



window



Appendix B: Revised stimuli in the no condition

Picture stimulus	Written name
apple	nectarine
anchor	harpoon
beetle	ladybird
wine bottle	milk bottle
bow	Bow tie
bowl	helmet
box	brick
bulb	lamp
butterfly	dragonfly
candle	lantern
caterpillar	centipede
cherry	plum
clock	compass
cloud	bush
crocodile	lizard
fish	shark
flower	rose
fly	wasp
frog	gecko
frying pan	wok
glass	test tube
gorilla	baboon
grasshopper	flea
gun	rifle
hat	beret
iron	sander
jug	decanter
lettuce	cabbage
lobster	prawn
mitten	glove
mouse	hamster
mushroom	radish
necklace	bracelet
nut	bolt
pear	mango
pepper	artichoke
pineapple	pomegranate
pot	milk pan
pumpkin	tangerine
purse (handbag)	satchel
ring	earring
salt cellar	pepper grinder

sandwich	omelette
sea horse	dragon
shoe	slipper
skunk	racoon
sled	go-cart
snail	slug
snake	salamander
sock	boot
sparrow	crow
spider	crab
squirrel	chipmunk
strawberry	blackberry
suitcase	wallet
table	bench
tea cup	mug
thread holder	fishing reel
tomato	orange
waist coat	life jacket
watermelon	banana
whistle	tin whistle
wine glass	champagne flute

Appendix C: Instruction and debriefing information

Instructions:

You will be presented with the name of an object followed by a picture,
if the picture and name are the same press button 'n',
if the picture is not what was named press button 'm'.
Use the index finger of your preferred hand to press the buttons.
Please respond as quickly and as accurately as possible when a picture appears.

Press the space bar when you see the word 'ready', this will take you on to the next trial.

You will be offered two opportunities to take a break, press the spacebar when you are
ready to
continue.

Debrief:

Thank you for taking part in this experiment.

Your data will be stored anonymously as a series of letters and numbers. It will be added to a bank of data from healthy participants.

You will have noticed that the pictures you saw were rotated to different degrees, previous experiments have shown that people take longer to recognise objects the further they are rotated from their usual upright.

This series of experiments has been designed to explore this finding by the use of dual task paradigms, please feel free to ask any questions about this.

Appendix D: Stimuli orientations in List One

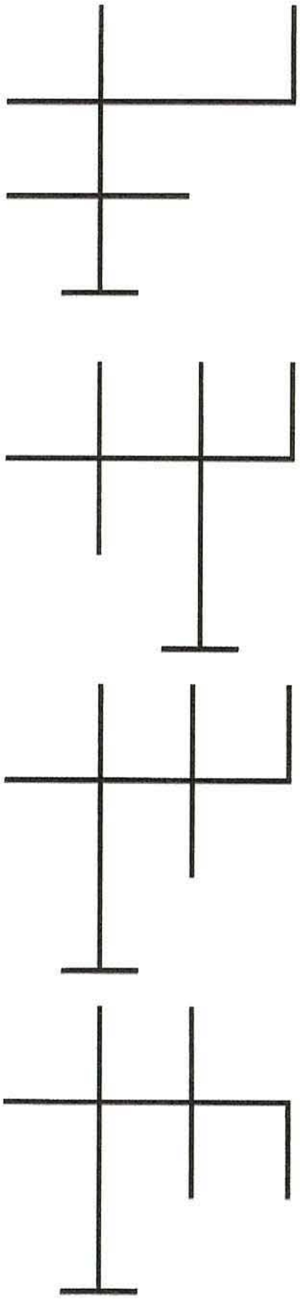
aeroplane 0
anchor 0
apple 0
barn 60
barrel 120
basket 180
bat 120
bear 240
beetle 300
bicycle 300
boat 0
bottle 180
bow 240
bowl 300
box 0
bread 60
brush 60
bulb 120
bus 120
butterfly 180
cake 180
camel 240
candle 240
car 300
carrot 300
cat 0
caterpillar 0
chair 60
cherry 60
chest of drawers 120
church 180
cigar 120
clock 180
cloud 240
cotton reel 180
cow 240
crocodile 0
crown 300
desk 0
dog 60
donkey 120
door 180
duck 240
dustbin 300

eagle 0
elephant 60
emery board 60
fence 120
fish 120
flower 180
flute 240
fly 300
fox 180
fridge 240
frog 60
frying pan 120
giraffe 300
glass 0
goat 0
gorilla 180
grasshopper 240
guitar 300
gun 0
handbag 60
harp 60
hat 120
hen 120
horse 180
house 240
iron 180
ironing board 300
jug 240
kangaroo 0
kettle 60
kite 300
lamp 120
leopard 180
lettuce 0
lion 240
lobster 120
lorry 300
mitten 180
motorbike 0
mountain 60
mouse 180
mushroom 240
necklace 180
nut 300
ostrich 120
oven 180

owl	240
peacock	300
pear	300
penguin	0
pepper	0
piano	60
pig	120
pineapple	60
pot	240
pram	180
pumpkin	60
rabbit	240
raccoon	300
rhino	0
ring	300
rocking chair	60
sandwich	0
screw	120
seahorse	60
seal	120
sheep	180
shoe	120
skunk	180
sled	240
snail	300
snake	0
snowman	240
sock	60
sparrow	120
spider	180
squirrel	240
stag	300
stool	0
strawberry	300
suitcase	0
swan	60
swing	120
table	60
teacup	120
telephone	180
television	240
toaster	300
tomato	240
train	0
tree	60
vase	120

waistcoat 300
watering can 180
watermelon 0
whistle 60
windmill 240
window 300
wineglass 120

Appendix E: The Tarr and Pinker set



References

Adini, Y., Moses, Y., Ullman, S., (1997). Face recogniton:the problems of compensating for changes in illumination direction. *IEEE Transactions on Pattern Analysis and Machine Intelligence* 19, 721-732.

Alivasatos, B., & Petrides, M. (1996). Functional activation of the human brain during mental rotation. *Neuropsychologia*, 35, 111-118

Atkinson, R.C. & Shiffrin, R.M. (1971). The control of short term memory. *Scientific American*, August 1971, 225(2) 82-90

Baddeley, A.D. (1986). *Working Memory*. Oxford. Oxford University Press

Baddeley, A.D., Hitch, G.J.(1974). Working Memory. In Bower, G. (Ed). *The Psychology of Learning and Motivation*, V111. New York: Academic Press, pp 47-49

Baddeley,A.D.,Lieberman,K.(1980). Spatial working memory. In R. Nickerson(Ed.), *Attention and performance* VIII(pp.521–539).

Biederman, I., (1987). Recognition-by-components: a theory of human image understanding. *Psychological Review* 94, 115-147

Biederman, I., (1995). Visual object recognition. In: Kosslyn, S.F. and Osherson, D.N., Editors, (1995). *An invitation to cognitive science* Vol 2, MIT Press, Cambridge, MA. pp 121-165

Biederman, I., Gerhardstein,P.C.. (1993). Recognising depth-rotated objects: Evidence and conditions for three-dimensional viewpoint invariance. *Journal of Experimental Psychology: Human Perception and Performance* 19 (6), 1162-1182.

Biederman, I., Ju, G., (1988). Surface versus edge-based determinants of visual recognition. *Cognitive Psychology* 20, 38-64.

Binford, T.O. (1971) Visual perception by computer. Presented to the IEEE conference on Systems and Control. December, Miami

Binofski, F., Dohle, C., Posse, S., Stephan, K.M., Hefter, H., Seitz, R.j., Freund, H.J. (1998). Human anterior intraparietal area subserves prehension. A combined lesion and functional MRI activation study. *Neurology*, 50, 1253-1259

Bonda, E; Petrides, M; Frey, S., & Evans, A. (1995). Neural correlates of mental transformations of the body-in-space. *Proceedings of the National Acadamy of Sciences*, 92, 11180-11184

Bricolo, E., Poggio, T., Logothesis, N.K., (1997). 3D object recognition: A model of view-tuned neurons. In: Mozer, M.C., Jordan, M.I., Petsche,

T. (Eds), *Advances in Neural Information Processing Systems* 9. MIT Press,Cambridge, MA.

Brooks, L.R. (1968). Spatial and verbal components in the act of recall. *Canadian Journal of Psychology*. 22, 349-368

Bulthoff, H.H., Edelman, S. (1992). Psychophysical support for a 2D view Interpolation theory of object recognition. *Proceedings of the National Academy of Sciences*, 89, 60-64

Cave, K.R., & Kosslyn, S.M. (1989). Varieties of size-specific visual selection. *Journal of Experimental Psychology: General*, 118, 148-161

Carpenter, P.A., Just, M.A. (1997). *A capacity theory of spatial working memory: Neural and behavioural evidence* (Technical Report) Pittsburgh, PA: Department of Psychology, Carnegie Mellon University.

Carpenter, P.A., Just, M.A., Keller, T.A., Eddy, W. (1999). Graded Functional Activation in the Visuospatial system with the amount of task demand. *Journal of Cognitive Neuroscience*, 11:1, 9-24

Cohen, M.S., Kosslyn S.M., Breiter, H.C., DiGirolamo, G.J., Thompson, W.L., Anderson, A.K., Bookheimer, S.Y., Rosen, B.R., & Belliveau, J.W. (1996). Changes in cortical activity during mental rotation: A mapping study using functional MRI. *Brain*, 119, 89-100

Cohen, M.S., Kubrovny, M. (1993). Mental rotation, mental representation, and flat slopes. *Cognitive Psychology*, 25, 351-382.

Cooper, C.G., Humphreys, G.W. (2000). Task specific effects of orientation Information: neuropsychological evidence. *Neuopsychologia*, 38, 1607-1615.

Corballis, P. M., & Corballis, M. C. (1993). How apparent motion affects mental rotation: Push or pull? *Memory and Cognition*, 21, 458-466

Corballis, M.C., & Nagourney, B.A., (1978). Latency to categorise disoriented alphanumeric characters as letters or digits. *Canadian Journal of Psychology*, 32(3), 186-188

Corballis, M.C., Zobradoff, N.J., Shetzer, L.I., & Butler, P.B., (1978). Decisions about identity and orientation of rotated letters and digits. *Memory and Cognition*, 6, 98-107

Craik, F.I.M. (1968). Types of error in free recall. *Psychonomic Science*, 10 353-354

Craik, F.I.M., Lockheart, R.S. (1972). Levels of processing: a framework for memory research. *Journal of Verbal Learning and Verbal Behaviour*, 11, 671-684

Cutting, J.E. & Millard, R.T. (1984). Three gradients and the perception of flat and curved surfaces. *Journal of Experimental Psychology: General*. 113, 221-224

Decety, J., Grezes, J., Costes, N., Perani, D., Jeannerod, M., Procyk, E., Grassi, F., Fazio, F. (1997). Brain activity during observation of actions. Influence of action content and subject' Brain, 120, 1763-1777.

Deiber, M.P., Honda, V., Ibanez, N. Sadato, N. Hallett, M. (1999). Mesial motor areas in self-initiated versus externally triggered movements examined with fMRI: effect of movement type and rate. *Journal of Neurophysiology*. 81, 3065-3077

Deiber, M.P., Ibanez, N., Sadato, N. Hallett, M. (1996). Cerebral structures participating in motor preparation in humans: a positron emission topography study. *Journal of Neurophysiology*, 75 (1) 233-247

Della Sala, S., Logie, R.H. (1993). When working memory does not work: the role of working memory in neuropschology. In: Boller, F., Grafman, J. (Eds) *Handbook of Neuropsychology*. Amsterdam. Elsevier Science, 8, 1-44

Eley, M.G., (1982). Identifying rotated letter-like symbols. *Memory and Cognition*, 10,(1), 25-32

Farah, M.J., Hammond, K.M., (1988). Mental Rotation and orientation-invariant object recognition: Dissociable processes. *Cognition*, 29, 29-46.

Farah, M.J., Hammond, K.M., Levine, D.N., Calvaniro, R., (1988). Visual and spatial mental imagery: Dissociable systems of representation. *Cognitive Psychology*, 20, 439-462.

Friedman-Hill, S.R., Robertson, L.C., Triesman,A., (1995). Parietal contributions to visual feature binding: evidence from a patient with bilateral lesions. *Science*, 269, 853-855.

Formisano, E., Linden, D.E., DiSalle, F., Trojano, L., Esposito, F., Sack, A.T., Grossi, D., Zanella, F.E., Goebel, R. (2002). Tracking the mind's image in the brain I: Time-resolved fMRI during visuospatial imagery. *Neuron* 35, 185-194

Gallese, V., Fadiga, L., Fogassi, L., Rizzolatti, G. (1996). Action recognition in the premotor cortex, *Brain*, 119, 593-609

Georgopoulos, A.P., Lurito, J.T., Petrides, M., Schwartz, A.B., Massey, J.T. (1989). Mental rotation of the neuronal population vector. *Science*, 243 234-236.

Gibson, J.J. (1979). *The ecological approach to visual perception.* Boston: Houghton Mifflin.

Gibson, J.J., Robson, D., (1935). Orientation in visual perception: the recogntion of familiar plane forms in differing orientations. *Psychological Monographs*, 46, 39- 47

Goodale,M.A., Meenan, J.P., Bulthoff, H.H., Nicolle,D.A., Murphy, K.J., Racicot, C.I. (1994). Separate neural pathways for the visual analysis of object shape in perception and prehension. *Current Biology*, 4, 604-610.

Goodale,M.A., Millner,A.D. (1992). Separate visual pathways for perception and action. *Trends in Neuroscience*,15, 20-25

Gregory, J.L. (1972). Cognitive contours. *Nature*, 238 (5358), 51-52.

Graziano, M.S.A., Yap, G.S., Gross, C.G. (1994). Coding of visual space by premotor neurons. *Science*, 266, 1054- 1057.

Hayward, W.G., (1998). Effects of outline shape in object recognition. *Journal of Experimental Psychology: Human Perception and Performan*ce 24, 427-440

Hayward, W.G., Tarr, M.J., (1997). Testing conditions for viewpoint invariance in object recognition. *Journal of Experimental Psychology: Human Perception and Performance* 23, 5, 1511-1521

Hitch, G.J., Halliday, M.S., Schaafstal, A.M., Schraagen, J.M.C. (1988). Visual working memory in children. *Memory and Cognition*, 17, 175-185

Hitch, G.J., Woodin, M.E., Baker, S. (1989). Visual and phonological components of working memory in children. *Memory and Cognition*, 17, 175-185

Hoffman, D.D., & Flinchbaugh, B.E., (1982). The Interpretation of biological motion. *Biological Cybernetics,* 42, 195-204

Hoffman , D.D., & Richards, M. (1984) Parts of recognition. *Cognition*, 18, 65-96

Hopfield, J.J., (1982). Neural networks and physical systems with emergent collective computational abilities. *Proceedings of the National Academy of Sciences USA,* 79 2554-2558

Horn, B.K.P., (1975) Obtaining shape form shadowing information. In P.H. Winston (ed). The Psychology of Computer Vision. New York, McGraw-Hill

Hubel, D.H., Wiesel, T.N., (1959). Receptive fields of single neurons in the cat's striate cortex. *Journal of Physiology*, 148, 547-591

Hummel, J.E., (1998). Where view-based theories break down: The role of structure in shape perception and object recognition. In: Dietrich, E., Markman, A. (Eds), *Cognitive Dynamics: Conceptual Change in Humans and Machines.* MIT Press, Cambridge, MA.

Humphreys, G.W., Riddoch,M.J., (1984).Routes to object constancy: Implications from neurological impairments of object constancy. *Quarterly Journal of Experimental Psychology*, 36A, 385-418

Humphreys, G.W., Quinlan, P.T. (1987). Normal and pathological processes in visual object constancy. In G.W., Humphreys & M.J. Riddock (Eds) *Visual object processing: A cognitive neuropsychological approach*, 43-105. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.

Jackson, S.R., Hussain, M. (1997). Visuomotor functions of the lateral pre-motor cortex. *Current Opinion in Neurobiology*, 6, 788- 795

Johnston, S., Leek, E.C., Atherton, C., Thacker, N., Jackson, A. (2004). Functional contribution of medial premotor cortex to visuo-spatial transformations in humnas. *Neuroscience Letters*, 355 (3), 209-212

Jolicoeur, P., (1990). Identification of disoriented objects: A dual-systems theory. *Mind and Language* 5 (4), 387-410

Jolicoeur, P., (1988). Mental Rotation and the Identification of Disoriented Objects. *Canadian Journal of Psychology*, 42, 461-78

Jolicoeur, P., (1985). The time to name disoriented natural objects. *Memory and Cognition*, 13, 289-303.

Jolicoeur,P., & Landau,M.J., (1984). Effects of Orientation on the Identification of Simple Visual Patterns, *Canadian Journal of Psychology*, 38, 80-93

Just, M.A, Carpenter, P.A. (1985). Cognitive coordinate systems; Accounts of mental rotation and individual differences in spatial ability. *Psychological Review*, 92, 137-172

Kahneman, D. (1973). *Attention and Effort*. New Jersey: Prentice Hall

Kawashima, R., Naitoh, E., Matsumura,M., Itoh.H., Ono, S., Satoh, K., Gotoh,R., Koyama,M., Inoue, K., Yoshioka, S. & Fukuda, H. (1996).

Topographic representation in human intraparietal sulcus of reaching and saccade. *Neuroreport*, 7, 1253-1256

Kinnear, P.R., Gray, C.D. (2000). *SPSS for Windows Made Simple Release 10.* East Sussex. Psychology Press Ltd. pp 216-217

Kohonen, T., (1978). *Associative memories: A system theoretic approach.* Springer, Berlin.

Kosslyn, S.M. (1980). *Image and Mind.* Cambridge, MA. Harvard University Press

Kosslyn S.M. (1991). A cognitive neuroscience of visual cognition: Further developments. In R.H. Logie, & M. Denis (Eds.), *Mental Images in human cognition* (pp. 351-381). North-Holland: Elsevier Science Publishing Co.

Kosslyn,S.M., Alpert, N.M., Thompson,W.L., Chabris, C.F., Rauch, S.L., Anderson, A.K., (1994). Identifying objects seen from different viewpoints: a PET investigation. *Brain*, 117, 1055-1071.

Kosslyn,S.M., Flynn,R.A., Amsterdam, J.B., Wang,G. (1990). Components of high- level vision: a cognitive neuroscience analysis and accounts of neurological syndromes. *Cognition*, 34, 203-277

Landis, T., Regard, M., Bliestle, A., Kleihues, P., (1988). Prosopagnosia and agnosia for noncanonical views: An autopsied case. *Brain*, 111,1287-1297.

Layman, S., Greene, E. (1998). The effect of stroke on object recognition. *Brain and Cognition*, 7, 87-114

Lawson, R., Humphreys, G.W. (1996) View specificity in object processing: Evidence from picture matching. *Journal of Experimental Psychology: Human Perception and Performance*, 22, 395-416

Lawson, R., Humphreys, G.W. (1998) View-specific effects of depth rotation and foreshortening on the initial recognition and priming of familiar objects. *Perception and Psychophysic*s, 60, 1052-1066

Leek, E.C., (1998). Effects of stimulus orientation on the identification of common polyoriented objects. *Psychonomic Bulletin and Review,* 5 (4) 650-658.

Logie, R.H. (1986). Visuo-Spatial processing in working memory. *Quarterly Journal of Experimental Psychology*, 38a, 229-247

Logothetis, N.K., Pauls, J., Bulthoff, H.H., Poggio, T., (1995). Shape representation in the inferior temporal cortex of monkeys. *Current Biology* 5, 552-563

Lowe, D.G., (1987). The viewpoint consistency constraint. *International Journal of Computer Vision,* 1, 57-72

Marr, D. (1977). Artificial intelligence: A personal view. *Artificial Intelligence* 9.37-48.

Marr, D., (1982). *Vision: a computational investigation into the human representations and processing of visual information.* Freeman, San Francisco, CA

Marr, D., Nishihara, H.K., (1978). Representation and recognition of the spatial organisation of three dimensional shapes. *Proceedings of the Royal Society of London B* 200, 269-294.

Marr, D. & Poggio, T. (1977) Cooperative computation of stereo disparity. *Science,* 194, 283-287

McCarthy, R.A., (1993). Assembling routines and addressing representations: An alternative conceptualisation of 'what' and 'where' in the human brain. In N. Elian, R.A.McCarthy, B.Brewer. *Spatial representation: Problems in philosophy and psychology.* Oxford, England: Blackwell.

McMullen, P. A., & Farah, M.J. (1991). Viewer-centered and object-centred representations in the recognition of naturalistic line drawings. *Psychological Science.* 2, 275-277

McMullen, P. A., Jolicoeur, P., (1990). The Spatial Frame of Reference in Object Naming and Discrimination of Left-Right Reflections. *Memory and Cognition,* 18.99-115

Mikolajczyk, K., Schmid, C., (2002). An affine invariant interest point detector. *Proceedings of the European conference on computer vision* pp128-142

Milner, A.D., (1995). Cerebral Correlates of visual awareness. *Neuropsychologia,* 33, 1117-1130

Milner, A.D., Goodale, M.A.,(1993). Visual Pathways to perception and action. *Progress in Brain Research,* 95, 317-337

Milner, A.D., Goodale, M.A., (1995).*The visual brain in action.* Oxford, England: Oxford University Press.

Morel. A., Bullier,J., (1990). Anatomical segregation of two cortical visual pathways in the macaque monkey. *Visual Neuroscience,* 4, 555-578.

Mountcastle, V.B., Lynch, J.C., Georgopoulos, A.P., Sakata, H., Akuna, C. (1975). Posterior parietal association cortex of the monkey: Command functions for operating within extrapersonal space. *Journal of Neuropsychology,* 38, 871-908

Murray, J.E., Jolicoeur, P., McMullen, P.A., & Ingleton, M. (1993). Orientation-invariant transfer of training in the identification of rotated natural objects. *Memory and Cognition,* 21(5), 604-610

Neisser, U. (1967). *Cognitive Psychology.* New York. Appleton

Newell, F., Findlay, J.M. (1992). Viewpoint invariance in object recognition. *Irish Journal of Psychology,* 13, 494-507

Palmer, S.E. (1975). The effects of contextual scenes on the identification of objects. *Memory and Cognition,* 3, 519-526

Parsons, L.M., Fox, P.T., Downs, J.H., Glass, T., Hirsch, T.B., Martin, C.C., Jerabeck, P.A., & Lancaster, J.L. (1995). Use of implicit motor imagery for visual shape discrimination as revealed by PET. *Nature,* 375, 54-58

Pashler, H.E. (1998). *The psychology of attention.* London: MIT Press

Perret, D.I., Smith. P.A.J., Potter. D.D., Mistlin. A.J., Head. A.S., Milner. A.D., & Jeeves, M.A. (1985). Visual cells in the temporal cortex sensitive to face view and gaze direction. *Proceedings of the Royal Society London B,* 223, 293-317

Picard, N., Strick, P.L. (2001). Imaging the premotor areas. *Current Opinion in Neurobiology.* 11, 663-672

Pinker, S. (1984). Visual Cognition: An introduction. *Cognition* 18, 1-63.

Price, C.J., Humphreys, G.W. (1989). The Effects of Surface Detail on Object Categorization and Naming. *Quarterly Journal of Experimental Psychology,* 41A,797-828

Podzebenko, K., Egan, G.F., Watson, J.D.G. (2005). Real and Imaginary Rotary motion processing: Functional parcellation of the human parietal lobe revealed by fMRI. *Journal of Cognitive Neuroscience,* 17:1, 24-36

Poggio, T., Edelman, S., (1990). A network that learns to recognise three-dimensional objects. *Nature* 343, 263-266.

Richter, W., Somorjai, R., Summers, R., Jarmasz, M., Menon, R.S., Gati, J.S., Georgopoulos, A.P., Tegeler, C., Ugurbil, K., Kim, S.G. (2000). Motor area activity during mental rotation studied by time-resolved single-trial fMRI. *Journal of Cognitive Neuroscience,* 12:2. 310-320

Selfridge, O.G., (1959). Pandemonium: A paradigm for learning. In *Symposium on the Mechanization of Thought Processes*. London: HMSO.

Shepard, R.N. and Metzler, J. (1971) Mental rotation of three-dimensional objects. Science, 171, 701-703.

Shepard, R.N & Cooper, L.A., (1982). *Mental Images and their transformations.* Cambridge, M.A:MIT Press

Simion, F., Bagnara, S., Roncato, S., & Umilta, C. (1982). Transformation processes upon the visual code. *Perception and Psychophysics*, 31(1), 13-25

Sirugu, A., Cohen, L., Duhammel, J.R., Pillon, B., Dubois, B. & Agrid, Y. (1995) A selective impairment of hand posture for object utilization in apraxia, *Cortex*, 31, 41-55

Smyth, M.M., Scholey.K.A., (1994). Interference in immediate spatial memory. *Memory and Cognition*, 22 (1), 1-13.

Smyth, M.M., Pendleton, L.R. (1989). Working memory for movements. *Quarterly Journal of Psychology*, 41a, 235-250

Snodgrass, J.G., Vanderwart, M., (1980). A Standardized Set of 260 Pictures: Norms for Name Agreement, Image Agreement, Familiarity, and Visual Complexity. Journal of Experimental Psychology: Human Learning and Memory, 6 (2), 174-215

Snyder, L.H., Batista, A.P., & Andersen, R.A., (1997). Coding of intention in the posterior parietal cortex. *Nature*, 386, 167-170

Stevens, K.A. (1981). The information content of texture gradients. *Biological Cybernetics*, 42, 95-105

Suzuki, S., Peterson, M.A., Moscovitch, M., Behrmann,M., (1997). *Viewpoint specificity in the identification of simple volumetric objects (geons) is evident in control subjects and very exaggerated in visual object agnosia.* Cognitive Neuroscience Society, Boston, MA

Takano, Y., (1989). Perception of Rotated Forms: A Theory of Information Types. *Cognitive Psychology,* 21,1-59

Tagaris, G.A., Kim, S.G., Strup, J.P., Andersen, P., Ugurbil, K., Georgopoulos, A.P. (1996). Quantitative relations between parietal activation and performance in mental rotation. *Neuroreport*, 7, 773-776.

Tagaris, G.A., Kim, S.G., Strup, J.P., Andersen, P., Ugurbil, K., Georgopoulos, A.P. (1997). Mental rotation studied by functional magnetic resonance imaging at high field (4 Tesla): Performance and cortical activation.

Journal of Cognitive Neuroscience, 9, 419-432

Tagaris, G.A., Richter, W., Kim, S.G., Pellizzer, G., Andersen, P., Ugurbil, K., Georgopoulos, A.P. (1998). Functional magnetic resonance imaging of mental rotation and memory scanning: A multidimensional scaling analysis of brain activation patterns. *Brain Research Reviews*. 26, 106-112

Tarr, M.J., (1995). Rotating objects to recognise them: A case study on the role of viewpoint dependancy in the recognition of three-dimensional objects. *Psychonomic Bulletin and Review*, 2, 55-82.

Tarr, M.J., Bulthoff, H.H., (1995). Is human object recognition better described by geon-structural-descriptions or by multiple-views? *Journal of the Experimental Psychology: Human Perception and Performance*, 21, 1494- 1505.

Tarr, M.J., Bulthoff, H.H., Zabinski, M., Blanz, V., (1997). To what extent do unique parts influence recognition across changes in viewpoint? *Psychological Science* 8 (4), 282-289.

Tarr, M.J.,Pinker. S. (1989). Mental Rotation and orientation dependance in shape processing. *Cognitive Psychology*, 21, 233-282.

Tarr, M.J.,Pinker. S. (1990). When does human object recognition use a viewer centered reference frame?. *Psychological Science* 1 (42), 253-256

Tarr, M.J., Williams, P., Hayward, W.G., Gauthier, I., (1998). Three dimensional object recognition is viewpoint dependant. *Nature Neuroscience* 1.

Trehub, A. (1977). Neuronal models for cognitive processes: Networks for learning, perception, and imagination. *Journal of Theoretical Biology*., 65, 141-169

Turnbull, O.H., Carey, D.P., McCarthy, R.A., (1997). The neuropsychology of object constancy. *Journal of the International Neuropsychological Society*, 3, 288-298.

Turnbull, O.H., Laws, K.R., McCarthy, R.A. (1995). Object recognition without knowledge of object constancy. *Journal of the international Neuropsychological Society*, 3, 288-298.

Turnbull, O.H., Beschin, N., Della Sala, S. (1997). Agnosia for object orientation: Implications for theories of object recognition. *Neuropsychologia*, 35, 567-570

Tuytelaars, T., Gool, L.V., (2000). *Wide baseline stereo matching based on local, affinely invariant regions.* British machine vision conference pp 412-425

Ullman, S, (1979). *The interpretation of visual motion.* Cambridge, MA: MIT press

Ullman, S, (1989). Aligning pictorial descriptions; an approach to object recognition. *Cognition,* 32,193-254.

Ullman, S., Bart, E., (2004). Recognition invariance obtained by extended and invariant features. *Neural Networks* 17 (5-6) 833-848.

Ullman, S., Vidal-Naquet, M., Sali, E., (2002). Visual features of intermediate complexity and their use in classification. *Nature Neuroscience* 5 (7) 682-687.

Ungerleider, L.G., Mishkin, M., (1982). Two cortical visual systems in D.J. Ingle, M.A. Goodale, R.J.W. Mansfield (Eds), *Analysis of Visual Behavior.* Cambridge, MA: MIT press.

Van Essen. D.C., (1985). Functional organization of primate visual cortex. In A. Peters & E.G.Jones (Eds.) *Cerebral Cortex vol 3.* New York: Plenum Press.

Van Selst, M., Jolicoeur, P. (1994). Can mental rotation occur before the dual-task bottleneck? *Journal of Experimental Psychology: Human Perception and Performance,* (20), 4, 905-921

Voyer, D. (1995). Effect of practice on laterality in a mental rotation task. *Brain and Cognition,* 29, 326-335

Wallis, G., Bulthoff, H.H., (2001). Effects of temporal association on recognition memory. Proceedings of the National Academy of Sciences USA, 98 (8) 4800-4804

Warrington, E.K., James, M., (1986). Visual object recognition in patients with right hemisphere lesions: Axes of features? *Perception,* 15, 355-366

Warrington, E.K., Taylor,A.M., (1973). The contribution of the right parietal lobe to object recognition. *Cortex,* 9, 152-164.

Warrington, E.K., Taylor,A.M.,(1978). Two categorical stages of object recognition. *Perception,* 7, 695-705

Warrington, E.K., Davidoff, J. (2000). Failure at object identification improves mirror image matching. *Neuropsychologia,* 38, 1229- 1234

Watson, R.T., Valenstein, E., Day, A., Heilman, K.M. (1994). Posterior neocortical systems subserving awareness and neglect. *Archives of Neurology,* 51, 1014-1021

Welford, A.T., (1952). The psychological refractory period and the timing of high speed performance. *British Journal of Psychology*, 43, 2-19

Welford, A.T., (1967). Single-channel operation in the brain. *Acta Psychologia*,27, 5-22

White, M.J. (1980). Naming and categorization of tilted alphanumeric characters do not require mental rotation. *Bulletin of the Psychonomic Society,* 15(3), 153-156

Wise, S.P., DiPelligrino, G., Broussaoud, D. (1996). The premotor cortex and nonstandard sensorimotor mapping. *Canadian Journal of Pysiology and Pharmacology*, 74, 469- 482

Wiser, M. (1981). The role of intrinsic axes in shape recogniton. In *Proceedings of the Third Annual Conference of the Cognitive Science Society*,184-186

Wohlschlager,A., & Wohlschlager, A. (1998). Mental and manual rotation. *Journal of Experimental Psychology; Human Perception & Performance*, 24, 397-412

Wohlschlager,A. (2001). Mental object rotation and the planning of hand movements. *Perception & Psychophysics*, 63 (4), 709-718