

**'How Do Healthy Individuals Adapt To Reversed
Vision Generated When Using Mirror Specs? An
Investigation into Mirror Devices, Adaptation to Body
Schema and Imagery Ability in Healthy Participants'**

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Abstract

Introduction: This study investigates a new form of Mirror Therapy (MT), the Mirror Specs. Evidence suggests that MT is a non-invasive, cost effective method of reducing pain and increasing functioning in some chronic pain conditions. There is no clear explanation for the underlying mechanisms of MT, however, a plausible hypothesis suggests that adaptation to the Body Schema is an integral component.

Aims and Hypotheses: The current study examined Body Schema adaptation in healthy participants when performing a Finger Tapping Task with both Mirror Specs and a Mirror Box. It was hypothesised that adaptation would be indicated by increases in Reaction Times (RTs) and Error Rates when comparing unimanual phases of a Finger Tapping Task, following a bimanual 'adaptation' phase. It was hypothesised that there would be no difference between participants' ability to adapt to each device. Finally, the study proposed that there would be a relationship between the adaptation observed on the Finger Tapping Task and participants individual imagery abilities.

Method: Participants performed 4 phases of a Finger Tapping Task with alternate bimanual and unimanual phases when using both the Mirror Specs and Mirror Box. Imagery abilities were measured using self-report questionnaires and a Motor Imagery computer task.

Results and Discussion: Repeated Measures ANOVAs revealed reductions in RTs and Error Rates in Phase 3 compared to Phase 1 on the Finger Tapping Task. There were no differences between RTs and Error Rates when using the Mirror Specs and Mirror Box. These findings suggest that healthy participants were able to use each Mirror Device effectively and this provide impetus for the proposal that Mirror Specs could provide a practical, cost effective addition to rehabilitation services. Finally, there were no clinically significant relationships between use of the Mirror Devices and imagery abilities, thereby indicating imagery abilities did not influence how participants adapted to using the Mirror Devices.

Chapter 1: INTRODUCTION

This study investigates a new form of Mirror Therapy, the Mirror Spectacles (hereafter they are referred to as the Mirror Specs). Mirror Therapy (MT) is becoming a growing area of interest to researchers and clinicians working in pain and neurorehabilitation. It has frequently been employed in relation to treatment interventions for physical conditions such as Phantom Limb Pain (PLP)/Phenomenon, Chronic Regional Pain Syndrome and stroke.

This chapter will begin by briefly outlining the key interventions that are the focus of this study and the intended contribution of the current investigation. Following this, a number of conditions that MT has been applied to, will be described, highlighting common symptoms and implications for physical and psychological functioning as well as healthcare systems.

An introductory discussion of some of the central hypotheses surrounding the underlying mechanisms of the key conditions, including sensorimotor incongruence and cortical reorganisation, will then follow. Current available treatments, including psychological interventions, will subsequently be considered, along with variation in outcomes.

Following on from this, there will be a description of interventions that aim to address sensorimotor incongruence and cortical change. Therefore, Mirror Therapy and Motor Imagery Interventions, and indeed Graded Motor Imagery Interventions, will be explored in more detail, with an examination of the variety of studies that have investigated their utility in rehabilitation settings. The weaknesses of the research, as well as the nature of current implementation of MT in a therapeutic setting, will also be highlighted.

In the next section, the available evidence surrounding hypothesised mechanisms of MT and Imagery will be discussed, leading to a theoretical basis for investigating the utility of Mirror Specs.

The notion of Body Schema will then be examined, along with evidence suggesting its potential link with plasticity in the brain and how this may be used to explain MT. Evidence from prism studies using healthy participants and patients will be considered in terms of understanding the changes that can occur in relation to Body Schema and in identifying some of the potential underlying mechanisms that could apply to Mirror Specs.

Finally, the last section will draw upon the aforementioned evidence in order to describe the aims, hypotheses and methods of the current study.

1.1.1 Glossary of Terms

Throughout this chapter, a variety of terms are employed in order to explain factors linked to MT. The main terms are therefore defined in a glossary contained in Appendix 1, in order to aid understanding of the theories presented.

1.2 Central Themes and contribution of this study

1.2.1 Mirror Therapy (MT)

Mirror Therapy is a therapeutic technique that relies on a visual image of a moving limb provided through a mirror. It involves placing a limb (for example, a right arm) in front of a mirror and observing the subsequent mirror image of that limb moving as if it were the opposite limb (the left arm). This creates an ‘illusion’ of two limbs being present and moving at once. Traditionally, this has involved using a Mirror Box (as illustrated in Appendix 2), which is commonly a wooden box with a mirror in the middle, whereby each limb can be placed either side of the mirror. As this

chapter will describe, a range of empirical findings indicate some utility of MT in a clinical setting.

1.2.2 Imagery

The research on MT has generated a range of hypotheses about treatment approaches and the mechanisms of MT. Stevens and Stoykov (2003), for example, indicated that the crucial mechanism of MT involves Motor Imagery and providing visual feedback of movement in a paralysed limb. The term ‘mental imagery’ is often used in the literature on Mirror Therapy to refer to Motor Imagery (as opposed to Visual Imagery). Motor Imagery is defined as ‘a covert cognitive process of imagining a movement of your own body (-part) without actually moving that body part’ (de Vries & Mulder, 2007, p.6).

Motor Imagery is known to facilitate sport performance. It is thought that a similar process underlies simulating an action and executing an action (Decety, 1996) and that simulating a movement is thought to activate the same parts of the brain although the action is not actually performed (Hanakawa *et al.*, 2003). Motor Imagery, as the following chapter outlines, has generated a notable amount of interest in the literature on MT. Hence, many MT studies now include a combination of mirror and imagery techniques.

1.2.3 Contribution of the Current Study

Although there is evidence supporting the use of Imagery techniques and Mirror Therapy using Mirror Boxes, these are large and not easy to move around, therefore limiting how frequently individuals can perform MT. As a result of the interest and findings indicating efficacy of MT with the Mirror Box, a new form of MT, the Mirror Specs (as illustrated in Appendix 3), have been developed locally with the intention of investigating the value of implementing them for specific therapeutic use in patient groups.

The present study was developed to assess and compare the impact of Mirror Specs and the Mirror Box in healthy individuals and to inform future research with the Mirror Specs. It is hoped this information can be used to inform future studies such as two patient-focused studies in stroke and pain in development, to investigate the efficacy of the Mirror Specs, which aim to enhance the process of implementation with, hopefully, the same outcome.

1.2.4 Development of the Current Study

The Mirror Specs were invented by Dr Jonathan Bannister, Consultant Anaesthetist, Chronic Pain Clinic, Ninewells Hospital. Following the development of an interest in Mirror Therapy with Mirror Boxes, the experimenter was introduced to the Mirror Specs via the inventor, a colleague in the Chronic Pain Clinic. The Mirror Specs were made by SHIL, a Scottish government funded health innovation organisation and were bought by Dr Bannister and made available to the researcher for use in the current study. This study was not funded by SHIL and there is no obligation to report any findings to them. Finances to offer participants £5 were made available from a University of Dundee Endowment Fund, via Dr Bannister.

The researcher acknowledges the working relationship with the inventor and that access to finance and the device was made available via him. However, the study was developed independently from and was not supervised by the inventor thus avoiding any conflict of interest. Care was taken to develop an impartial method of comparing each device and present the results fairly. The information generated by the study may be used to inform further research with the Mirror Specs.

Before proceeding further, it is useful to provide background information on the conditions MT and imagery are commonly used to treat.

1.3 Background Information

This section will describe the conditions and patient groups with which Mirror Therapy is employed, with a focus on Pain of Predominantly Neuropathic Origin (POPNO). Neuropathic pain is pain that is associated with damage to the nervous system (Bogduk & Merskey, 1994), such as Phantom Limb Pain and Chronic Regional Pain Syndrome. The section will also review common associated limitations, including physical and emotional consequences.

1.3.1 Phantom Limb Pain (PLP): Definition and Phenomenology

The 'Phantom Limb' has been a recognised phenomenon for many years, the phrase having been initially coined by S.W. Mitchell (1872, cited in Flor, 2002) after observing amputees experience a sensation of their amputated limb continuing to be present. In some cases, this was also accompanied by a 'cramping sensation' and pain. A Phantom Limb is observed in around 90-98% of amputees immediately following amputation (Ramachandran & Hirstein, 1998). Pain associated with the Phantom Limb is estimated to occur in 72 per cent of cases immediately after amputation and in 67 per cent 6 months after amputation (Jenson *et al.*, 1983).

There are also reports that Phantom Limb Pain can be longstanding and can persist after 25 years (Sherman *et al.*, 1984). Phantoms do not only occur in cases involving removal of the arm. Some studies, for example, have estimated PLP to occur in 51% of upper limb amputees while the prevalence of lower limb phantom pain has been estimated at 54% (Shukla *et al.*, 1982). Removal of other body parts has also reportedly produced painful phantoms, for example, phantom tongues following surgery (Hanowell & Kennedy, 1979).

1.3.2 Functional Limitations due to PLP

An important issue for psychologists is that there is some indication that phantom pain can affect daily functioning, including sleep and work (Sherman *et al.*, 1997) and it can influence the quality of life of amputees. Van der Schans *et al.*, (2002), for example, found that 80% of amputees experienced phantom pain following removal of a lower limb and had ‘considerably poorer health-related quality of life’ (van der Schans *et al.*, 2002, p432), than those without phantom pain. Post-amputation anxiety and depression are common, although there is evidence that these symptoms can reduce quickly and may be facilitated by improved independence and mobility (Singh, Hunter, & Philip, 2007).

Other studies have also investigated PLP and psychological factors such as catastrophising, with results indicating an association between focus on the worst possible outcomes and levels of disability in amputees (Whyte & Carroll, 2004). Generally, it is thought that emotion plays a role in pain, both as a consequence and as a cause (Craig, 1994).

1.3.3 Chronic Regional Pain Syndrome (CRPS)

In addition to PLP, MT has been employed as a treatment strategy for Chronic Regional Pain Syndrome (CRPS). It has been hypothesised that potentially similar underlying mechanisms exist for CRPS and PLP (McCabe *et al.*, 2003; Harris, 1999).

CRPS is characterised by clinical features including pain, hyperalgesia (augmented pain response to an unpleasant stimulus) and allodynia (increased pain response to a non harmful stimulus) and usually occurs following a painful event, either traumatic or non-traumatic (Rho, Brewer, J, & Wilson, 2002). Pain is often described as ‘burning’, ‘throbbing’ and ‘shooting’ (Rho, Brewer, J, & Wilson, 2002, p175) and the condition is associated with disability and disuse of the affected limb (e.g. Schurmann *et al.*, 1999, as cited in Tichelaar *et al.*, 2007).

1.3.4 Stroke

MT is also employed following stroke as a method of addressing associated symptoms. Post-stroke pain, including neuropathic pain, is a known symptom (Klit, Finnerup, & Jensen, 2009). Motor impairments are also common following stroke and are indicated in around 80% of cases (Barker & Mulhooly, 1997), with around 50-60% experiencing chronic motor problems (Hendricks *et al.*, 2002). Paralysis of a limb(s) and motor impairment can cause significant disability (de Vries & Mulder, 2007) and, as a consequence, rehabilitation therapies often focus on helping individuals to regain some functionality and movement.

1.3.5 Summary

This section has briefly outlined the conditions that are central to the application of MT. The next section will go on to briefly describe the leading hypothesised mechanisms of PLP before proceeding to a discussion of current available interventions, including medical and psychological treatments. The contribution of MT to the treatment of the aforementioned conditions will follow.

1.4 Hypothesised Mechanisms underlying PLP

The intention of this brief section is to give a flavour of the principal hypothesised mechanisms of PLP that are also central to MT and to this study. It is important to note that, as yet, there is no clear, definitive explanation for PLP. The following, however, are widely recognised theories.

1.4.1 Sensorimotor Incongruence

A central theory regarding underlying PLP and MT mechanisms involves sensorimotor incongruence. Movement involves the integration of sensory and motor

information in what is known as a 'sensorimotor loop'. This loop is where sensory information is transformed into motor commands and motor commands are transformed into sensory consequences (Sumitani *et al.*, 2008). A variety of sources of information contribute to the integration of the sensorimotor loop including somatosensory information, such as touch and pain.

A proposed theory is that, following amputation of a limb, the sensorimotor loop is interrupted due to a lack of expected, or matching, visual and proprioceptive feedback, and the loop subsequently becomes incongruent. This incongruence, it is proposed, leads to the perception of a phantom and unpleasant symptoms associated with it (Ramachandran & Altschuler, 2009).

In amputation, the literature proposes that the pre-existing neural pathways remain active, therefore, the brain continues to respond as if the limb is still there (McCabe *et al.*, 2005). Hence, it is thought that phantom limb pain arises because the body does not produce the anticipated sensory feedback (from a moving limb) and this leads to a resultant incongruent sensorimotor loop (Harris, 1999). Pain associated with damage to the somatosensory pathways and consequent loss of sensory input from a body part is often known as 'deafferentation pain' (Sumitani *et al.*, 2008), therefore PLP can be considered to fall under this category.

Moreover, the literature suggests that other chronic pain states, such as CRPS, are the result of an incongruent sensorimotor loop (McCabe *et al.*, 2003; Harris, 1999). Hence, this chapter will go on to describe the potentially important role of this incongruence with regards to MT treatment of such conditions.

Furthermore, sensorimotor incongruence is central to the notion of Body Schema, an internal representation of the body within the environment. A more detailed discussion of this will take place later in the chapter when considering underlying mechanisms of MT.

1.4.2 Plasticity in the Brain

The sensorimotor incongruence has an hypothesised link to changes in the activity of specific areas of the brain, and indeed, several chronic pain conditions have become associated with reorganization of the primary somatosensory cortex, for example, in phantom limb pain (Flor *et al.*, 1995; Flor *et al.*, 1998; Ramachandran *et al.*, 1993). These changes or reorganisations of cortical structures have been the centre of a compelling theory of pain and MT - plasticity in the brain.

Plasticity involves the ability of the brain to modify or adapt and involves the reorganisation of neural connections (Kolb & Wishaw, 2009). Previously, plasticity was considered less possible in mature, adult brains compared to that in children (Kennard, 1938, 1940). Yet, more recent evidence, including that regarding Phantom Limbs, suggests that this is not the case. Outcomes from studies using animals (e.g. Pons *et al.*, 1991; Jones & Pons, 1998) and human participants suggest that cortical reorganisation can occur because of injury and training/stimulation (e.g. Jenkins *et al.*, 1990, as cited in Flor, 2003).

Whilst cortical change is not directly measured in this present study, it is useful to have an understanding of the functioning and associated changes of key areas of the brain that are linked to MT. This is intended to provide a context to MT and the visuomotor changes the current study intends to investigate. It is worthwhile, then, to briefly describe the most important regions and their functions briefly, as we consider hypotheses surrounding their association with MT and their potential relationship to Mirror Specs.

1.4.2.1 Critical Cortical Structures

1.4.2.1.1 The parietal lobes

Research indicates the parietal lobes are of importance when considering the neural changes that occur in pain conditions such as amputation. This region of the brain has an important functional role in integrating sensory information to generate a consistent picture of the surrounding world and in visuospatial processing. It integrates information about what and where an object is from the ventral and dorsal pathways to facilitate coordination of movements in response to objects in the environment (Kolb & Wishaw, 2009).

1.4.2.1.2 Somatosensory Cortex

The somatosensory cortex forms part of the parietal lobe. The somatosensory cortex is involved in the process of receiving and integrating sensory information, such as information about touch, pain and temperature, and representing body parts (Holmes & Spence, 2006). Thus, it provides the neuroanatomical basis for the somatosensory loop. Furthermore, changes in the organisation of somatosensory cortex, as is described next, have increased the understanding of chronic pain conditions including PLP.

1.4.2.2 Cortical change

1.4.2.2.1 Somatosensory Maps – reorganisation

The integration of sensory information in the somatosensory cortex provides the basis for a homunculus, a cortical representation of body parts (Holmes & Spence, 2006). Different body parts are therefore ‘mapped’ onto or represented in, cortical structures in the brain in what is known as a ‘sensory homunculus’ (Holmes & Spence, 2006). This allows sensory information, such as touch and pain, to be experienced in the correct locations. That is, if the arm is touched, the associated part of the homunculus processes this stimulus so that the individual who is touched feels this sensation in the arm, not in another part of the body (Kolb & Wishaw, 2009).

The following evidence suggests that ‘intact’ representation zones or maps can activate or become involved in representation zones for body parts, for example,

amputated limbs that have lost their sensory feedback/input, known as 'deafferented' body parts. When a hand or arm is amputated, the representation of the missing limb is 'invaded' by a neighbouring area, such as the representation zone for the face (Ramachandran *et al.*, 1992). In addition, fMRI studies have indicated that, within the primary sensorimotor cortex, the map for the mouth on the 'amputated' side of the brain can invade the region representing the hand that is missing (Flor *et al.*, 1995; Birbaumer *et al.*, 1997). This remapping, it is proposed, involves 'sprouting' of new neural connections or exposing connections that were previously inactive (Churchill & Garraghty, 2006).

Support for this plasticity theory is linked to studies connecting cortical reorganisation or remapping to chronic conditions, such as pain. The degree of cortical reorganisation following amputation is associated, for instance, with the level of pain resulting from the phantom limb (Flor *et al.*, 1995). The greater the extent of remapping, the greater the level of pain is observed. To return to the notion of plasticity, this reorganisation is proposed to arise from a functional system within the brain for responding or adapting to damage. However, studies suggest that PLP represents a 'maladaptive' form of plasticity (Flor, 2008)

To extend the Flor *et al.*, (1995) study, Birbaumer *et al.*, (1997) investigated the possibility of a functional relationship between such neural reorganisation and PLP and made an important suggestion regarding treatment approaches. The study assessed the effects of anaesthesia on cortical remapping in the somatosensory cortex and PLP in 6 amputees with PLP and 4 without PLP. Following anaesthesia, 3 participants, who initially experienced PLP and had evidence of cortical reorganisation, had almost no PLP and cortical reorganisation was eliminated.

No cortical change occurred either for participants who had no pre-existing PLP or for those who experienced no beneficial effect of anaesthesia upon pain levels. This suggested a 'functional relationship' between cortical change and pain but did not define whether relief of pain caused cortical reorganisation or vice versa (Birbaumer

et al., 1997). It is therefore important to note that there is evidence only to suggest a link between the two factors and not a causal relationship.

This study did however make an important hypothesis. Given such a functional relationship between PLP and reorganisation in the somatosensory cortex, the study recommended that interventions, including behavioural modifications that aim to modify cortical reorganisation following amputation might have beneficial effects on PLP (Birbaumer *et al.*, 1997).

Furthermore, a studies have demonstrated a shift in organisation in the Primary Motor Cortex (M1) following amputation (e.g. Karl *et al.*, 2001). The M1 also has a theoretical ‘map’ for different body parts, known as the ‘motor homunculus’ (Kolb & Wishaw, 2009). This region of the brain is located in the posterior part of the frontal lobes and, in conjunction with the Premotor Cortex, is involved in planning and executing movements (Kolb & Wishaw, 2009).

Further discussion of this remapping takes place later in the chapter with reference to the underpinnings of MT.

1.4.3 Pain Memories

A further theory that has gained recognition in relation to understanding the mechanisms of phantom limbs and MT is that of somatosensory pain memories (as described in Flor, 2008). This notion was originally postulated by Melzack & Katz (1990) following reports that those who suffered phantom limb pain, experienced a similar type of pain and in similar locations to that experienced prior to amputation.

The theory suggests that pain memories are generated following sustained unpleasant input, such as pain, which results in changes, for example, in processing in the somatosensory cortex (Diesch & Flor, 2007), an area of the brain involved in pain processing, as previously described. Such ‘memories’ are purportedly *implicit* and

therefore do not involve conscious processing of pain. As such, the individual is not consciously aware of them (Flor, 2003).

It is hypothesised that, following the establishment of pain memories and associated altered processing of pain signals, subsequent amputation and reorganisation of cortical mapping (as described previously) may lead to the activation of neurons that are involved in coding for pain. Such activation, as noted in Flor (2002), may be interpreted as phantom sensation and phantom limb pain.

Evidence to support the notion of pain memories emanates from studies indicating that the presence of chronic pain prior to amputation is a greater predictor of phantom limb pain than is acute pain experienced at the time of amputation (Huse *et al.*, in press). It links to, and further extends, the theory of cortical plasticity by presenting a mechanism or explanation for why cortical reorganisation following amputation might result in pain.

However, it has also been noted by Flor (2008) that not all individuals who experience phantom limb pain report a previous experience of chronic pain. This suggests that there may be other mechanisms at play.

1.4.4 Neuromatrix Theory

The Neuromatrix Theory offers a similar theoretical perspective to the Body Schema Hypothesis, as described later, and can be seen as an extension of these theories. The Neuromatrix Theory postulates that pain results from an extensive neural network, referred to as the ‘body-self neuromatrix’ (Melzack, 2001). This neuromatrix is genetically determined but can be altered during lifetime according to experience including traumatic injury.

These experiences create ‘neurosignature’ patterns of nerve impulses (Melzack, 2001), which establish how body parts are perceived consciously (Bittar, Otero,

Carter, & Aziz, 2004). It is also thought that such neurosignature patterns are involved in producing movement and are converted into the experience of movement (Melzack, 2005). Therefore, an ‘action neuromatrix’ generates patterns of movement that aid goal-directed action (Melzack, 2005).

It is proposed that pain following amputation occurs because the neuromatrix continues to produce an altered neurosignature pattern, and without modulating input from limbs, is experienced as a burning sensation. Similarly, cramping sensations are hypothesised to arise from ongoing neural messages to move muscles in order to produce movement, which become stronger in an attempt to move the limb. Finally, shooting pains are purportedly experienced due to ongoing activity in the neuromatrix attempting to move body parts (Melzack, 2005). It is therefore the persistence of a neurosignature, despite removal of a limb, that is purportedly responsible for phantom limb pain and sensation.

Such a theory adds to the concept that phantom limb sensation and phantom limb pain result from the continuation of signals in the brain aiming to induce movement and the absence of motor feedback to produce the anticipated feedback. Such maladaptive functioning and sensory mismatch and consequent conscious sensory experiences can therefore be viewed as a critical aid to our understanding of why phantom limbs and phantom pain are experienced.

1.4.5 Velmans’ Theory of Projected Consciousness (Velmans, 2009)

The theory of projected consciousness adds to the concept of pain memories, a neuromatrix and the notion of an important role of cortical processes in phantom limb phenomena by considering the nature of consequent conscious experiences of phantoms following altered cortical activity.

It is proposed that the individual is an embodiment of consciousness and the processes that underlie it. The conscious individual therefore represents the

underlying processes (Velmans, 2009). The theory suggests that the contents of consciousness, such as thoughts and feelings, are not exclusively located in the brain but in the world as it is perceived (Velmans, 2009).

Velmans introduces the concept of ‘perceptual projection’, which suggests that the neural representations of experience are ‘perceptually projected’ onto the physical world, which results in conscious experience (Velmans, 2009). The theory emphasises that our conscious experiences are not therefore identifiable as the neural representations in the brain. The body, as represented in the brain, is different to the body that is perceived. The somatotopic map of the body in the brain, for example, is different to the physical map of the body in space/reality. In the brain, the map for the face is located next to the ‘hand map’ rather than the face map next to head map or eye map as is the case in reality (Velmans, 2009).

The theory proposes that neural substrates inside the brain support conscious experiences outside of the brain. As such, perceptual processing *inside* the brain can result in subjective experience *outside* of the brain (Velmans, 1998). Therefore, the tactile system, for example, projects our experiences of touch, pain etc onto where our body parts are positioned and as such the phenomenal world is located outside of the brain (Velmans, 2009).

This theory proposes to enhance our understanding of phantom limbs by suggesting that people who experience phantom limbs and associated pain do so because the brain produces signals (in part based on memory), for example regarding movement and touch, that are *projected out* onto the body where the limb previously existed. Such projection results in the conscious experience of phantom limbs (Velmans, 2009) and might therefore account for the perception of a limb that is not physically present.

This theory expands on the notion of pain memories and supports the notion of an important link between continued activity inside the brain and subsequent sensory

experiences outside of the brain. It therefore provides a proposed explanation for the resultant conscious experiences following altered processing in the brain.

1.4.6 Summary

This section has briefly outlined some of the central theories of PLP and some of these will be revisited when considering underlying mechanisms of MT. The next section will outline available treatments for POPNOs, such as PLP, highlighting the limitations of many widely used treatments at present. This leads to a review of newer therapies, such as Mirror Therapy and Graded Motor Imagery, whose hypothesised mechanisms target sensorimotor incongruence and cortical remapping.

1.5 Treatment of Chronic Pain Conditions

Research indicates that POPNOs, such as PLP, can result in disability and they are linked to increased risk of emotional problems, as described earlier. This suggests a role for a variety of professionals working in health settings, including psychologists, addressing the relationship between emotional factors and pain, managing limitations to quality of life and daily living and implementing rehabilitation programs such as MT.

A range of treatments from across a variety of modalities have been employed to tackle POPNOs, including surgical procedures, drug treatments, physiotherapy (McCabe *et al.*, 2003) and psychological interventions. Yet, as will be outlined here, the research has indicated that such interventions have had limited therapeutic effect on pain symptoms. A possible reason for this is that many treatments have not taken into consideration the sensorimotor theory and cortical remapping hypothesis of PLP.

For the purposes of this study, given the focus on Mirror Therapy, psychological interventions are not discussed in detail. However, it is important to be aware that

psychologists working in health-related settings, such as chronic pain, can play a role in treating/managing the variety of presenting/associated symptoms. Indeed, as will be indicated, treatment for the above conditions often involves a multi-disciplinary approach that includes psychological interventions. Given their scientist-practitioner skills, psychologists also have a potential role in evaluating multi-disciplinary interventions including those carried out by other disciplines.

1.5.1 Current Treatments

1.5.1.1 Pharmacological Treatments

Pharmacological treatments, including antidepressant medication and muscle relaxants, are often employed to treat pain, such as PLP, yet the literature suggests they have limited success (Finnerup, *et al.*, 2007, cited in Flor, 2008). Unfortunately, few Randomised Controlled Trials, to assess the efficacy of these drugs thoroughly, have been employed. Of the studies that exist, results have been mixed. Bone, Critchley, & Buggy, (2002) and Smith *et al.*, (2005) found evidence for the efficacy of Gabapentin in the treatment of PLP, however, drugs such as Amitriptyline have been less successful (Robinson *et al.*, 2004). Generally, the literature suggests that drug treatments result in only a 30% reduction in PLP, which is not unlike effects observed by placebo (as observed in Flor, 2008). It is noted, however, that many of these treatments do not address potential underlying causes of PLP.

1.5.1.2 Psychological Interventions in Chronic Health Settings

As previously outlined, evidence suggests that psychological/psychosocial factors play a role in several chronic pain conditions (Pincus *et al.*, 2002). For example, pain can be modulated by factors such as attention and anxiety (Craig, 1994).

Psychological Interventions are therefore employed to address such factors.

Interventions in chronic pain conditions have shifted from a focus on reducing pain to improving quality of life, limiting the impact of pain upon daily well being and

functioning, and thus reducing disability (Leeuw, 2008). Common approaches used in chronic pain settings are derived from a Cognitive Behavioural Model of Pain / Biopsychosocial Approach (Flor, 2008). These models suggest that pain is modulated by a variety of factors including emotion, thinking style/attention, and behavioural management.

Interventions, therefore, address a variety of these elements. For example, behavioural interventions address 'pain behaviours' such as unhelpful postural changes or positions, and inactivity, which can exacerbate pain (Morley, 2007) through, for example, goal setting (based on realistic, achievable expectations of self) and graded activities. Therapy can also include relaxation (progressive muscular relaxation, diaphragmatic breathing and imagery/distraction) to reduce levels of arousal, including emotional states, that can be associated with and, in the case of muscle tension, exacerbate (Leeuw, 2008) pain.

In conjunction with a behavioural approach, cognitive strategies aim to address unhelpful beliefs about pain and/or associated disability. This can include education about common misunderstandings, for example, the fear-avoidance cycle (Vlayen & Linton, 2000) where patients interpret pain as threatening or dangerous and are fearful of movement, viewing it as harmful and predictive of further injury. This can lead to safety behaviours such as avoidance of activities, which can in turn have a negative impact on pain, disability and mood problems. Cognitive Restructuring, aimed at tackling beliefs and perceptions that exacerbate the experience of pain, includes identification and challenging of common thinking errors and catastrophising (Whyte & Carroll, 2004).

Therapy also aims to strengthen the individual's sense of self-efficacy and control over their pain, and reduce feelings of helplessness (Ogden, 2007). Furthermore, excessive focus on pain and disability is a recognised factor that can intensify an individual's experience of pain. Attention management aims to encourage individuals to either switch their attention away from pain and onto other sources of

stimulation or to focus on their pain but to reframe it into a less threatening experience (Morley *et al.*, 2004).

Finally, the biopsychosocial model emphasises the role of social and cultural factors in chronic pain and it is known that social support can both be helpful and obstructive (Craig, 1994). Consequently, management interventions can also address relationships with family members, for example, by discouraging over-attentive styles of support that can create over-dependency on others (Morley, 2007).

Therefore, as highlight here, psychological interventions are commonly based on theoretical models incorporating cognitive and behaviour modulating factors. The evidence of their efficacy is mixed, with some studies indicting the benefit of such interventions in pain (as reviewed in Flor, 1998). However, there is also evidence that the effectiveness of the multi-disciplinary interventions when applied to PLP is limited (Darnall, 2009).

Previous research indicates that many patients who receive treatment for post-amputation pain are dissatisfied with treatment (Hanley *et al.*, 2009) (although the specific reasons for this dissatisfaction were not specified in this study) and, as previously stated, many medical treatments are unsuccessful at alleviating pain. Moreover, treatments that are often unsuccessful at relieving PLP do not address the proposed underlying mechanisms of PLP (Flor, 2008). This suggests a need for new, more effective interventions that do address such mechanisms to add to current mutlidisciplinary approaches.

1.5.1.3 Summary

This section has described current available interventions for chronic pain, highlighting their limitations. The next section will go on to describe interventions that aim to address sensorimotor incongruence and cortical change, the proposed underlying mechanisms of PLP. As such, there will be a discussion of Mirror

Therapy and Motor Imagery Interventions (including Graded Motor Imagery), along with the evidence surrounding their efficacy.

1.6 Innovative Treatments

This section will examine the evidence for interventions that aim to address the hypothesised mechanisms of PLP, beginning with Mirror Therapy and leading to Imagery. The key studies on MT have been summarised in Appendix 4. This table is not intended to function as a systematic review, rather to summarise the research and highlight relevant details and limitations of some of this work. Some of these will be highlighted in the following section, while others are referred to later on when considering underlying mechanisms. Following this, the section will consider some wider clinical applications of MT.

1.6.1 Mirror Therapy (MT)

As previously stated, Mirror Therapy is a therapeutic technique that relies on the visual image of a moving limb provided through a mirror. MT offers an alternative to traditional forms of therapy for PLP, stroke etc. It addresses limitations of such traditional therapies that are, for example, labour intensive and can require individual one-to-one interventions over a substantial period of time (e.g. Yavuzer *et al.*, 2008) within the context of limited resources. MT therefore offers a simple method of rehabilitation that can be conducted by the patient themselves, and is of little cost in terms of labour and finance to the healthcare system.

1.6.2 Mirror Therapy Research

Over the past 2 decades, interest in Mirror Therapy has increased significantly and this has resulted in extensive research into its efficacy, underlying mechanisms and a variety of associated factors. Such is the extent of this literature, it is impossible to

include all studies that relate to it. The following studies have been chosen for inclusion in this review due to the quality of the journal they have been published in, the significance of their outcome, methods used and implications for our understanding of MT across a variety of participant samples, settings and employing a range of measures and methods. Historical cases, although lacking in robust methodology, have been included to provide a historical perspective and illustrate the outcomes that are often described in the literature. Larger studies with more robust designs and participant number have also been included to assess more robust findings around the efficacy of the therapy.

1.6.2.1 Mirror Therapy and Chronic Pain Studies

1.6.2.1.1 Initial Case Studies

Professor Ramachandran and colleagues (e.g. Ramachandran, 1993b) first investigated the use of Mirror Therapy in healthcare. They used what they called a ‘virtual reality box’, or Mirror Box, in a series of case studies with patients experiencing conditions including Phantom Limb Pain. In the case of one patient with PLP, who had had an upper limb amputated 9 years previously, bilateral mirror-symmetric movements were performed with his intact hand and stump in the box. The patient described having a clear sensation of his non-existent limb moving when he looked into the mirror, which stopped when the mirror was removed (Ramachandran, 1993b).

Another patient, who had had his left upper limb amputated 7 months previously, experienced a sensation of his amputated fist ‘clenching’ and of his finger nails ‘digging into his palm’. However, when clenching and unclenching his intact limb when using the Mirror Box, the patient described feeling able to ‘unclench’ the fist in his phantom limb (Ramachandran, 1993b).

A clear limitation of these findings is that the ability to generalise the outcomes of these case examples to wider samples is questionable and the outcomes are based on subjective reporting. Furthermore, over a series of 10 initial case studies,

Ramachandran and colleagues found mixed results, with 4 out of 10 experiencing no changes in the phantom symptoms (Ramachandran & Rogers-Ramachandran, 1996), thereby indicating MT might not benefit everyone. However, these case studies have instigated further research into the efficacy of MT over a variety of settings.

1.6.2.1.2 Recent Literature

Further to Ramachandran's work, additional case studies and cases series have identified promising outcomes for MT in early (<8weeks) to intermediate (<1 year) CRPS (McCabe *et al.*, 2003) and have demonstrated reductions in levels of pain and stiffness and increased sense of motor control over the phantom in lower-limb amputation (MacLachlan, McDonald, & Waloch, 2004). Other studies have presented interesting data on the utility of a combination of MT and psychological interventions such as Cognitive Behaviour Therapy (CBT) in three cases (Tichelaar *et al.*, 2007). Outcomes, indicated by visual analogue scales, and assessment of functioning such range of movement, suggested improvement in case 1 (less pain and increased walking unaided), some improvement in case 2 (improvement in pain only) and no improvement in case 3. The conclusions drawn from these outcomes indicated that CBT combined with MT could have a potential role in treatment processes for CRPS (Tichelaar *et al.*, 2007).

Despite the small sample size, this study highlighted a number of factors that should be considered in the implementation of this treatment strategy. These include consideration of the duration of the illness and whether the patient's limb remains part of their Body Schema, as discussed later. It is also difficult to establish the relative benefit of each of the components of the treatments. For example, it is possible that increased range of movement and reduced pain could be linked to cognitive re-appraisal of the causes of pain and behavioural strategies to minimise exacerbation of pain states. Nonetheless, this study would suggest that exploring the efficacy of Mirror Therapy is worthwhile.

In one of the largest, most comprehensive studies on the efficacy of MT, Brodie *et al.* (2007) conducted an RCT with 80 lower limb amputees who were assessed for factors including age at, and years since, amputation as well as levels of phantom limb awareness, sensation and pain. Participants were randomly allocated to a mirror condition, using a Mirror Box, and a control condition, where participants viewed movement of the intact limb only. In each condition, they were required to attempt to perform 10 movements on 10 occasions with both their intact and their phantom limb.

This single session was found to reduce the severity of PLP and phantom limb sensation, however, there was no difference between using the Mirror Box compared to attempting to move the phantom leg along with the intact leg. The mirror condition was found to significantly increase the amount of awareness and movement elicited following viewing of a virtual (mirror image of) limb significantly more so than the control condition. An important contribution of this study was the suggestion by Brodie *et al.* that their findings indicated the potential of MT to alter or reverse maladaptive changes in the cortical networks linked to PLP. Subsequent RCTs have also found favourable results for MT when applied to CRPS following stroke (Cacchio *et al.*, 2009)

A number of factors suggest this study could provide a more substantial form of evidence for MT efficacy than previous case studies, including the larger sample size, initial assessment and randomisation to treatment. It provides an important contribution to the literature by highlighting the importance of taking into consideration different aspects of the phantom limb experience when assessing different MT outcomes. Conversely, a drawback of this study is the absence of a clear protocol of movements during MT and, given that MT lasted for only one session, it is not clear whether these effects were short-term or open to greater improvement over time.

The literature also indicates that there might be a degree of difference in the effects of MT determined by the type of pain the individual experiences. This has been

indicated in a study with 15 lower limb amputees, which found that MT for 15 minutes daily over a four-week period was more effective at reducing shooting, stabbing and sharp PLP, than throbbing or burning pain (Hussey-Anderson, Hughes, & Tsao, 2009).

Further to this research, studies have investigated the range of possible methods of implementing MT. Case study research has demonstrated the efficacy of MT applied in a domestic, as opposed to a hospital, setting in a lower limb amputee (Darnall, 2009). MT sessions over 1 month, with additional relaxation training, resulted in an extinction of phantom pain, along with decline in the impact of pain on daily functioning, such as work and mood. No adverse symptoms were reported during MT and the improvements were maintained at follow-up, 4 months after treatment. In addition, in this case, the patient reported an increased sense of control over pain and felt confident that he could manage his pain more independently.

This case study indicates MT could be beneficial when performed in a domestic setting. Only tentative conclusions can be drawn from a study based on one individual. The case also presents further questions about the nature of the unstructured treatment protocol and the utility of relaxation strategies employed. In addition, the patient noted that diaphragmatic breathing reduced the ‘tingling’ sensation he experienced, however outcomes reported for this study focussed only on the efficacy of MT, thus ignoring any potential benefit of behavioural interventions.

1.6.3 Further Applications of MT

Despite the immature state of the research evidence, there is growing interest in the positive outcomes of MT in the rehabilitation process and, as such, MT is being applied in varying contexts.

The therapeutic effect of mirrors has, for example, been applied to rehabilitation interventions following hand surgery (Rosen & Lundberg, 2005). This study

presented 3 case studies including an individual with rheumatoid arthritis who had surgery involving transfer of tendons. Participants completed a 'structured' programme of MT involving bimanual symmetrical exercises, which resulted in improved mobility and improvements in daily functioning, for example, return to work.

Hanling *et al.*, (2010) recently published the results of a study of 4 cases of MT implemented *prior to* amputation. 4 individuals completed 14 sessions of MT before undergoing an elective amputation. In the post-amputation period (1 month), patient 1 reported no PLP and was able to participate fully in a post-operative programme of physical therapy, patient 2 reported 'rare and mild' episodes of PLP and was able to engage in post-operate physical therapy. Patient 3 reported 'brief and mild' episodes of PLP and was also able to engage in physical therapy while patient 4 reported brief, moderate episodes of PLP however these were reported to be 'tolerable' and did not interfere with his ability to engage in post-operative treatment or quality of life.

This study indicates the potential benefits of pre-operative MT on level PLP and ability to engage in rehabilitation therapy. However, the content of MT sessions was not described in detail and it is difficult to tell whether these 'positive outcomes', in terms of level of pain etc, would have differed in these cases without MT. Furthermore, as this study only involved 4 cases and follow-up was at 1 month, once again further studies with larger samples, clearer protocols and long-term follow-up for MT are needed to give more robust indications as to whether MT could be employed in this way.

1.6.4 Evidence from Stroke Studies

In addition to research using pain patient samples, there is evidence of the utility of Mirror Therapy with stroke patients (Altschuler *et al.*, 1999; Sathian, Greenspan, & Wolf, 2000; Sutbeyaz *et al.*, 2007; Yavuzer *et al.*, 2008). Given that the current study focuses largely on MT and pain-related conditions, this evidence will not be

discussed in detail here and the main studies are included in Appendix 5. It is important to note, however, that this literature has produced some important indications about MT research and implementation.

In Stevens & Stoykov (2003)'s study, outcomes following MT varied according to the length of time since stroke with the greatest and longest benefit occurring for the patient who had experienced his stroke more recently. More importantly, this case study evidence was confirmed in a larger RCT with 36 patients who had experienced a stroke *no more* than 8 weeks previously (Dohle *et al.*, 2008). This provides a strong indication of the utility of early implementation of MT for Stroke rehabilitation and this recommendation is further supported by pain research (McCabe *et al.*, 2003).

1.6.5 Conclusions and summary of limitations of MT research

This section has outlined some of the key studies on MT use with pain, and briefly stroke, patients. Although pain and stroke studies suggest there is evidence for the efficacy of MT, it must be noted that many studies have involved small participant numbers and supporting evidence has largely been derived from anecdotal evidence from case studies. This raises the problem that such studies risk presenting conclusions that are 'excessively optimistic' (Moseley, Gallace, & Spence, 2008) and any conclusions about the efficacy of MT drawn from a small number of participants may not generalise to a wider population. Few large, well designed studies with follow-up analysis have been conducted to thoroughly assess the long-term therapeutic value of MT, which would provide a more robust basis from which conclusions can be drawn (Moseley, Gallace, & Spence, 2008).

Of the pain studies highlighted here, six present case studies/series that limit the extent to which one can conclude the results might be applicable to the wider POPNOs population. Four larger studies overcome this problem however limitations, in terms of the absence of replicable measures and methods (such as standardised treatment protocols), limit the reliability of conclusions drawn from the research.

Thus far, considerable variability has existed in the selection criteria for participation in MT studies and in the treatment protocols and measures used, as highlighted in a recent study investigating contraindications when using a Mirror Box (Casale, Damiani, & Rosati, 2009). Such limitations in methodology make it difficult to compare the outcomes of various studies reporting results on differing methods of assessment and implementation. It is also difficult to assess how, in terms of patient selection, timing, duration and intensity, MT can be applied to generate optimal benefit. This issue is discussed in more detail later in the chapter.

Furthermore, other studies involved a combination of therapies such as physiotherapy (Sutbeyaz *et al.*, 2007; Yavuzer *et al.*, 2008) and psychological therapy (Tichelaar *et al.*, 2007). Whilst it is difficult to extrapolate the relative benefits of each, the evidence at least suggests the utility of MT in combination with other multi-disciplinary interventions, particularly at an early stage (e.g. Dohle *et al.*, 2008).

Therefore, in conclusion, although these studies can be used to indicate MT is a potentially useful therapy, several questions remain unanswered as to, for example, the types of pain and individuals MT might be most beneficial for.

1.6.6 Summary

A variety of empirical findings from case studies and RCTS indicate some utility of MT in therapeutic settings and its application has been demonstrated in wider settings, such as hand surgery. Thus far, a range of methodological weaknesses of the research limit the ability to draw robust conclusions. Yet, this suggests the potential value of further research in the field.

The next section will go on to discuss the literature on Imagery interventions in PLP, beginning with a definition of the term and proceeding to a discussion on its link to MT.

1.7 Imagery

This section will examine the importance of imagery to MT literature and will consider the research suggesting its efficacy with the patient groups previously outlined. As in the previous section, the main studies are summarised Appendix 6.

1.7.1.1 Imagery Research

Several studies have evidenced the impact of using mental imagery in the rehabilitation of conditions including stroke and PLP. For example, MacIver *et al.*, (2008) assessed the impact of 6 weeks of training in Mental Imagery on 13 individuals experiencing PLP following upper-limb amputation. Following training, over half of participants experienced more than a 50% reduction in pain, with a reduction in the number of exacerbations in pain, as measured by the Phantom Limb Pain Questionnaire (Koojman *et al.*, 2000). In addition, Gaglioli *et al.*, (2006) found promising results in a case study using ‘computer assisted’ mental practice with an individual who experienced motor problems in the left upper limb following a stroke.

More robust evidence in favour of imagery was reported by Page *et al.*, (2007) in an RCT with 36 stroke patients. Although details regarding the type and variance in duration of stroke were not reported, the improvement in functioning described in this study provides more convincing support for imagery techniques than previous case studies.

Further research has assessed the differential outcomes for MT and Imagery use, demonstrating outcomes that are more favourable for MT (Chan *et al.*, 2007). A further RCT assessed the differential effects of MT and Imagery Therapy in 22 lower limb amputees (Chan *et al.*, 2007). Participants were assigned to three groups; a mirror group or a ‘covered mirror group’, where participants performed movements with both their amputated and intact limbs in front of a mirror or covered mirror, or a

‘mental-visualisation group’, where participants imagined performing movement with their amputated limb only and with their eyes closed. Following intervention, all patients in the mirror group reported a reduction in pain. In the mental-visualisation group, only two patients reported a reduction in pain, whilst four experienced increases. Finally, in the covered mirror group, one patient reported a decrease in pain and three reported increased pain.

Chan *et al* interpreted this as evidence of the efficacy of MT and it does indeed provide a more credible source of support than other case study reports. Yet, given that the findings were based on a sample of only 18 participants (6 in each group), caution may also be exercised when drawing conclusions about the efficacy of MT based on these results. In addition, few details of the treatment protocol were described, which limits the extent to which it is possible to compare this study to others using imagery and MT and makes replication of the methods difficult.

In a review of Motor Imagery combined with conventional therapy (occupational therapy or physiotherapy) and conventional therapy alone for stroke rehabilitation, Zimmermann-Schlatter *et al.*, (2008) indicated “modest evidence” in support of the efficacy of Motor Imagery alone. As with the Mirror Therapy studies, they also identified methodological weaknesses of many Motor Imagery studies, which included small sample sizes, a lack of standardised imagery training procedures and outcome measures. Many studies were also found to investigate only short-term effects of Motor Imagery. The review concluded that larger and methodologically stronger research was required to fully assess the impact of Motor Imagery (Zimmermann-Schlatter *et al.*, 2008).

Other identified methodological weaknesses in the imagery literature include an absence of clearly reported details regarding clinical presentation (such as the type and location of brain injury following stroke) of many patients included in these studies. In the literature that includes these details, wide variability in the nature of the brain injury has existed. This, consequently, has implications for an individual’s cognitive ability and therefore the ability to form mental images (Sharma, Pomeroy,

& Baron, 2006), which could subsequently impact upon their ability to benefit from imagery interventions. As with MT research, variability in outcome measures (Sharma, Pomeroy, & Baron, 2006) also limits the ability to make comparisons between imagery studies and draw meaningful conclusions.

1.7.2 Combined MT and Imagery

The available studies on MT and Imagery indicate some evidence that both interventions have some utility. As a result, further empirical investigations have combined MT, using the Mirror Box, and Imagery techniques into Mirror Visual Feedback (MVF) protocols (Sumitani *et al.*, 2008) and Graded Motor Imagery Programmes (GMIP) (Moseley, 2006). In Moseley (2006)'s RCT, 51 patients with Phantom Limb Pain (PLP) or Chronic Regional Pain Syndrome Type 1 (CRPS1) received 2 weeks therapy of either a Graded Motor Imagery Intervention or physical therapy (Moseley, 2006).

The GMIP intervention consisted of three phases beginning with a limb laterality phase, where patients were presented with pictures of a limb and were required to identify whether that limb was left or right. An imagined movement phase required participants to imagine adopting a posture displayed in a presented image. Finally, a mirror movement phase required participants to adopt the posture presented to them with both hands whilst using the Mirror Box.

Results showed a decrease in pain levels and increase in functionality following the Motor Imagery Programme for both groups of participants (PLP or CRPS1) and improvements were maintained at a 6 month follow-up (Moseley, 2006).

Furthermore, the control group, which received 'usual' treatment, such as medical intervention and physiotherapy, displayed no improvement in pain or functioning. This study therefore suggests that combining both MT and Imagery can have beneficial outcomes on pain and functioning.

Further studies have indicated differential effects of Mirror Visual Feedback (MVF) on differing types of pain. Research indicates that it may be more beneficial for ‘deep pain’ i.e. pain described as ‘crushing’, than ‘superficial’ pain i.e. ‘shooting’ or ‘burning’ pain (Sumitani *et al.*, 2008). Although this study involved 22 patients with a number of chronic pain conditions, the study lacked a structured, replicable MVF protocol and no distinction was made between effects of MVF on differing pain conditions (as opposed to types of experienced pain).

1.7.3 Conclusions

There is no clear verdict on the relative efficacy of MT and Imagery, partly due to the clear methodological weaknesses in the investigating studies. However, tentative evidence of a combined approach, including both MT and Imagery into Graded Motor Imagery Programmes, exists. Despite questions regarding the mechanisms and benefit of MT, many current studies suggest MT and Imagery have a potential, if not a promising, role in healthcare. MT and GMI continue to be applied across a variety of settings with some evidence that it can be used as an effective rehabilitation tool. The following section outlines a number of theories as to the underpinnings of this efficacy.

1.8 How does MT/MIP work?

The following Section will outline and discuss some of the main hypotheses regarding underlying mechanisms of MT and Imagery, specifically sensorimotor incongruence and cortical plasticity. Thus, this section will highlight the importance/value of these techniques in addressing the underlying mechanisms of pain conditions, such as PLP, as a basis for considering the utility of Mirror Specs.

1.8.1 Underlying Mechanisms of GMIP

The aforementioned outcomes have generated a number of hypotheses as why MT, and indeed imagery, might improve pain and functioning in these patient groups. Such information has contributed to the development of models of our understanding of these pain states. Discussion of potential underlying mechanisms is important because it provides an indication of the circumstances under which MT might be beneficial and it provides a basis for which future and new therapeutic methods, such as the Mirror Specs, can be generated and implemented appropriately.

It should be noted that much of the literature is somewhat speculative and there is a degree of overlap between proposed theories. As yet, no conclusive evidence of specific mechanisms that underlie MT efficacy exists, in part due to the lack of a clear explanation for chronic pain states such as PLP. However, the literature suggests that MT and imagery address the theories of sensorimotor incongruence and cortical remapping, as previously outlined, which might provide an explanation for their utility.

1.8.2 Sensorimotor Incongruence

MT is purportedly effective because it provides appropriate visual feedback, which matches motor feedback, in order to re-establish a congruent sensorimotor loop (Sumitani *et al.*, 2008) and therefore re-wires the associated neural circuitry. It has also been suggested that, in stroke patients, MT creates a visual ‘illusion’ of greater movement in the paralysed limb (Garry, Loftus & Summers, 2005) and that visual input ‘compensates’ for absent proprioceptive feedback. It is proposed that this fundamental mechanism underlies MT efficacy with this patient group (Altschuler *et al.*, 1999; Yavuzer *et al.*, 2008).

With respect to the role of imagery, some studies have suggested that imagining the limb moving might also provide appropriate visual input to compensate for incongruent sensorimotor information (Sumitani *et al.*, 2008). Therefore, Motor

Imagery, like MT, might potentially reduce the incongruent sensorimotor loop by providing congruent visual feedback.

Evidence from studies with healthy participants supports the sensorimotor incongruence theory (McCabe *et al.*, 2005). For example, 41 healthy participants performed bilateral upper and lower-limb movements in front of a mirror, thereby creating incongruent sensorimotor feedback. Consequently, two thirds reported unpleasant symptoms. Such symptoms included pain, numbness and pins and needles along with a change in Body Image and disorientation, all of which discontinued once participants regained normal visual feedback. This suggests that it is possible to *induce* pain through sensorimotor mismatch in healthy individuals over just a 20 second period of movement (McCabe *et al.*, 2005).

This study highlights the importance or dominance of visual information over other sensory modalities such as touch, and therefore demonstrates the role of ‘visual capture’. This concept is of particular interest to MT and the present study because visual capture involves the effect of vision upon the ‘felt’ location of a body part (Holmes & Spence, 2006). This can occur, for example, when one can see a body part, such as an arm, but it feels like it is in a different position (Holmes & Spence, 2006) and therefore when individuals experience sensorimotor incongruence. The result of visual capture is that the ‘felt’ position tends to recalibrate (or adjust) towards the ‘seen’ position, therefore vision becomes the predominant modality (Mon-Williams *et al.*, 1997, cited in Holmes & Spence, 2006).

The extent of visual capture is influenced by which modality attention is allocated to (Kelso *et al.* 1975, cited in Holmes & Spence, 2006), however, some experimental findings highlight the role of vision as a principal factor in congruent sensorimotor integration, moreso than other sensory modalities (Jeannerod, 2003). Visual feedback therefore has a particularly important role in establishing a congruent sensorimotor loop (Sumitani *et al.*, 2008). The role of visual capture is highlighted again in later chapters.

1.8.3 Cortical change

Ramachadran's work, as described earlier, generated a further hypothesis regarding MT efficacy, that MT might facilitate a reversal of cortical plasticity, which may well 'compensate' for the effects of damage following amputation or stroke (Flor *et al.*, 2006).

Birbaumer *et al.*, (1997) indicated that potential interventions that positively affect PLP are those that aim to modify the resultant cortical reorganisation. Indeed, there is evidence that MT plays a role in remapping maladaptive cortical reorganisation following amputation. Flor *et al.*, (2006) for example found that, following MT, maladaptive reorganisation could be reversed at least partially with a corresponding reduction in pain (Flor *et al.*, 2006).

The Primary Motor Cortex (M1) map is also linked to MT and its impact on functional recovery in stroke. For instance, M1 activity in healthy individuals can be stimulated when looking at a mirror image of a moving hand (Garry, Loftus & Summers, 2005). Given the importance of this region in movement, this finding has been used to provide neurophysiological basis for MT efficacy, as previously demonstrated, in stroke rehabilitation settings (Garry, Loftus & Summers, 2005).

The recommendation made by Birbaumer *et al.*, (1997), along with studies such as Flor *et al.*, (2006) that indicate MT has an influence on cortical reorganisation, provide a theoretical rationale for the proposition, made by previous research, that MT could provide a valuable addition to treatment regimes.

In addition to cortical change associated with MT, the literature also suggests that there are similar changes during imagery.

1.8.4 Cortical Change in Imagery

Thus far, the chapter has considered evidence that conditions such as phantom limb pain can be treated using mirrors and that a change in the organisation or remapping of cortical structures occurs. Evidence of the efficacy of imagery with these patient groups has also been considered. Further to this, there is evidence to suggest that there is an overlap between neural pathways for thinking about movement and those for actual movement (Gerardin *et al.*, 2000; Decety *et al.*, 1994, cited in Sirigu & Duhamel, 2001; Parsons *et al.*, 1995). This information has generated the hypothesis that mental imagery (i.e. thinking about moving) is likely to produce similar brain activity and facilitate plasticity in the brain to MT. This strengthens the rationale for the implementing interventions that combine mirror and imagery techniques. The following studies present some of the relevant evidence.

The literature has demonstrated an association between cortical remapping and following imagery interventions. Hanakawa *et al.*, (2003) used fMRI scanning to monitor cortical change in healthy participants during two ‘phases’ of a sequential Finger Tapping Task. Participants completed a movement phase (where they actually executed the tapping movement) and an imagery phase (where they imagined themselves making the movement). fMRI results revealed equal levels of activity in the front parietal region and areas of the cerebellum in both phases. Other regions activated included the Primary Motor Cortex, although the level of activity in this region was greater during the movement phase (Hanakawa *et al.*, 2003). These findings therefore demonstrate overlap between activated neural regions involved in both Motor Imagery and movement (as in MT).

Evidence of cortical activity during imagery has also been demonstrated with patients. Referring to the MacIver *et al.*, (2008) study, which found reductions in pain following imagery training, fMRI scanning was also used to investigate cortical changes or plasticity generated following imagery training. Before training, cortical activation when performing lip purse movements indicated a level of reorganisation of motor (M1) and sensorimotor (S1) cortices from the lip area to the hand area.

Following training, the fMRI scans indicated that reductions in pain scores corresponded to reductions in the reorganisation of areas of the M1 and S1.

1.8.5 Conclusions

In conclusion, it seems possible that MT and MIP work by re-establishing a congruent sensorimotor loop. The evidence examined here suggests that both MT and Imagery produce changes in cortical activity and that there is potentially some overlap between the two methods. Thus, both appear to have some relevance to the recovery process following for example PLP, and this provides an anatomical basis the combination of mirror and imagery techniques.

1.8.6 Summary

This section has outlined some central hypotheses about underlying mechanisms of MT, with a focus of sensorimotor incongruence and cortical reorganisation.

The next section will outline a particularly important theory of the mechanism of MT and one that is central to the current investigation, Body Schema.

1.9 Body Schema

A further potential MT hypothesis links some of the aforementioned themes of MT, imagery and sensorimotor reorganisation. As such, the notion of Body Schema has gained significance within research on reversed vision and Mirror Therapy. The notion of Body Schema provides a possible explanation for the hypothesis regarding sensorimotor incongruence and why the brain continues to be active following amputation.

This section will present the notion of Body Schema and examine evidence, particularly from prism adaptation studies, that this theory provides an explanation

for the positive outcomes in the literature. The section will then lead on to its significance in the current study.

1.9.1 Debate over Definition

The literature presents a variety of definitions of Body Schema. Body Schema was originally defined as ‘an internal representation, or perception, of the body within the surrounding environmental space’ (Head, 1918). This definition has appeared in recent literature (Sekiyama, 2006) along with the notion of an online representation of body posture (Head & Holmes, 1911) and a ‘rich internal model of the body’s structure’ or ‘centrally maintained model of the body’s form’ (Graziano & Botvinick, 2002, p.145).

Firstly, an important point to note is that the term Body Schema can encompass two different concepts, (as described in Appendix 7). It is important to note the Body Image/Body Schema distinction, as the two terms are often used interchangeably in the literature and there is some debate over the definition of each concept (Paillard, 1999). It is important to bear this in mind when considering the following empirical findings. In the current study, the unconscious definition is termed Body Schema and the conscious process is termed Body Image.

1.9.2 MT and Body Schema

The notion of Body Schema adds to the aforementioned theories because it offers an overarching framework drawn from cognitive psychology that links these theories. The Body Schema ‘framework’ outlines an important role in coordinating and integrating incoming information with reference to existing information about the body’s position in relation to the surrounding environment. When new input is presented, visual or motor information is sent to specific sensory and motor areas that are dedicated to processing such information in the cortex. The output of this is processed by other areas of the parietal cortex and this is believed to underlie the processing of a representation of an individual’s ‘coherent Body Image’ (In Dohle *et al.*, 2004).

The Body Schema is, therefore, believed to facilitate performance of goal-directed movements, such as pointing, through linking or matching multi-modal information such as proprioceptive, motor and visual signals (Sekiyama, 2006). Hence, this integration of incoming input is matched against a pre-existing, ‘globally-consistent’ representation of body parts in order to aid movement (Graziano & Botvinick, 2002).

In addition, studies suggest that the Body Schema encompasses two components i) a pre-existing or stored representation and ii) a variable, modifiable component that can be updated in response to current incoming information (Sekiyama, 2006). The former component could account for the hypothesis that, when a limb is removed, the brain continues to be active.

During movement, if one of the expected modalities is missing, such as motor feedback, this creates discordance in the coordination process as the brain continues to activate neural representations/signals for the intention to move a limb, as if the limb is still there. The literature suggests that this is due to continued input to cortical areas that have represented the limb prior to amputation (Ramachandran & Hirstein, 1998). Graziano & Botvinick (2002) suggest that this also involves interpreting the incoming information with reference to a ‘centrally maintained model of the body’s form’ (p.145) (or drawing on the stored schema representation of body parts).

It is therefore the Body Schema, the internal representation of body parts, that draws on the cortical maps (as previously described) and is involved in coordinating incoming information with reference to a consistent picture of the body, that facilitates the creation of anticipated feedback on the position of the body (Graziano & Botvinick, 2002). Given that the usual or expected feedback of actual movement (both visual and motor/proprioceptive) is not present, (because the limb no longer exists), there is no cancellation of the neural programme for movement. Therefore, the actual information being presented does not match the expected feedback according to the pre-existing Body Schema. This consequently leads to the

sensorimotor mismatch. Thus, this disruption to the coordination process and therefore to Body Schema, provides a basis for previously highlighted concepts of sensorimotor mismatch and an explanation for why amputees experience phantoms and pain.

1.9.3 Body Schema Research

A number of lines of research indicate the construct of Body Schema may play a role in pain and MT. For example, evidence suggests that Body Schema is influenced by peripheral factors, such as pain. Schwoebel, Coslett, & Buxbaum, (2001) conducted a study with 13 patients with CRPS to investigate the effects of pain on Body Schema during a hand laterality task. The task asked participants to determine whether hands presented at different orientations were left or right. The literature indicates that this requires the individual to mentally rotate their hand into the observed position (Parsons, 2001, cited in Moseley & Brugger, 2009). This task hypothetically requires the individual to draw on the model of the body's position whilst imagining moving their limb to match position of the limb presented visually and, subsequently, is linked to Body Schema.

The important finding of this study was that Reaction Times for mental rotation involving the painful limb were longer than for the unaffected limb therefore indicating that the coordination process, and therefore Body Schema, is influenced by pain (Schwoebel, Coslett, & Buxbaum, 2001).

In addition, evidence indicates that the modifiable aspect of Body Schema can be updated in response to new sensory input, including proprioceptive and/or motor information (Parsons, 1994) and Visual Imagery (Moseley & Brugger, 2009). This feature is particularly important to MT and the current study because, as the following studies indicate, it provides a rationale for improved functioning due to the alteration of incoming information (e.g. vision) through use of mirrors.

Modification of Body Schema has been investigated in a number of ways including, as will be outlined here, clinical studies and studies using prisms. The benefits of prism use have been demonstrated by studies such as Rossetti *et al.*, (1998), who showed that symptoms of neglect improved after a 2-5 minutes of prism adaptation involving 50 pointing trials (cited in Sekiyama, 2006). Improvements, measured by several tasks including copying drawings and text reading, continued over a 2 hour period.

A common method used in prism adaptation studies involves a paradigm with 3 phases: baseline phase before exposure, ii) the exposure phase and iii) a post exposure/compensatory phase (Redding, Rossetti, & Wallace, 2005, cited in Luaute *et al.*, (2009). Luaute *et al.*, (2009) recently used this method to investigate cortical activation during the typical 3 phases of prism exposure in 14 healthy volunteers. Participants completed a pointing and clicking task both with and without the prisms. Adaptation to prisms was indicated by correction of pointing errors when vision was reversed.

Results revealed during the process of adaptation and correction of errors, several cortical regions were activated during adaptation, including regions of the parietal cortex and the cerebellum, which the authors linked to differing stages of prism adaptation from error detection to successful realignment. These findings correspond to McCabe *et al.*, (2005)'s study of mirror use with healthy participants. Hence, they indicate overlap of critical regions activated when using mirrors and prisms, which points to an anatomical basis for an overlap between the two techniques.

Drawing on evidence from phantom limb studies and prism adaptation investigations, Sekiyama (2006) published a review of the evidence surrounding the plasticity of Body Schema. This review reached the conclusion that, following amputation, Body Schema is preserved but is damaged and becomes less efficient. This change can, however, be modified with visual feedback, which triggers

appropriate/matching kinaesthetic sensation of a limb e.g. through seeing an image of the missing limb moving in a mirror (Sekiyama, 2006).

Further literature indicates that Body Schema can be extended. After a period of use, for example using reversed prisms, evidence suggests that reversed image of a limb becomes 'incorporated' into the schema (as reviewed in Holmes & Spence, 2006). Sekiyama *et al.*, (2000) investigated Body Schema over 5 weeks of wearing reversed spectacles. After 3 weeks, participants' accuracy, when performing a mental rotation task wearing the spectacles, improved. The suggested explanation was that, following adaptation to reversed vision, participants had developed a new representation of the hand that was added to the Body Schema, and therefore incorporated into the sensorimotor coordination process.

This, the authors proposed, potentially involved reversing the visual and proprioceptive information therefore cancelling out the mismatch between visual and proprioceptive feedback, and therefore updating the Body Schema. As a result, when presented with visual information through the reversed spectacles, participants could then generate an appropriate motor response (Sekiyama *et al.*, 2000).

Returning to the concept of Body Image, other studies refer to changes in Body Image following MT. In the Tichelaar *et al.*, (2007) study (discussed earlier in the chapter), the CRPS case that failed to improve following CBT and MT reported feeling as if their affected limb 'did not belong' to them, whilst there was no such report from the other participants who benefitted from therapy. In this study, the description was interpreted as an indication that the limb was no longer part of the individual's Body Schema. Moreover, this perception was not influenced by CBT or MT.

The proposed implication of this study is that patients who experience their affected limb as 'foreign,' and therefore no longer part of their Body Schema, may be less likely to benefit from MT. Furthermore, the authors suggested this reflects

irreparable change in the somatosensory cortex (Tichelaar *et al.*, 2007), a theory that clearly requires further investigation.

Given that participants reported a conscious awareness of feeling as if the limb was not part of their body, this definition of Body Schema appears to relate to the Body Image, as defined in this chapter or sense of body ownership. However, it is interesting to note that the authors also make the link between the conscious perception of a body part and the underlying cortical change (Tichelaar *et al.*, 2007).

This study also makes a valuable contribution to assessment methods for future MT studies by indicating that assessing whether an individual's perception of their limb as belonging to them should be included as a potential method of targeting individuals who are most likely to benefit from MT. Indeed, previous studies, using the Mirror Box in rehabilitation following stroke, have even focussed on encouraging the participant to learn that the limb seen was their own paretic limb (Stoykov & Stoykov, 2004).

1.9.3.1 Alien Limb Syndrome

Such studies can be linked to Alien Limb Syndrome, a syndrome that involves a lack of sense of ownership of limbs and has been associated with disorders of Body Schema.

Alien Limb Syndrome is characterised by the occurrence of meaningful movements of a limb that occur without the conscious intention to move a limb. For example, some individuals report their limb reaching for objects in the surrounding environment and being unable to stop the limb from doing this. Such a lack of sense of agency can often cause frustration with the limb referred to in the third person (Biran & Chatterjee, 2004). Indeed, patients also report varying degrees of having a sense of ownership of the limb (Biran *et al.*, 2006).

Alien Limb Syndrome has been discussed in terms of a conflict between goal-based intentional movement and stimulus driven unintentional movement (Biran *et al.*, 2006). It has been hypothesised that the sense of being in control is dependent on a match between the intention to move a hand and the resultant sensory information, for example, by seeing the movement of the hand in the intended way (Spengler, von Cramon, & Brass, 2009).

This corresponds to the phantom limb experience, as previously discussed, where the presence of congruent visual and proprioceptive feedback appears important in terms of resolving some associated and unpleasant symptoms, guiding movement and of gaining a sense of control over the limb, by providing feedback to match signals for intended movement.

By contrast, in Alien Limb Syndrome the presence of visual feedback that matches motor/proprioceptive information in relation to environment does not give rise to a sense of control over the limb. There is no cancellation of the signals for 'intended' (referring to an unconscious level of processing) movement, despite no conscious intention to move the limb and interact with the surrounding environment.

Furthermore, the presence of congruent feedback or reafference (sensory information resulting from movement) makes no difference to the patient's experience of or sense of ownership of the limb.

In the case of phantom limbs, visual information appears to influence goal-directed movement and a sense of control over the limb. In Alien Limb Syndrome, however, the disproportionate influence of proprioceptive information about the body within the surrounding environment, appears to take precedence over the influence of visual information in controlling the limb.

Whilst this can be discussed in terms of body image and a conscious perception of one's body, it might also be considered in terms of one's Body Schema (De Vignemont, 2007). The presenting problem could be considered as a dysfunction or disruption to Body Schema and the process of integrating numerous sources of

sensory information in relation to environmental stimuli to create goal-directed movement and lead to a coherent body image, resulting in a disproportionate influence of environmental stimuli. Furthermore, neurophysiological evidence also indicates that individuals who experience a limb as 'alien' have damage to areas of the parietal cortex (Daprati *et al.*, 2000), an area associated with the Body Schema.

1.9.4 Conclusions

In conclusion, evidence suggests that repeatedly performing motor movements whilst using prisms results in 'perceptual adaptation' or a modification to the relationship between visual and proprioceptive information. This may lead subsequently to functional adaptation in terms of goal-directed performance, due to altered sensorimotor integration and changes or updates to the Body Schema.

Given previous evidence of modification or disruption to the processing of such information in pain conditions and MT, this leads one to an important hypothesis about the suggested underlying mechanisms by which MT works. MT could be effective by restoring disruption to the normal interaction between the intention to move a limb and a lack of appropriate sensory feedback (e.g. Ramachandran & Hirstein, 1998) through adaptation to the Body Schema by generating a new representation of a missing body part to reduce sensorimotor incongruence.

Furthermore, it is possible that implementing a form of MT, that is similar to the techniques used in reversed vision studies, might be efficacious in populations, such as PLP. The rationale for this suggestion is based on i) evidence that MT using a Mirror Box is beneficial for improvement of pain and functioning in PLP etc (perhaps through altering the Body Schema), and ii) reversed vision is effective at treating conditions such as neglect through adapting Body Schema. Therefore, prism adaptation (through, for example, Mirror Spectacles) might also facilitate adaptation to Body Schema, thereby initiating adaptive plasticity to reduce unpleasant

symptoms of phantom limbs etc. Empirical findings that indicate overlap in associated cortical regions could also bolster this proposition.

1.9.5 Summary

The previous section outlined evidence suggesting modifiability of Body Schema, including prism adaptation, and its link to underlying mechanisms of MT, leading to the suggestion that MT could be implemented through a form of prism spectacles. The following section will outline some important issues regarding implementation of MT as it stands before proceeding to the focus of the present study.

1.10 The Implementation of MT

In considering further applications of MT, it is useful to consider the previous evidence and issues surrounding the application of MT as it stands.

Concerning the numerous hypotheses surrounding MT, it is likely that no one theory provides a complete explanation for the process that underlies its' efficacy. The important mechanism underlying the aforementioned hypotheses regarding MT and conditions such as PLP, is that healthy systems become involved in and can compensate for unhealthy or damaged systems (plasticity) (Rijntjes, 2006). As indicated in Rijntjes (2006), however, the impact of therapies such as MT might be mediated by the nature of the damage inflicted and the stage of recovery of each individual. There are therefore a number of issues that impact upon the application of MT in therapeutic settings and that impact upon conclusions drawn from the available literature.

Brodie *et al.*, (2007) proposed that MT might have differing effects on pain in upper limbs versus lower limbs due to varying degrees of involvement of the motor and sensorimotor cortex and differing neural pathways. This study recommended future

investigations on MT remain aware of the varying elements of phantom limb phenomena and the potential for differing effects of MT.

Previous findings also indicate that MT might also be more or less effective depending on the type of pain condition or type of PLP it targets. For example, MT might be more effective at reducing ‘deep pain’, that is pain associated with pressure i.e. ‘crushing’, and pain associated with sense of movement i.e. ‘clenching’ (Sumitani *et al.*, 2008, p. 1039). Potentially, this is suggestive of differing underlying mechanisms for each type of pain (Sumitani *et al.*, 2008).

The concept of individual differences was raised in the McCabe *et al.*, (2005) study in which pain and other unpleasant symptoms were induced by sensorimotor incongruence using mirrors. Individual variability in the presence of these symptoms was linked to differences in ‘innate susceptibility’ (McCabe *et al.*, 2005, p515) to detecting sensory changes and changes in Body Schema. The suggestion is therefore that MT might be most beneficial if it is tailored to the individual’s presenting problem.

An additional important note is that the time frame for therapy in cases such as CRPS. Given that evidence suggests that mechanisms vary depending on the individual (Flor, 2008), it has also been suggested that there is a ‘critical window’ of opportunity to alter neural networks and facilitate plasticity (Giroux & Sirigu, 2003).

Increased disability and pain are associated with a long standing diagnosis and Tichelaar *et al.* (2007) noted that chronic cases may be less susceptible to any effects of MT, potentially due to more permanent changes in the brain (Tichelaar *et al.*, 2007). It has also been noted that some cortical change following amputation is more enduring in some patients compared with others (e.g. Birbaumer *et al.*, 1997). The advantage of early intervention on recovery has also been noted in studies with stroke patients (Biernaskie, Chernenko, & Corbett, 2004).

1.10.1 Summary

Based on current evidence, it is possible that MT can be implemented most effectively if it is used early in the process of recovery and if it is tailored to each individual and his or her condition etc. Future studies, with comparable protocols and outcome measures etc, as previously highlighted, might shed more light on this suggestion. The next chapter will describe the present study and introduce a new form of MT to which these issues apply.

1.11 The present study

As previously stated, the present study was developed to investigate the a new form of MT, the Mirror Specs, which have been produced locally with the intention of using them with patient groups. The Mirror Specs have been developed to enhance the process of implementation with, hopefully, the same effects as the Mirror Box.

The Mirror Specs are intended to allow patients to practice Mirror Therapy exercises independently with a user-friendly device. Mirror Specs are spectacles that have a prism attached to them. They reverse the observed image so they give the wearer the illusion that they are looking at their left hand when in reality it is their right hand, or vice versa. In this sense, they are similar to the Mirror Box, however, there are several potential benefits to the addition of Mirror Specs to treatment regimes. The Mirror Specs, as with the Mirror Box, offer a method of performing MT independently and facilitate patient-directed approach to rehabilitation. However, the Mirror Specs are small, light and potentially offer a more practical form of MT compared to the Mirror Box, which is often large, heavy and cumbersome. Given their structure, Mirror Specs are transportable and have the potential to be utilized across a variety of locations.

Several previous studies evidencing the beneficial effect of MT have involved repeated sessions, often daily, therefore the Mirror Specs offer a practical method of

implementing therapy on a regular basis and in a patient-directed manner. In addition, they are inexpensive to produce and offer a cost-effective addition to treatment processes for chronic conditions such as PLP that, as previously stated, can be difficult to treat with classic, often expensive, forms of drug therapy.

The notion that MT and prism adaptation might share similar underlying mechanisms has been raised previously (Holmes & Spence, 2006). They linked the experience of phantom limbs to experiences during visual displacement when using prisms and the resultant dissociation of seen and felt body parts (Holmes & Spence, 2006).

The present study therefore aimed to assess the impact of these specially produced Mirror Specs with normal subjects, investigating and comparing the capacity of the Mirror Specs and the Mirror Box to create changes in Body Schema. The outcome of the current investigation will be used to inform further research in addition to other investigations using pain and stroke patients. Given that evidence already exists to suggest the utility of the Mirror Box, this study also aimed to provide a comparison between the extent to which participants adapt to using each Mirror Device. This was intended to provide an indication as to whether the Mirror Specs provide a valuable alternative/additional form of MT that can be added to more traditional forms of rehabilitation.

Following confirmation of the design and commencement of data collection in this study, another research paper that had investigated the differential effects of Mirror Box and Prism adaptation, was published online (Bultitude & Rafal, 2009). This paper was discovered once all data in the present study had been collected and analysed. The published article presented a case study investigating each method used by a patient with CRPS. Prior to the introduction of prisms, Mirror Therapy (with a Mirror Box) and pharmacological medication has been implemented and found to be unsuccessful at providing pain relief. The prisms were introduced for use along with the Mirror Box and pharmacological medication, as required, and the patient was asked to make 50 pointing movements.

Following use of the prisms, reductions in pain and swelling were reported along with an increase in the range of movement. Reductions in pain were attributed to the possibility of an “error signal” that resolved the discrepancy between intention to move and visual and proprioceptive feedback, thus recovering ‘normal’ representations of the body (Bultitude & Rafal, 2009).

These results will be examined again in the Discussion Section. The current study adds to this by investigating spectacles that have been specifically designed for patient use using a robust sample size and a novel, objective task to assess healthy participants’ adaptation to each Mirror Device separately.

1.11.1 Aims and Objectives

The principal research question is;

‘Do Mirror Specs allow the same level of adaptation to reversed vision and modification to visuomotor information as the Mirror Box in healthy participants?’

As this chapter has described thus far, there are a variety of hypotheses relating to chronic pain conditions such as PLP and to the underlying mechanisms for the literature suggesting the efficacy of Mirror Therapy. In order to investigate the research question the present study drew upon some of these, in particular to the concept of Body Schema, and investigated the impact of Mirror Specs on Body Schema in terms of visuomotor abilities.

Previous studies have used fMIR techniques and sensorimotor tasks to investigate changes in Body Schema. This study suggested that modifications to Body Schema, and therefore to sensorimotor transformation, were indicated by alteration in Reaction Times and Error Rates on a specially designed computer task (as in

Sekiyama, 2006). Thus, the study aimed to access changes in Body Schema using an objective measure that directly accessed participants' performance.

Previous studies on prism adaptation and Body Schema have used one task, charting the changes in participants' abilities across the time course of the same movement (Luaute *et al.*, 2009). Some studies have used both bimanual and unimanual movements (e.g. Lewis *et al.*, 2010). In this task, two elements of the task were introduced to allow for a phase that would stimulate a form of mismatch between visual and proprioceptive feedback, as is experienced in PLP, for example. During the unimanual Phase 1, therefore, participants should experience a distinct mismatch between proprioceptive feedback of the moving hand and visual feedback (of a stationary hand) from the illusion in the mirror.

A phase to allow for an adaptation to Body Schema (bimanual phase) was also introduced. The bimanual phase was intended to facilitate adaptation to using the Mirror Device, through a reduction in the mismatch between visual and proprioceptive feedback, resulting from visual information indicating movement in both hands. Over the course of the phase, participants should generate a new representation of this hand into the Body Schema. This hypothesis drew on the work of, for example, Sekiyama (2006), which indicated adaptation to schema over 3 weeks, and the work of Rossetti *et al.*, (1998) demonstrating rapid changes over 50 pointing trials.

The procedure completed was unimanual (Phase 1), bimanual (Phase 2), unimanual (Phase 3). This has been chosen to reflect paradigm used in previous research on prism adaptation (Luaute *et al.*, 2009).

The rationale for a second unimanual phase (Phase 3), following the bimanual phase, was that on this occasion if participants had achieved adaptation to using the Mirror Device, there should be an increase in Reaction Times and decrease in accuracy during the task. This decrement should be due a greater discrepancy between visual and kinaesthetic feedback caused by a 'disruption' to the new representation of the

hand within the Body Schema. Therefore, if participants had incorporated the hand they could see into the Body Schema, this should influence the integration of incoming sensory input, when participants were then only presented with proprioceptive information and incongruent visual feedback of their 'new' hand' remaining still. Thus, this would create a greater amount of disruption to the sensorimotor transformation when completing the unimanual task for the second time.

The final hypothesis assessed individual differences in underlying imagery ability.

The rationale for a link between these two factors related to the literature on imagery and MT, as previously discussed, that indicates beneficial effects of each and that imagery may be a critical component of MT (Stevens & Stoykov, 2003). There is also evidence of overlap between neural networks involved in imagery and execution of movement. Consequently, this study investigated whether underlying imagery abilities would influence participants' ability to adapt to using the Mirror Devices on a visuomotor task and therefore impact on participants' performance on the Finger Tapping task under each of the conditions and phases.

Based on the information in the literature, it was not deemed possible to hypothesise about the nature or direction of the relationship between Visual and Motor Imagery abilities and performance on the Finger Tapping Task using the devices. It was not certain whether stronger imagery abilities would correlate with greater adaptation to the Mirror Devices or whether strong imagery would, in some way, interfere with how participants responded to the visual illusion. Given previous studies involving both Visual and Motor Imagery, a measure of each was included.

1.12 Hypotheses

Hypothesis 1: There will be an increase in Reaction Times and increase in Error Rates in Phase 3 compared with Phase 1 of the Finger Tapping Task, following adaptation to the Mirror Devices.

Hypothesis 2: Participants RTs and Error Rates between Phase 1 and 3 will increase. The level of adaptation will be similar in both the Mirror Box and Mirror Specs.

Hypothesis 3: Imagery abilities (both visual and haptic) will correlate with adaptation levels on the Finger Tapping Task, irrespective of the type of Mirror Device.

Chapter 2: METHODS

2.1 Design

The study design was a Multi Way Within Subjects (Repeated Measures) Design. The independent variables (IV) were a) *Device* (of which there were 2 levels; i) Mirror Specs and ii) Mirror Box) and b) *Phase* (of which there were 2 levels; Finger Tapping Task i) Phase 1 and ii) Phase 3). The dependent variables (DV) were Phase 1 R.T.s and Error Rates, and Phase 3 RTs and Error Rates. (To clarify, the hypotheses addressed the difference between phases 1 and 3, with Phase 2 acting as an adaptation phase. Phase 2 therefore, is not included in the diagram below).

An illustration of this design is presented in the diagram in Figure 1 below.

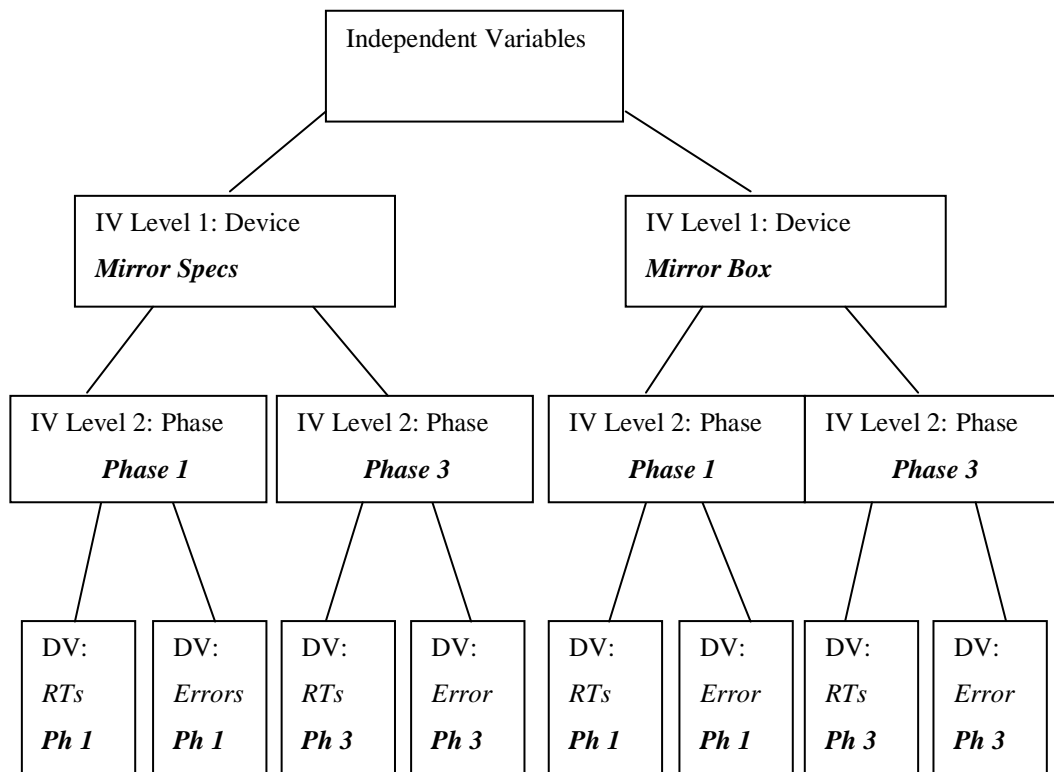


Figure 1: Diagram of Study Design

2.2 Ethical Issues

2.2.1 Approval

Approval for this study was granted by NHS Tayside Committee on Research and Ethics (B) and NHS Tayside Research and Development. The approval letters are contained within Appendix 8. The initial application involved a design that was subsequently altered substantially due to a change of supervisors and additional advice/resources. Three Notices of Substantial Amendments were subsequently made, to allow for the finalised design and materials.

2.2.2 Confidentiality

All data was treated as confidential in accordance with NHS Code of Confidentiality and was stored in accordance with the Data Protection Act (1999). Each participant was assigned a code. All completed materials had a participant code written on them instead of names, thereby anonymising their data. Information linking participants' codes with personal information (for example, participant names) was kept securely by the facilitator in a separate location in a locked cabinet within Ninewells Hospital and will be destroyed upon completion of the research.

2.2.3 Risks/Burdens and Benefits

There were no expected risks or burdens associated with participation in the study either through use of the Mirror Devices or through completion of the questionnaires. Potentially when individuals use a Mirror Device they might experience a strange sensation in the hand they are not moving in response to the movement of the other hand. Despite the potential for participants to be startled by this, however, it was expected this should only last very briefly and should stop once the both hands were stationary. The Chief Investigator was not aware of any other potential unpleasant experiences and was available to reassure participants that any sensation they experiences was not harmful and answer any queries. Participants were also aware they could discontinue at any point if they wished.

With regards to benefits, participants were given a choice of whether to receive a monetary payment of £5 or course credits. Permission was granted by the School of Psychology to place the study on the University SONA system, an online system advertising Psychology experiments that allows students to sign up and receive credits, which are a requirement for each semester of their course.

Depending on their choice of payment, £5 was paid at the end of the experimental session or course credits were granted through the SONA system after the participant had attended the experiment. The majority of participants received course credits.

2.3 Power Analysis

In order to determine the appropriate sample size required to carry out parametric analyses for a Repeated Measures design, an *A-priori* statistical power analysis was performed. A-priori power test using G power 3.1 was conducted for a Within Subjects (Repeated Measures) ANOVA with power set at 0.80 and alpha type 1 error probability of 0.05. This suggested the need for 34 participants in order to detect

medium effect sizes. This figure was rounded to 40 participants, 10 in each running order group (as described below).

2.4 Participants

Although permission was granted to recruit healthy adult volunteers from the University of Dundee College of Medicine, Nursing and Dentistry and School of Psychology, largely due to the SONA system all participants were undergraduate psychology students (ranging from academic year 1-4). A total of 44 students were recruited (22 in each Mirror Device condition and 11 in each running order group). 10 more than the number needed to achieve 80 per cent power to detect medium effect sizes were recruited in order to reduce the likelihood of a Type II error and increase the likelihood of finding a significant effect of the Mirror Devices.

2.5 Identifying Suitable Participants

2.5.1 Inclusion/Exclusion Criteria

Participants were identified according to the following criteria.

Inclusion Criteria;

i) Healthy volunteers from the College of Medicine, Nursing and Dentistry and School of Psychology, University of Dundee.

ii) For individuals who were short/long-sighted or had astigmatism, either prescription glasses or contact lenses were required to be worn.

Exclusion Criteria:

i) Blindness

ii) Difficulty moving hands

iii) Visual problems affecting the central/ peripheral visual field such as diagnosed glaucoma, macular degeneration, diabetic maculopathy, and corneal problems (as discussed during personal communication, S. Keys, Specialist Optometrist, June 2007).

2.6 Recruitment

Participants were recruited by initially placing posters (as in Appendix 9) on the University Noticeboard in Ninewells Hospital, and the School of Psychology, University of Dundee. These posters included the email address of the Chief Investigator to allow potential participants to express their interest.

The Chief Investigator was also given permission to visit a senior honours class to make a brief announcement about the study and provide them with Participant Invitation Letters, Information Sheets and Consent Forms.

Permission was granted by the School of Psychology to place the study on the University SONA system. This is an online system advertising psychology experiments that allows students to sign up and receive course credits for participating in research experiments. Participation in experiments is a requirement for each semester of the course.

Providing the individuals met the inclusion/exclusion criteria, as above, they were either invited to take part in the study and subsequent arrangements made for them to attend the experimental sessions or they could sign up for an available timeslot on the SONA system.

All experimental sessions took place in a testing laboratory in the School of Psychology, University of Dundee.

2.6.1 Informed Consent

All participants were required to have read the Invitation Letter, Information Sheet (describing the aims and procedure of the study) and signed the Consent Form before participating.

2.7 Materials

2.7.1 Participant Invitation Letter, Information Sheet & Consent Form

A Participant Invitation Letter, Information Sheet and Consent Form (See Appendices 10-12) were generated and distributed in accordance with Tayside Ethics Committee Guidelines.

2.7.2 Apparatus:

Pictures of the Devices are attached in Appendices 2 and 3 to clarify the nature of each Device.

2.7.2.1 Mirror Box

The Mirror Box (see Appendix 2) was a large wooden box with a mirror placed in the centre. The mirror was two sided so that an image could be generated on both the left and the right hand side. There was no roof to the box so that participants could see their hands inside the box. On the side facing participants, there were two holes so that participants could place each hand into the box at each side of the mirror.

2.7.2.2 Mirror Specs

The Mirror Specs (see Appendix 3) were plastic glasses with a prism attached. They were reversible, in that they could be turned upside down in order to be used for left and right hands. So, if the prism was placed on the left hand side of the participant's head, they would be able to see an image of their right hand and the opposite was true if the prism was rotated so that it sat on the right hand side. Only the eye that the prism was placed on was visible, the other was covered so that the participants could not see their 'real' hand, only the mirror image of the hand.

For those who had impaired vision, in most cases, participants were able to wear contact lenses. For those who could only wear glasses, the Mirror Specs were large enough to fit comfortably over their prescription glasses in order to complete the task.

2.7.3 Finger Tapping Task

The apparatus used in the task is described briefly here, whilst the task procedure is described in greater detail later in the section.

The apparatus involved participants wearing specially designed switches, or small buttons, that were attached to thimbles (see Appendix 1) and were placed on each of the fingers (minus the thumb). Wires were connected to the switches, which were then plugged into the computer response box to record participants' responses. This same procedure was used for each hand.

The participants were given sample cues to indicate which tones corresponded to which finger. Participants were required to respond to each tone by touching the sensor on the corresponding finger with their thumb as quickly and accurately as possible (The Task Instruction Script, containing details of the instructions given to each participant, is included in Appendix 13).

During each phase of the experiment, each of the four tones was presented in a random order at equal intervals during a block of 60 trials. Responses were recorded by the Superlab programme (a stimulus presentation software that facilitates the building of experiments, as described in the following section).

2.8 Main Measure: Computerized Finger Tapping Task.

2.8.1 Previous Research Methods

In this task, in order to assess how well participants adapted to using each Mirror Device, they completed a specially designed computerised Finger-Tapping Task. Several previous studies have investigated prism adaptation using both healthy participants as well as individuals who have suffered a stroke or PLP.

Previous research on prism adaptation/imagery has used a number of methods to investigate adaptation to prisms including pointing trials (Luaute *et al.*, 2009; Sarri *et al.*, 2008) and a line bisection task (Michel *et al.*, 2003). The current, novel experimental task was generated specifically for this study with the aim of gaining a sensitive measure of the effects of the Mirror Devices on the ability to complete the kinaesthetic movements.

A Finger Tapping Task was chosen following a review of previous imagery/motor research. This indicated this task has been used, for example, to successfully provide a measure of imagery performance (e.g. Hanakawa *et al.*, 2003), to investigate motor cortex activity when producing unimanual hand movements (Verstynen *et al.*, 2005) and to investigate unimanual and bimanual tapping in children (Njiokiktjien *et al.*, 1997). Some studies have asked participants to complete finger tapping movements using a keypress (Andres *et al.*, 1999) and tapping with just the index finger (Njiokiktjien *et al.*, 1997; Zelaznik, Spencer, & Ivry, 2002) or sequential tapping (Hanakawa *et al.*, 2003).

In Zelaznik, Spencer & Ivry (2002), finger tapping was included in a design that demonstrated differences between implicit and explicit timing in finger tapping and drawing movements. More recently, Matthys *et al.*, (2009) conducted a study using healthy participants performing a Finger Tapping Task to investigate cortical activity when using mirrors. They asked participants to complete self-paced finger tapping movements for each finger with a short rest in between. This study evidenced cortical activation in several regions including the somatosensory cortex when performing finger tapping with and without a mirror.

Thus, given the demonstrated utility of finger tapping methods in a variety of studies, and likely involvement of the somatosensory cortex, this task was chosen for the current study as a way of measuring differences in participants' ability to complete a sensorimotor task when each Mirror Device had altered their visual input.

2.8.2 The current study

The current study recorded responses by attaching switches to participants' fingers in order to enable the task to be completed whilst participants' hands were in position when using the Mirror Devices. The computer task was generated using Superlab, stimulus presentation software that facilitates the building of experiments.

Superlab has been used to produce experiments used in a number of published studies, including Fadardi & Cox (2006) who investigated attentional bias and cognitive functioning in alcohol consumers. They used Superlab for measures including the Stroop Test and the Shipley Institute of Living Scale, which measure aspects of executive cognitive functioning. They found that dependent drinkers were poorer on cognitive measures and had greater alcohol attentional bias than social drinkers and that this attentional bias was not a result of poorer cognitive performance.

In addition, Pell *et al.*, (2006) investigated the impact of Parkinson's disease on vocal-prosodic communication using Superlab by having listeners rate recordings of healthy adults and those with Parkinson's Disease (PD) in terms of intended meanings of the stress and intonation patterns of their speech. The results indicated that statements made by PD participants were often seen as neutral and lacking in emotion, particularly for anger and disgust.

2.8.3 Recording Of Responses – Speed-Accuracy Trade-off

A Speed-Accuracy Trade-Off is a common observation in cognitive and motor tasks (Mozer, Kinoshita, & Davis, 2004). It occurs when, for example, individuals perform a task slowly in order to reduce the likelihood of making errors, or perform a task quickly but increase the chances of being less accurate. Accordingly, it is necessary to calculate both Reaction Times and Error Rates to observe the interaction between these variables.

2.8.4 Piloting Work

Despite the range of studies employing finger tapping techniques, within the literature detailing number of trials included there has been considerable variability in the number of trials used in these types of experiments (e.g. Matthys *et al.*, 2009; Verstynen *et al.*, 2005; Hughes & Franz, 2007). Studies such as Zelaznik, Spencer & Ivry (2002) conducted an experiment using a Finger Tapping Task where participants were required to respond to tones. They, however, conducted extensive piloting before deciding on a repetitive finger tapping with the dominant hand in response to high-pitched tones lasting 1000ms. In this study, time was therefore taken to generate a task that was novel, but effective, and that it included an appropriate stimulus and the required number of trials that were likely to allow adaptation to take place and to detect an effect of adaptation.

2.8.4.1 Stimulus presentation

During initial piloting of the task, the stimulus presentation involved a voice recording of a series of numbers via the computer. Piloting trials, however, indicated a difference in the timing of the presentation of these numbers. The word ‘three’ appeared to be presented slightly earlier causing faster Reaction Times for the ring finger. As a result, special tones were designed to provide an auditory cue for each finger with exactly the same presentation times (200 milliseconds) to control for varying RTs between different stimuli corresponding to each finger. Piloting trials using different pitches of tones indicated that 4 tones of 100Hz (indicating the participant should tap the index finger), 300Hz (indicating a response for the middle finger), 2000Hz (indicating a response for the ring finger) and 6000Hz (indicating a response for the pinky finger), were suitably easy to distinguish and could be presented on the Finger Tapping Task.

2.8.4.2 Correct number of trials

Extensive piloting of the new Finger Tapping Task was completed to determine the number of practice trials needed to allow participants to become fully acquainted with the equipment and to produce fast responses. Piloting statistics suggested that responses became fastest after 40 trials. Therefore, to allow for potential differences in speed of skill acquisition, 3 Blocks of 20 trials were included in the Practice Phase. Similarly, piloting statistics for experimental phases indicated that responses became fastest and most accurate after 2 Blocks of 20 trials, therefore, 3 Blocks (60 trials) were included in the experimental phases.

2.8.4.3 Practice Phase.

Initial trials suggested that using the Mirror Device in the practice phase might allow participants to begin to adapt (as is described later) to using the Mirror Device. During the initial piloting, it became clear that, in addition to getting used to the task and getting responses up to speed, participants might also be getting used to the effect of the device. In order to have an ‘uncontaminated’ baseline, which allowed

participants to concentrate on getting their responses up to speed only, the procedure was altered to include no Mirror Device during the initial Practice Phase.

2.9 Measures of Individual Differences in Imagery Ability

To measure participants' Visual Imagery ability the following standardised questionnaires were included.

2.9.1 Vividness of Visual Imagery Questionnaire (VVIQ) (Marks, 1973).

The VVIQ is a standardised measure of ability to form mental images, (see Appendix 14). The VVIQ asks participants to visualise four different scenes, both with their eyes open and their eyes closed. Participants are also required to rate how vivid the image they generate is on a 5 point Likert Scale from 1-'perfectly clear and as vivid as normal vision' to 5- 'No image at all, you only know you are thinking of an object'.

The VVIQ was included as it has a high reliability (Marks, 1973) and has been used in many previous studies of, for example, imagery abilities. Some of the more recent include Holmes *et al.*, (2006), Mast *et al.*, (2003), Lobmaier & Mast, (2008), Schienle, Schafer, Vaitl, (2008) and Allbutt *et al.*, (2008).

Amedi *et al.*, (2005), for example, used the VVIQ and BOLD functional magnetic resonance imaging to measure the correlation between subjective vividness of imagery ability and the extent of activation in the auditory cortex respectively. Results found an association between Visual Imagery and deactivation in non-visual sensory processing including the auditory cortex ($r = 0.67$, indicating a large effect size) and somatosensory cortex (correlation co-efficient not reported).

2.9.2 The Spontaneous Use of Imagery Scale (SUIS) (Reisberg, Pearson & Kosslyn, 2003).

The SUIS is a standardised measure of participants' spontaneous use of imagery (see Appendix 15). It consists of 12 statements including; '*If I catch a glance of a car that is partially hidden behind bushes, I automatically complete it, seeing the entire car in my mind's eye*' and '*If I am looking for new furniture in a store, I always visualize what the furniture would look like in particular places in my home*' (Reisberg, Pearson, & Kosslyn, 2003).

The participant is asked to indicate to what extent each statement applies to them on a Likert Scale from 1-'never appropriate' to 5-'always completely appropriate'. It has been used in several previous studies including Amedi *et al.*, (2005), Holmes *et al.*, (2006) and Mast *et al.*, (2003).

Mast *et al.*, (2003) included the VVIQ and the SUIS as measures of individual imagery ability when investigating the link between body position and different types of imagery processing. Outcomes suggested that specific Visual Imagery processes, for example the ability to compose a mental image from separate shapes, are affected by the position of the body.

Holmes *et al.*, (2006) also found a significant relationship between scores on the VVIQ and SUIS, in that imagers with higher levels of vividness also reported higher use of imagery than low-vividness imagers.

To measure participants Motor Imagery ability, the following unstandardised task was included.

2.9.3 Motor Imagery/Haptic Task

In addition to the VVIQ and SUIIS, an adapted version of a previously used task (for example, Klatzky, Lederman, & Matula, 1991) was administered to gain a measure of individual differences in hand-related kinaesthetic/Motor Imagery in addition to Visual Imagery. This task was chosen in favour of questionnaires, such as the Motor Imagery Questionnaire (MIP), which provide a subjective account of imagery abilities (as in de Vries & Mulder, 2007), in order to provide a more objective measure of Motor Imagery abilities. The task involved presenting participants with a number of questions on a computer screen about haptically salient objects. They were presented with a question and two object names. These questions related to making a comparison about the object on dimensions relevant to interacting using the hands. For example, *'Which is heavier? A wine bottle, a tin of beans? Which is rougher? a dry sponge, a piece of toast? Which is squashier? a pea, a grape? Which requires a larger hand grip to hold? a tennis ball, an apple?'*

Participants responded by pressing one of two keys (left and right keys) and their responses were timed. Participants were then asked how strongly they felt as if they were holding / lifting etc the object on a Likert Scale from 1 (not strongly) to 7 (very strongly). To be clear, in this task the researcher was not looking for 'correct' or 'incorrect' answers. The task aimed to investigate how long it took participants to decide which object to select, and therefore generate a motor image. The rationale for this was that, in order for participants to make a decision, they would be required generate an image of them interacting with the objects. The task also aimed to provide a subjective measure of how vividly they generated that image using the Likert Scale.

The current task was previously generated and permission to use it was granted (Masson, personal communication, July 2009). It was based on an adapted version of that used in Newman *et al.*, (2005) who, using fMRI scanning, investigated brain activation during imagery of material and geometric object features when completing a similar task. This showed that questions about geometric features produced visual

images, which activated the region in and around the intraparietal sulcus while questions about material features produced the processing of semantic object representations, which involves the inferior extra striate region. This, along with Klatzky, Lederman, & Matula, (1991), indicate this task is a valid and reliable measure of the ability to form haptic images and by using imaging techniques it can be used to assess underlying brain activation during imagery.

2.10 Procedure

Participants were identified, recruited and informed consent obtained, as previously described. In order to counterbalance possible order effects, handedness and practice, the experiment was completed in four different sequences. Participants were then randomised to four running orders. Each participant completed the experimental task with each Mirror Device and using each hand however the order of Mirror Device and hand was randomised as follows. In each, the *visible* hand created a mirror image of what appeared to be the opposite, *invisible* hand (i.e. the hand behind the mirror).

The four sequences were as follows;

1) *Mirror Box Left* - where participants used the Mirror Box when completing the Finger Tapping Test and they did so with their left hand being visible to the naked eye (i.e. the hand was in front of the mirror or was visible through the Mirror Box and was not a reversed image). They therefore had a mirror image of the left hand that looked like the right hand. They then repeated the task using the Mirror Specs with their right hand being visible to the naked eye, thereby creating a mirror image of an apparent left hand;

2) *Mirror Box Right* - participants used the Mirror Box and their right hand was visible when performing the task (creating a mirror image of an apparent left hand). Then they used the Mirror Specs with their left hand visible;

3) *Mirror Specs Left* - participants used the Mirror Specs with their left hand visible then the Mirror Box with their right hand visible: and

4) *Mirror Specs Right* - participants used the Mirror Specs with their right hand being visible when performing the task then used the Mirror Box with their left hand visible.

Participants were randomly assigned to each condition with participant one completing condition 1, participant 2 completing condition 2 and so on (A Running Order Sheet is contained in Appendix 16), a process known as Latin Square Randomisation (Clark-Carter, 1997, p. 52-53). They were then administered the following procedure. Full details are included in the Instruction Script (Appendix 13).

2.10.1 Experimental Sessions

The switches were placed onto each of the fingers, using plasters to keep them in place, if necessary. In keeping with previous research (McCabe *et al.*, 2005), identifying markers such as jewellery asked to be removed.

The Computer Finger Tapping Task was administered, which involved 4 phases, each with 60 trials. Each trial involved one auditory cue and one press of the thumb to a switch on one of the forefingers.

Phase 0 (Practice) involved participants gaining a familiarity with the switches, tones and the computer task with the aim of getting their responses up to their optimal speed. The computer played the Superlab task and participants performed this using both hands. This was completed without a Mirror Device, as described earlier.

Therefore, participants completed the task with normal visual and proprioceptive feedback, thereby allowing them to become familiar with the task but not the Mirror Device. The purpose of this phase was to allow participants to become fully acquainted with the stimulus presentation, with which finger corresponded to which number and of the required response during the experiment. Therefore, they could respond as quickly, and as accurately, as possible.

Phase 1 involved each participant completing unilateral movements during the computerised Finger Tapping Task with the hand that was not visible while the visible hand remained still. Therefore, participants were presented with an image of both hands being stationary as the Mirror Device created a reversed image of the visible, stationary hand and therefore an image of the invisible hand as being still. It was intended that when participants performed the motor movement (finger tapping), this would create a discrepancy between visual and proprioceptive information, thereby re-creating a similar discrepancy that can be experienced by amputees.

During Phase 2, the participant completed the task using both hands. Participants were therefore presented with a visual image of both hands moving along with proprioceptive information from both hands. This was intended to close the sensorimotor feedback loop and reduce the discrepancy between the two modalities.

During Phase 3, the same task was completed exactly as in Phase 1.

This procedure was then completed again (including the familiarity/practice phase to allow for consistency between different running orders) with the other Mirror Device and the opposite hand being visible (as in Running Order, Appendix 16).

2.11 Additional Descriptive Information

During this Finger Tapping Task, several participants made a range of spontaneous comments regarding their experience of using the Mirror Devices and of completing

the experiment. These arose unexpectedly but were systematically recorded verbatim as they arose, including details of the context in which they were said i.e. during unimanual/bimanual tasks and whether the participant was using the Mirror Specs or Box, as a possible way of facilitating understanding of doing the task. Participants' verbal consent to record these was requested and granted. A previous study also recorded spontaneous comments made by participants (Sumitani *et al.*, 2008) and then grouped these comments into categories. They reduced the potential to introduce experimenter bias by avoiding prompting participants to comment on particular aspects of their experience.

Following the Finger Tapping Task, each participant then completed the Haptic Task, the VVIQ, and SUIS.

The total duration of participation was a maximum of approximately 60-70 minutes, depending on how quickly the participants understood the instructions and became familiar with the tasks.

2.12 Data Analysis

The plan for analysis included three stages. 1) checking the assumptions for statistical analysis, conducting appropriate transformations etc; 2) conducting Repeated Measures ANOVAs for Hypothesis 1 and 2; 3) conducting correlation analyses for Hypothesis 3.

During stage 1, The raw data from 44 participants were analysed firstly using Pivot Tables on Microsoft Excel 2007 to calculate combinations of simple means and average percentage rates for RTs and Error Rates across different phases for each participant. Levels of adaptation on the Finger Tapping Task were indicated by the difference in RTs and Error Rates between Phase 1 and Phase 3. These scores were then analysed using Statistics Package for Social Sciences Version 15.0 for

Windows. In order to meet the requirement of normality, data for Reaction Times and Error Rates were transformed using a logarithmic transformation (as described later).

During stage 2, because the data met the assumptions required, Parametric Analyses (Repeated Measures ANOVAs) were performed for the data on Reaction Times and Error Rates for Phase 1 and 3 of the Finger Tapping Task.

During Stage 3, in order to investigate any potential relationships between levels of individual Visual and Motor Imagery abilities and adaptation levels using each device, a (Bivariate) Correlation Matrix was generated using raw data. All variables for adaptations scores (as a measure of change in performance on the Finger Tapping Task) and average scores for the imagery measures (VVIQ, SUIIS, Haptic Task) were entered into a Correlation Matrix to investigate relationships between them.

The decisions regarding data handling at each stage are described in the next section.

Due to a technical difficulty, data for one participant was required to be discarded as it did not include all RTs across all fingers (and therefore an elevated number of NRs that did not represent the participant's ability to complete the task). A further participant was therefore recruited and tested under the same running order procedure as that undertaken in the set of discarded set of data. This was to ensure equal numbers of data across each order of task completion.

Chapter 3: Results

3.1 Demographic Information

A total of 44 participants completed the study. 40 were female and 4 were male. The overall age range was 17-55 years, with the majority in the range of 17-25 years (see Table 1, below). 2 participants were left-handed whilst 42 were right handed.

Table 1: Age-ranges of Participants

Age-range	Number of Participants
17-25 years	31
26-35 years	5
36-45 years	3
46-55 years	1

3.2 Exploratory Data Analysis

3.2.1 Raw Data Entry - Excel.

Raw data of Reactions Times (RTs) and Error Codes were selected from the Superlab Finger Tapping Task and entered into an Excel Worksheet. A total of 21,120 responses, which included Reaction Times (RTs) and Error Codes (indicating Correct (C), Error (E) or No (NR) responses) from 44 participants were entered. When reporting the results of visuomotor experiments, previous studies have calculated Reaction Times and Error Rates (e.g. Mast *et al.*, 2003). Following this convention, in the present study, the following average rates for Reaction Times and of the percentage of incorrect responses were calculated for each completed phase of the task, for each device and for all participants.

3.2.2 No Responses (NRs)

It is difficult to determine if an NR reflects a correct response (that has missed the intended button, an error (that has missed the intended button) or no response at all (i.e. made due to lapse in concentration, indecisiveness). It is possible that these data points might not be reflective of participants' attempt to make a judgement on the task and their ability to respond accurately and more reflective of factors such as accidentally missing the button, momentary lapse of concentration or taking a long time to make decision.

Previous studies have not reported recording or including/excluding NRs from data sets (Mast *et al.*, 2003; Hughes & Frans, 2007), perhaps because their equipment has not recorded such responses. Given that the equipment used in this study recorded NRs, the number and percentage of NRs were calculated to give an indication of whether they were likely to significantly impact upon further calculations and analyses. The total number of NRs was calculated at 115, which was 0.055 per cent of the total number of responses.

The number of NRs is contained in a table in Appendix 17, whilst Figure 2 below shows the pattern of NRs across each phase and each device.

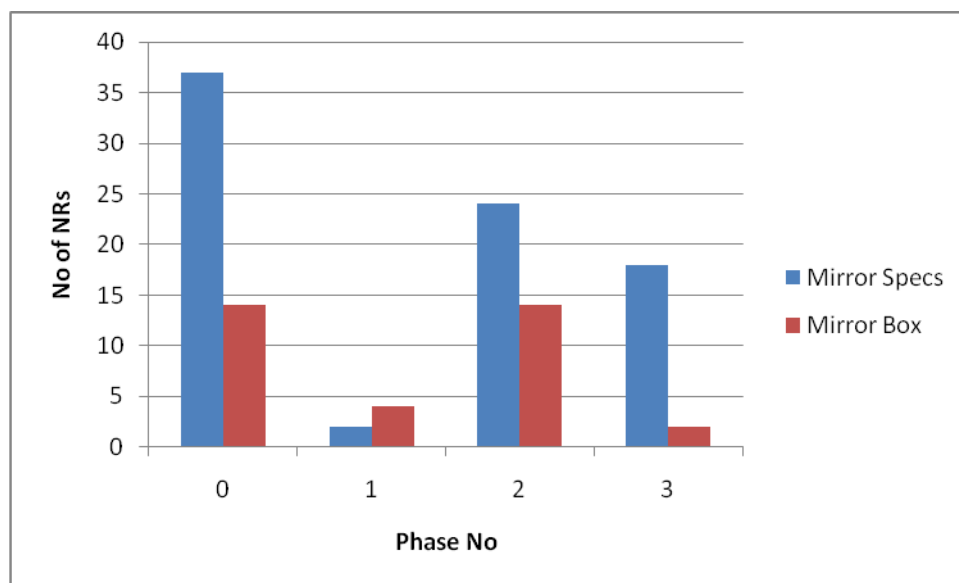


Figure 2: NRs plotted across all 4 Phases of Finger Tapping Task

This indicates that the number of NRs in the Mirror Specs condition (total = 81) was higher than in the Mirror Box condition (total = 34), with a greater number of NRs occurring in the bimanual trials.

In this study, the researcher was wary of including data that might not give an accurate account of participants' judgements of the Finger Tapping Task. Given the very small percentage of NRs and the ambiguity of their significance the decision was taken to exclude them in the calculations for Error Rates as such a small percentage was thought to be highly unlikely to impact significantly upon average rates or skew the data in any direction.

3.2.3 Phases 0 and 2 (Bimanual Phases)

Mean scores were calculated for the bimanual phases, however, given that Phase 0 was completed with no Mirror Device and was considered a Practice Phase, these means were not included in further statistical analyses.

3.2.4 Reaction Times (RTs)

Data for each participant over each of the 8 phases (4 for each device) was entered. Pivot Tables were generated to allow selection of different variables and to calculate functions such as the count, mean and standard deviation of specific variables. No Responses, which generated RTs of 0 were removed to avoid no responses skewing the response data (i.e. of actual responses).

Previous studies have calculated RTs based on correct trials (Schwoebel *et al.*, 2001; Mast *et al.*, 2003; Noordzij *et al.*, 2006) and outliers excluded prior to analysis. For example, previous studies have removed RTs greater than 2.5 times the mean for each condition for each subject (Mast *et al.*, 2003, Biermann-Ruben *et al.*, 2008) and 2 standard deviations from the mean, thereby removing 5 per cent of the data before further analysis (Schwoebel *et al.*, 2001). Similarly, Hughes & Frans (2007)

reported removing RTs that were very slow (>450ms) or very fast (<100ms) prior to analysis, thereby removing 2.6 per cent of their data.

In this study, a Pivot Table was then used to remove RTs above or below 2 standard deviations from the mean for each phase using the Standard Deviation function. RTs that fell between +/- 2 standard deviations from the mean were termed 'acceptable RTs'. This was performed to remove unusual responses, that is, ones that were unusually slow (for example, due to momentary loss of concentration) and not indicative of the individual's true performance.

There are several possible ways of dealing with unusual responses including calculating the trimmed mean by removing extreme responses of the highest 10 per cent and lowest 10 per cent (Clark-Carter, 1997, p119). Removing unusual responses greater than and less than 2 SDs from the mean was chosen in order to capture responses that were most likely to be meaningful. The total number of RTs removed at this stage was 1121, which was 5.3 per cent of the total number of responses.

Average rates for RTs for correct responses only and within the acceptable RT range were then entered into SPSS and used for further analysis. As reported in previous studies (Schwoebel *et al.*, 2001; Mast *et al.*, 2003; Noordzij *et al.*, 2006), the measure of RT performance in this study was based upon RTs for correct responses because (as previously stated) incorrect and no responses have the potential to reflect responses that would generate unusual RTs. Examples of this include very short times that were made spontaneously, or impulsively, or at the expense of making a reasoned judgement (i.e. Speed-Accuracy Trade-Off), or very long times due to inattention.

3.2.5 Error Rates

Previous studies have calculated Error Rates, however, the formula for achieving Error Rates has not been explicitly stated (Mast *et al.*, 2003). Some studies have

reported calculating percentage Error Rates (Noordzij *et al.*, 2006) and there has been no reporting of removal of any outlying rates prior to further analysis.

Error Rates in the current study (the percentage of incorrect responses) for each phase completed by each participant were calculated using the following formula.

No of Errors/No of Recorded Responses (C+E) x 100.

The total number of errors was 2316 (10.97 per cent of the total number of responses).

3.2.6 Imagery Measures

Average scores for the VVIQ Open and Closed and SUIIS were calculated for each participant and for the group as a whole. Similarly, on the Haptic Task average scores for Reaction Times and ratings of vividness of Motor Imagery were calculated. Average scores were used as opposed to total scores (as has been the case in previous studies, (e.g. Mast *et al.*, 2003), as it was felt that average rates would be more easily comparable to the rating scales in the questionnaires and offer a more useful indication of the level of vividness etc.

3.2.7 'Adaptation' Scores

As previously stated, levels of adaptation on the Finger Tapping Task were indicated by the difference in RTs and Error Rates between Phase 1 and Phase 3. These differences were calculated for each participant and termed 'Adaptation Scores'. These 'Adaptation Scores' were calculated for RTs and Error Rates (both Box and Specs across all phases with raw data) using the formula;

Phase 1 mean scores – Phase 3 mean scores.

In relation to Hypothesis 2, a negative adaptation score for RT indicates an increase in RTs, and a negative score for error rate indicates an increase in the number of

errors made in Phase 3 compared to Phase 1. This calculation is similar to that used in a previous study by Hughes & Franz (2007). The adaptation scores were then entered into SPSS for further analysis.

3.2.8 Normality of Data

The data were checked for normality of distribution. Recommended tests for Skewness and Kurtosis (Field, 2009, p.138) were performed for average Reaction Time and Error Rates for each phase for each device.

A z score of >3.29 is considered to be significant at $p <.01$ and a score of >1.96 is considered to be significant at $p <.05$ (Field, 2009, p. 139). The data for Reaction Times indicated positive skews for Mirror Specs, Phase 0 (z score = 3.41, $p <.01$) and Mirror Specs, Phase 2 (z score = 3.52, $p <.01$), therefore the data was transformed using logarithmic transformation.

In order to perform parametric analyses, which provide a more powerful method of detecting statistical significance, a logarithmic transformation was chosen as an appropriate procedure to tackle positive skews (Field, 2009, p. 155). This was applied to *all* RTs data in order to compare RT rates across Phase and Device. This produced a normal distribution for RTs (Specs Phase 0, z score = 0.001; Specs Phase 2, z score = 0.027).

This procedure also was performed for Error Rates. A significant positive skew was identified in the distributions for Error Rates Specs Phase 1 (z = 3.29, $p <.01$), Specs Phase 3 (z = 4.02, $p <.01$), Box Phase 1 (z = 2.39, $p <.05$) and Box Phase 3 (z = 3.29, $p <.01$). This was addressed by applying a logarithmic transformation of $\log_{10} + 1$. A constant of 1 was added, as recommended by Field (2009, p. 155), due to the presence of 0 values in the data. This produced a normal distribution for all variables (that is, a z score for Skewness and Kurtosis of less than 1.96).

In terms of the data used to investigate relationships between variables, out of 17 variables, stem and leaf plots and box plots indicated skewness for 4 sets of data. VVIQ Closed ($z = 3.04, p < .01$), Haptic Average RTs ($z = 3.56, p < .01$), and Error Rate Box Adaptation Score ($z = 8.61, p < .01$) were positively skewed, whilst RTs Box Adaptation Score ($z = 2.73, p < .05$) was negatively skewed.

This data was transformed using a logarithmic transformation, as described above. This produced normal distributions for all 3 sets of scores. Given the negative skew in the data for RT Box Adaptation Score, these scores were first of all reversed and then transformed using a logarithmic transformation. This failed to produce a normal distribution. Non-parametric analyses were therefore performed, thereby reducing the influence of outliers and non-normal distributions (e.g. Field 2009), for any correlation analysis involving this variable.

3.2.9 Outliers

The data were explored for the presence of outliers using stem and leaf plots and box plots.

One outlier was identified in the Reaction Times Mirror Box Phase 3 data, however it was not identified as extreme. Examination of the raw data indicated this RT was significantly longer than the mean for the group. Further analyses were performed with and without this outlier. Presence or removal of this outlier had no impact on the outcome of the statistical analyses for hypotheses 1 and 2. In order to have appropriate numbers for inferential analyses and, given that 5.3 per cent of the data had already been removed, at an earlier stage of the analysis, the outlier was therefore included in the data reported here.

A number of outliers were identified in the adaptation and imagery variables used in the correlation analyses. 2 cases were identified as extreme. These outlying scores were not removed due to the potential to remove meaningful data and reduce the

power of the analyses, therefore, transformations were used to reduce the impact of these.

3.2.10 Phases 0 and 2 (Bimanual Phases)

A small number of outliers were identified in the data on a minority of phases 0 and 2. Given that this study was interested in calculating only significant differences between phases involving use of a Mirror Device, (and therefore further statistical analyses on this data only were performed), it was not deemed necessary to relevant to remove outliers from Phase 0 data. One outlier was identified in the transformed data for RTs Specs Phase 2. Further analyses were performed with and without this outlier. Removing the outlier did not influence the outcome, therefore, the results reported in this chapter include the outlier.

3.3 Descriptive Statistics

3.3.1 Finger Tapping Task

The Mean Scores (Standard Deviations) for Reaction Times and Error Rates across Phases 1 and 3 and for Mirror Box and Mirror Specs are included in Tables 2 and 3, respectively.

Table 2: Mean Score and Standard Deviations for Reaction Times

	Reaction Times (ms)	
	Phase 1	Phase 3
Mirror Specs	942.07 (216.07)	891.86 (181.80)
Mirror Box	963.36 (198.26)	904.24 (211.21)

The mean scores in Table 2 for Reaction Times indicate that, for both Mirror Devices, the time taken for participants to respond on the unimanual phases of the Finger Tapping Task reduced between Phase 1 and Phase 3.

Table 3: Mean Score and Standard Deviations for Error Rates

	Error Rates (% of errors) Mean (SD)	
	Phase 1	Phase 3
Mirror Specs	12.72 (11.06)	11.63 (10.45)
Mirror Box	11.79 (12.37)	8.67 (8.19)

The mean scores in Table 3 indicate a lower Error Rate in Phase 3 compared to Phase 1 for both Mirror Devices. Errors appeared to be lower in the Mirror Box condition than Mirror Specs condition.

In order to examine changes in patterns of RTs and Error Rates across all phases, mean raw scores were plotted and can be viewed in the graphs below.

Figure 3 contains the pattern of RTs and Figure 4 contains the pattern of Error Rates across all 4 phases. These patterns were plotted to gain a sense of how participants' ability to complete the task varied across trials, and between bimanual and unimanual phase when using both devices.

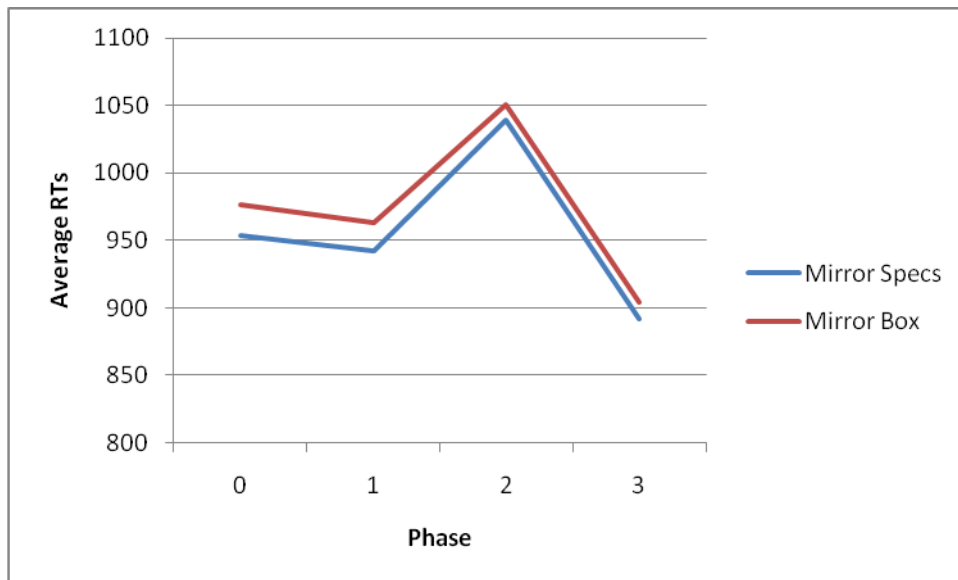


Figure 3: Pattern of Means for RTs across all phases of Finger Tapping Task.

The plot indicates that following introduction of each Mirror Device, RTs reduced slightly before showing a marked increase during the bimanual (adaptation) phase and then reducing in Phase 3 to the shortest times overall.

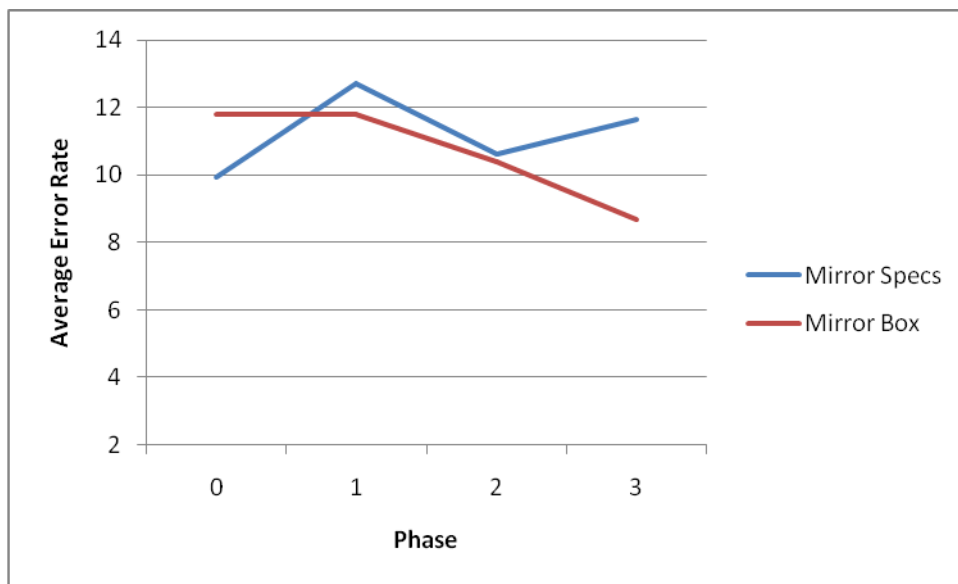


Figure 4: Plot of Means for Error Rate (percentages) across all 4 Phases for Finger Tapping Task.

The plot shows each Device displayed slightly different trajectories for Error Rates. For the Mirror Specs, the number of errors increased following introduction to the device then there was a reduction during the bimanual phase followed by an increase in Phase 3. For the Mirror Box Condition, Error Rates remained the same following introduction of the Device and then decreased following Phase 1, through Phase 2 and Phase 3.

3.3.2 Measures of Individual Imagery Ability

Average scores, including the range, for each of the measures of Imagery Ability are presented in Table 4, below. Total scores for the VVIQ and SUIS, as reported by previous studies (e.g. Mast *et al.*, 2003), are included in Appendix 18.

Table 4: Average Scores for Imagery Measures

	VVIQ Open	VVIQ Closed	SUIS	Haptic Task Likert Rating	Haptic Task Reaction Times
Average score	2.65	2.31	4.45	5.51	2698.08
Range of ratings(min- max)	1.13-4.69	1.00-4.94	2.67-5.67	2.88-7.00	1.156- 5402.67

The VVIQ descriptive data indicate a broad range of responses from 1 to 5. Given that a score of 1 on the VVIQ indicates high level of vividness and a score of 5 indicates a low level, average scores of 2.65 and 2.31 for the VVIQ open and closed scores indicates that sample of participants had a moderate ability to form vivid visual images. The score of 4.5 on the SUIS indicates participants tended to show a greater likelihood of forming spontaneous mental images, however, there was again distinct variability in the range of scores (2.67-5.67). Given that a rating of 1

indicates low and 7 indicates a high level of vividness, the average score of 5.5 on the Haptic Average Rating scores indicate participants had an ability to form reasonably vivid haptic images. RTs were included to assess relationships with ratings, for example, if ratings become higher when RTs are slower, this would indicate participants take more time to form vivid images (that is, the level of Speed-Accuracy Trade-Off between RTS and ratings of vividness).

Further analyses were conducted to investigate potential relationships between these measures and the measures of performance on the Finger Tapping Task or level of adaptation.

3.4 Main Analyses

The normal distributions resulting from the transformations suggested it was appropriate to apply parametric analyses upon the data as the assumptions required for performing parametric analyses (interval data, normality, homogeneity of variance) were satisfied. Mauchley's test statistic was found to be significant ($p < .05$) in all cases, apart from the analysis of the unimanual versus bimanual phases for RT Phase, Error Rate Phase, Device * Phase ($p > .05$). When Mauchley's test statistic is significant, we cannot be sure that the assumption of sphericity is met. Therefore, as recommended by Field (2009, p.461), the F statistic, as corrected by Greenhouse-Geisser, is reported.

A General Linear Model Repeated Measures ANOVA was applied in order to test whether there were significant differences between performance on the Finger Tapping Task (as measured by RTS and Error Rates) using each Mirror Device on Phase 1 of the task compared to Phase 3.

3.4.1 Effect Sizes for ANOVAs.

The p value tells us whether two or more means differ significantly. Considering the nature of an effect size in addition to considering the level of statistical significance,

or p value, is important, however, because an effect size provides an indication of the the *degree* to which the dependent variable is observed to be influenced by independent variable (Clark-Carter, 1997, p. 201). The effect sizes for the results of the following ANOVAs are reported using partial eta squared (η_p^2).

3.4.2 Hypothesis 1: There will be an increase in Reaction Times and increase in Error Rates in Phase 3 compared with Phase 1 of the Finger Tapping Task, following adaptation to the Mirror Devices.

A significant main effect was detected of Phase on Reaction Times ($F(1,43) = 26.860, p < .01$) with a large effect size. Secondly, a significant main effect was detected for Error Rates ($F(1,43) = 4.579, p < .05$) with a medium to large effect size.

A significant difference was, therefore, observed between participants' Reaction Times and Error Rates in Phase 1 compared to Phase 3 of the Finger Tapping Task. Mean scores indicate that there was a significant reduction in Reaction Times and Error Rates.

3.4.2.1 Conclusion

These results indicate that participants became faster and more accurate in their responses on the task in Phase 3 than in Phase 1. Medium to large effect sizes suggest we can be confident in reaching this conclusion. Hypothesis 1 is therefore not supported.

3.4.3 Hypothesis 2: Participants RTs and Error Rates between Phase 1 and 3 will increase. The level of adaptation will be similar in both the Mirror Box and Mirror Specs.

Results of the ANOVA indicated there was no significant effect of Device for Reaction Times ($F(1,43) = 1.164, p > .05$). No significant effect of Device was found for Error Rates ($F(1,43) = 3.102, p > .05$).

3.4.3.1 Conclusion

These results indicate that participants' performance using the Mirror Specs did not significantly differ from performance using the Mirror Box in terms of Reaction Times and Error Rates. Hypothesis 2 is therefore upheld.

3.5 Interactions Between Independent Variables

The Repeated Measures ANOVAs revealed no significant interaction between Device and Phase for RTs ($F(1,43) = .903, p > .05$). No significant was observed between Device and Phase for Error Rates ($F(1,43) = .623, p > .05$).

3.5.1.1 Conclusion

No significant interaction effects between the type of device used and the difference between Phase 1 and 3 on Reaction Times or Error Rates was observed. Therefore, no Device caused a greater difference between Phases 1 and 3 on any of the dependent variables.

3.5.2 Additional Analysis: Comparison of unimanual phases and bimanual Phase 2.

To assess whether the difference in responses between the unimanual phases and the bimanual Phase 2 were statistically different and to assess for any interactions between these variables, Repeated Measures ANOVAs were performed.

For RTs, no significant effect of Device was detected ($F(1,43) = 2.007, p > .05$). There was a significant main effect of Phase ($F(2,86) = 60.085, p < .01$) with a large effect size. Observation of the means indicate that RTs were longer in the bimanual phase. Finally, no significant interaction was detected between Device and Phase ($F(2,86) = .279, p > .05$).

For Error Rates, there was no significant effect of Device ($F(1,43) = 1.715, p > .05$) and no significant effect of Phase ($F(2,86) = 2.281, p > .05$). Finally, there was no significant interaction between Device and Phase ($F(2,86) = 0.827, p > .05$).

3.5.2.1 Conclusion

The results indicate that participants' performance when using the Mirror Box and Mirror Specs did not differ significantly in terms of RTs and Error Rates, however there was a significant increase during the bimanual phase for RTs. There were no significant interactions between these variables.

3.5.3 Hypothesis 3: Imagery abilities (both visual and haptic) will correlate with adaptation levels on the Finger Tapping Task, irrespective of the type of Mirror Device.

Correlations were performed to investigate the relationship between levels of adaptation (indicated by the difference between RTs and Error Rates for the Mirror Box and Mirror Specs between Phase 1 and 3) and imagery abilities (average scores for the VVIQ Open and Closed, The SUIS and the Haptic Task).

Pearson's r was performed for all normally distributed data and the results are reported in table 5. As stated previously, one set of data could not be transformed to produce a normal distribution. Pearson's r assumes that both variables will be normally distributed (Clark-Carter, 1997, p.318-319). It is advised that, when one of the variables in the correlation contains a skewed distribution or if the two

distributions are skewed in opposite directions, this can “limit the size of the correlation co-efficient” (Clark-Carter, 1997, p.319).

It is therefore recommended that, when the assumptions of Pearson’s r are not met, as in the case of non-normally distributed data, an alternative correlation coefficient to Pearson’s r should be considered (Clark-Carter, 1997, p.310). Spearman’s Rho is a non-parametric correlation and as such does not assume normal distribution of the data. Spearman’s Rho was performed for the RT Box Adaptation data and the results are reported in the final column of Table 5.

The hypothesised correlations are highlighted in bold, whilst additional hypotheses are included for further information about the relationship between the measures used.

Table 5: Pearsons's r statistics for Imagery Measures (VVIQ Open, SUIS, Haptic Ave Rating) (N=44) and Transformed Adaptation Scores (RT Specs, Error Specs and Error Box) (N=44).

	Adaptation Scores								
	VVIQ Open	VVIQ Closed	SUIS	Haptic Ave RT	Haptic Ave Rating	RT Spec	Error Spec	Error Box***	RT Box
VVIQope	-	.502**	-.375*	-.201	-.436**	-.057	.174	-.137	-.062
VVIQClos	-	-	-.563	-.111	-.453**	-.100	.102	-.043	-.052
SUIS	-	-	-	.051	.576**	-.095	-.148	-.030	.096
HapticRT	-	-	-	-	-.014	.233	-.123	.018	.307*
HapticRat	-	-	-	-	-	.031	-1.05	.162	-.035
RT Spec	-	-	-	-	-	-	-.119	.158	-.158
Error Spec	-	-	-	-	-	-	-	-.242	-.015
Error Box	-	-	-	-	-	-	-	-	-.225

* Correlation is significant at $p < .05$ level

** Correlation is significant at $p < .01$ level

***Spearman's Rho statistic reported

As can be seen from Table 5, a significant negative correlation was identified between Haptic Task RTs and the RT Adaptation Score (difference between Reaction Times on Phase 1 and 3) when using the Mirror Box ($r_s = -.307$, $p < .05$, two tailed) with a medium effect size. This relationship is demonstrated in Figure 5. This indicates that, as the positive score for RTs (indicating a reduction between Phase 1 and 3) increased (indicating greater reduction), the RTs for the Haptic Task

decreased.

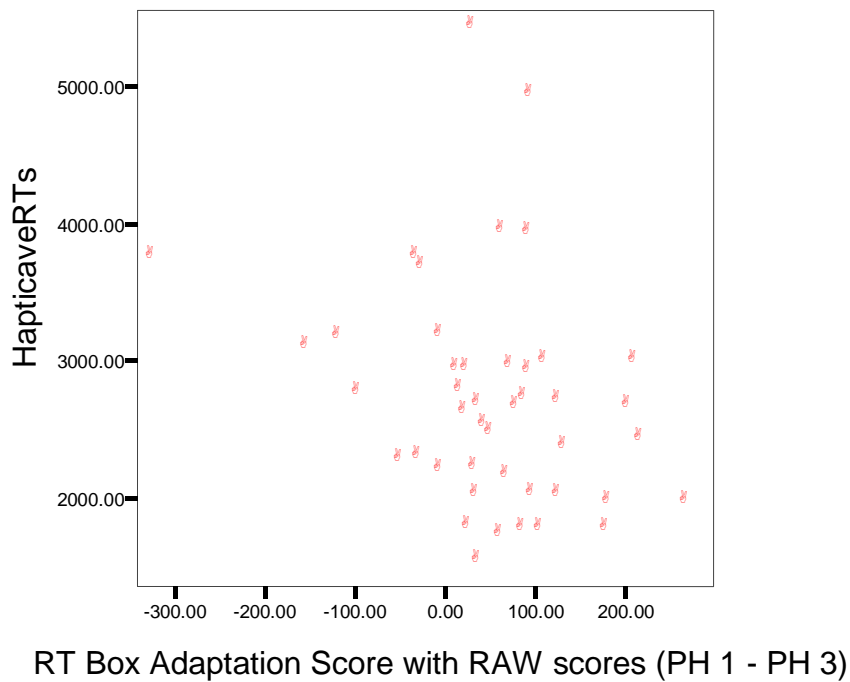


Figure 5: Relationship between Adaptation Score for Mirror Box RTs and Haptic Task RTS.

No other significant correlations were detected between measures of imagery and adaptation scores on the task. Significant correlations were, however, found for a number of the imagery variables. These results, whilst not unexpected or unusual, were not part of the hypothesis. They, therefore, are included in Appendix 19, for information and are referred to in the discussion.

3.5.3.1 Conclusion

The results of the Correlations therefore showed few relationships between imagery abilities and performance on the task. This indicates that individual imagery abilities

did not influence how participants performed the task or adapted to using each Mirror Device and, as a consequence, Hypothesis 3 is not supported.

3.6 Additional Descriptive Information

During the Finger Tapping Task, participants made a range of comments, including the following, which were not scored but were intended to be used as a way of helping to make sense of the quantitative data and to further our understanding of the experiences of using the Mirror Devices and completing the experiment.

The range of comments appear to broadly fall into the four different categories or themes of i) experience of using Mirror Devices, ii) experience of using bimanual versus unimanual tasks, iii) the strategies adopted to master the task and iv) indications of change to Body Image. The term ‘Body Image’ is used here because the comments were thought to reflect a more conscious change in how participants perceived the body parts, rather than a change corresponding to sensorimotor integration (as measured in the Finger Tapping Task). The comments are listed under these headings in Table 6 below.

Table 6: Comments from Participants

i) Experience of using Mirror Devices	
<p>Mirror Specs: Mirror Specs, Phase 3 “disturbing not seeing hand moving.”</p> <p>Mirror Specs, Phase 1 “it looks like a dead hand!” (<i>when looking at ‘invisible’ hand in mirror</i>).</p> <p>Mirror Specs “it feels like there’s a picture being held up in front of my eyes.”</p> <p>Mirror Specs invisible hand “felt numb - it didn’t look like it was moving.”</p>	<p>Mirror Box; Mirror Box, Phase 1 “fingers feels weird, like they’re not there.”</p> <p>Mirror Box – “felt disoriented, actual fingers are not where they are in the mirror.”</p> <p>Mirror Box – “worse than the glasses – more realistic, had to really think in my head about response rather than relying on visual feedback.”</p> <p>Mirror Box “fingers are not where you</p>

<p>Mirror Specs “odd, mismatch between what I could see and what I could feel.”</p> <p>Mirror Specs – initially felt dizzy”, “sick”, “wierd”.</p>	<p>expect them to be.”</p> <p>Mirror Box Phase1 “I feel paralysed, think I’m moving hand but it’s not moving in visual image.”</p>
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<p>ii) Experience of using bimanual versus unimanual tasks</p>	
<p>Bimanual task;</p> <p>Several participants described the bimanual task as “more difficult”, “strange”, “odd”.</p> <p>“confusing – the hand that I was seeing wasn’t moving as I expected, ...didn’t correspond to what I was feeling.”</p> <p>“I didn’t know where the feeling (...<i>in hand</i>..) was coming from.”</p> <p>“harder than phase one, had problems coordinating..think it’s my left hand but it’s not.” (Mirror Box (Left hand invisible) Phase 2).</p> <p>“more distracting”.</p> <p>“more weird – left hand felt uncontrollable - not quite matching what can see.”(Mirror Specs – left).</p> <p>“like there was a delayed response.” [of hand behind mirror compared to hand seen in mirror].</p> <p>“easier than unimanual..because had visual feedback of hand moving.”</p> <p>“easier – you think you have an idea of where fingers are going even though you don’t.”</p>	<p>Unimanual;</p> <p>“Feeling normal, getting used to it.”(Phase 3).</p> <p>“difficult because can’t see which finger is moving <i>behind the mirror</i>.”</p> <p>“what I see doesn’t match what I do.”</p>

iii) Potential strategies adopted to manage the task/cope with the different phases/Mirror Devices.

“(I was) trying to match the position of my fingers from what I feel behind the mirror with what I see.” unimanual phases.”

“I had a tendency to want to look away and rely on what could feel.” Unimanual phase.

“I tried to imagine my right (invisible) hand rather than focussing on the image of the hand.” (Mirror Box Phase 1).

“I started to separate out what I was seeing from what I was feeling.”

“it was weird at first but I started to ignore the mirror image.”

“I was looking at the corresponding fingers on the visible hand while tapping with the invisible hand.”

“I was still relying on touch.” (unimanual phase).

“ I was feeling for the button I could see in the mirror.”(unimanual phase).

“I was trying to match the fingers in the mirror with what I could feel I was doing – I was looking at the fingers and trying to find them behind the mirror.”

“I was relying more on the feeling of my hand after being disoriented by the glasses.”

iv) Indications of change to Body Image.

“I started to believe it was my hand!” bimanual phase (when looking at image of hand.)

“I started to associate what I could feel with what I could see.”

“I forgot what my own hand looked like!”

“it really felt like my hands were doing the same thing!”

“it was normal I was getting used to it.”

The importance of these comments, and relevance to the outcomes of the statistical analyses, is discussed in the next chapter.

3.7 Summary of Main Results

No significant differences between performances using each of the Mirror Devices were found for Reaction Time and Error Rates. Significant differences between Phases 1 and 3 were found for RTs and Error Rates, however, mean scores indicate a reduction in RTs and Error Rates in Phase 3 compared to Phase 1. There was also a significant difference between Phase 2 (bimanual) RTs and unimanual RTs.

One significant correlation was found between Haptic Task RTs and the difference between Reaction Times on Phase 1 and 3 when using the Mirror Box. No other significant correlations were detected between adaptation to the Mirror Devices and individual imagery abilities.

Finally, several spontaneous comments regarding the Mirror Devices and experiences of completing the task were provided. These comments and the results are discussed in the next chapter.

Chapter 4: DISCUSSION

4.1 Introduction

In this section, the main results will be reviewed and discussed in relation to each hypothesis. These findings will also be considered in terms of previous research and implications for future research. Descriptive information contained within participant comments will also be considered as a way of extending our understanding of the results, as well as participant experiences of using the Mirror Devices and completing the experiment. Exploration of the possible clinical implications will then take place. Finally, an examination of strengths and limitations of the design and methodology of the current study will follow.

4.1.1 Overview of the Study

Over the past two decades, Mirror Therapy (MT) has gained an increasing amount of attention in a number of empirical fields including pain management and stroke rehabilitation. Several studies examining the efficacy of MT have used a variety of methods from case studies (e.g. MacLachlan *et al.*, 2004) to larger, randomised controlled trials (e.g. Chan *et al.*, 2007). Although these studies are somewhat lacking in consistent methods of implementation and evaluation, outcomes suggests MT can be effective at reducing pain and increasing functioning in conditions such as Phantom Limb Pain (Brodie *et al.*, 2007; Chan *et al.*, 2007; Sumitani *et al.*, 2008).

A variety of hypotheses on the underlying mechanisms of MT exist, yet, there is no clear explanation as to how the therapy works. Many of these theories overlap. A widely recognised concept, however, involves adaptation or disruption to the sensorimotor loop and changes to associated brain structures. This arises when expected visual and proprioceptive feedback of moving a limb does not match actual visual and proprioceptive feedback due to the lack of a limb to provide such

feedback. The notion of Body Schema (as defined in this study), the internal representation of one's body parts, appears to add to this idea in that this representation is involved in integrating new sensory information. It provides a general 'overview' of the body and with reference to the environment.

It is proposed that the Body Schema is involved in generating signals for anticipated motor feedback in relation to a consistent picture of the body and can be altered under varying circumstances to generate new representations of body parts. MT is linked to Body Schema as it is thought to provide the conditions under which new representation of missing limbs can be generated through vision, thereby providing appropriate visual feedback to match signals for intended movements. Adaptation to Body Schema involves a modification to the process of transforming sensorimotor commands, in relation to a model of the body and the position of body parts, to allow performance of sensorimotor tasks under new conditions. This adaptation to Body Schema facilitates recalibration (or readjustment) of limbs (and hence motor response) in response to visual information and influences goal-directed movement.

The present study investigates whether a new form of MT, Mirror Specs, can create a similar level of sensorimotor transformation, linked to adaptation to the Body Schema, to the Mirror Box in healthy individuals. Therefore, the study considers whether Mirror Specs should be investigated further in terms of providing an addition to rehabilitation methods that is easy to use and cost-effective to produce.

44 participants completed a sensorimotor task, the Finger Tapping Task, whilst using the Mirror Box and Mirror Specs. Analysis of their responses indicates there was a significant difference between Phases 1 and 3 (unimanual phases) in RTs and Error Rates, indicating that participants became faster and more accurate in the final phase. There was no difference in Reaction Times or Error Rates between the Mirror Specs and Mirror Box conditions. Finally, one significant correlation indicated that a relationship between RTs on the Mirror Box condition and RTs on the Haptic Task.

4.2 Discussion of the main results

4.2.1 Hypothesis 1

The results of the Repeated Measures ANOVAs indicated significant differences between RTs and Error Rates on Phase 1 compared with Phase 3 of the Finger Tapping Task. The direction of the differences (reductions in Reaction Times and Error Rates) did not however support Hypothesis 1.

A number of explanations could be proposed to make sense of this result. Potentially the most obvious supposition would be that participants simply got better at the task over time, hence they benefitted from the effect of practice.

An alternative explanation is that the initial premise, regarding the origins of adaptation and the conditions under which interference to using the Mirror Devices would occur, incorrectly suggested this would take place *after* the bimanual trials. This would be due to the adaptation achieved when using both hands.

It is possible that the hypothesis, that ‘adaptation’ to using the Mirror Devices and to one’s Body Schema would largely happen during the bimanual trial, was incorrect. Although it was intended that the bimanual phase should reduce the mismatch between visual and proprioceptive modalities and contribute to a new representation of the hand in the Body Schema, it is possible this smaller mismatch created a *greater* level of disruption to participants’ ability to complete the task. Therefore, the original hypothesis incorrectly suggested interference would be less so in the bimanual trials compared to the latter unimanual trial.

It may also be the case that the terms ‘adaptation’ and ‘adaptation scores’ used in this study might have been somewhat misleading. It is possible that the results provide a greater indication of the participants’ ability to adapt to the task rather than the

devices themselves and it might be more useful to describe the results as indicating changes in scores on the Finger Tapping Task using each device. On the other hand, the fact participants' performance improved in Phase 3 when using both devices provides an indication that participants 'adapted to' or were able to use each device effectively.

Yet, the increased demand and focus of attention in Phase 2 might have encouraged participants to work harder, thereby facilitating performance in Phase 3.

Furthermore, it may simply be the case that they got used to ignoring the mismatch in the unimanual trials, indicated by comments made by one participant that they were able to separate out what they could see from what they could feel and another about managing to ignore the mirror image. This may have facilitated performance during Phase 3.

An alternative explanation is that the length of the current task allowed for adaptation to using the task and reversed vision but was not long enough to allow for the subsequent generation of a new hand representation (e.g. Sekiyama, 2006). As previously stated, however, there was a rationale for including the specified number of trials. A greater number of trials were not included to avoid facilitating practice effects and of increasing the likelihood of participants becoming bored or fatigued and therefore complacent during the task.

4.2.1.1 Participant Comments

Some comments made by participants during the experiment may shed some light on the proposed explanations. With respect to the first suggestion, a number of factors could account for increased disruption. Several participants, for example, commented on their experience of finding the bimanual task more difficult, of feeling that there was a 'delayed' response (*of their hand*) behind the mirror, of coordination difficulties, of feeling more distracted and of the visual feedback still not corresponding to what they could feel.

It should be noted that some participants also thought the bimanual task was easier than unimanual, with one specifically stating they benefitted from having visual feedback (of a hand moving). Given that these comments were recorded as and when they arose, there is no way of assessing how many participants experienced a greater perceived difficulty in the bimanual trials versus the unimanual trials and how many did not report it. Again, whilst no definite conclusions can be drawn from these comments, it is possible they offer an insight into the experiences during the task.

Furthermore, other comments perhaps indicate potential strategies used to master the task, and potentially offer an insight into why participants' responses got better in Phase 3. Some indicated that participants purposefully attended to different modalities in order to help them complete the task. For example, by relying on what they could feel, or touch. It is possible this strategy was used to help participants manage the mismatch between different types of feedback. Others appeared to reduce the mismatch by trying to match the fingers they could see with the fingers they could feel. It might also be that participants adopted a particular strategy during the unimanual phase, which was then ineffective during the bimanual phase, thereby causing interference.

The importance of the attended modality has been noted in the literature on visual capture and Body Schema (Holmes & Spence, 2006). The extent of visual capture can be modulated depending on which sensory modality attention is allocated to, for example, whether visual or proprioceptive cues are attended to (Kelso et al. 1975, cited in Holmes & Spence, 2006). The 'attended modality' displays less recalibration than the unattended modality. The degree of dominance of visual versus proprioceptive modalities can also vary according to different conditions (Holmes & Spence, 2006). Research indicates, that under conditions of prismatic displacement, the position of the unseen hand is matched to the seen hand, or visually presented hand (Mon-Williams *et al.*, 1997, cited in Holmes & Spence, 2006), indicating dominance of vision.

Bimanual trials provide sensory input from both visual and motor modalities however, unimanual trials have the potential to perhaps ‘devalue’ vision in favour of an emphasis on kinaesthetic feedback given the mismatch. In the present study, we would have expected increased visual capture during the bimanual trials such that the congruent visual information could be used to facilitate motor performance on the task and generate a new relationship between the two modalities. It seems possible that, in fact, there was a conflict between two modalities, which caused a disruption to performance rather than vision being the most dominant.

The finding that RTs were longer for the bimanual phase supports previous research that indicates that RTs are generally longer for bimanual tasks than unimanual tasks (Hughes & Frans, 2007; Njiokiktjien *et al.*, 1997). A number of reasons could account for this, including greater sensory input/demands and therefore greater attentional demands in terms of integration of vision and proprioception (e.g. Fink *et al.*, 1999). In the current study, the task involved matching of incongruent proprioceptive information and visual information. Given the reduction in the mismatch of the modalities, we would have expected an improvement in performance over the bimanual phase.

In terms of considering the role of Speed-Accuracy Trade-Off, the results indicate that in the unimanual trials, as RTs got faster, Error Rates also decreased. This builds confidence in the assumption that a reduction in RTs was not due to participants taking less care to respond to the auditory cues accurately and therefore sacrificing accuracy for speed. Instead, the scores indicate participants genuinely became faster and more accurate.

In contrast, it is interesting to note the change in average scores on the bimanual phase, compared to the unimanual Phase 1. In both the Mirror Specs and Mirror Box conditions, RTs increased whilst errors decreased. Thus, as participants responded more slowly, they were able to perform more accurately. This points to a trade off between speed and accuracy, which could make interpretation of levels of meaningful adaptation to the Mirror Devices more difficult. It could be that

participants were less motivated during this part of the experiment, however, this seems unlikely given the randomisation of order of completion of tasks and the lack of Speed-Accuracy Trade-Off in the bimanual phases of the task. There seems to be no clear evidence to suggest participants became de-motivated at this point in the task and with each device.

Alternatively, this provides further possible evidence that the bimanual phase might have resulted in more disruption to the sensorimotor process when moving both hands and having the addition of visual feedback that was not completely congruent to proprioceptive information. The visual feedback of the hand moving might have caused participants to respond more slowly in order to respond accurately rather than being able to improve performance on both measures. This again points to a disruption caused by a reduction in the discrepancy between two modalities, rather than a facilitative effect, as might have been expected following changes in Body Schema.

A point to note is that 'robust' comparisons are more likely when considering two phases that have been completed under the same conditions (for example, the unimanual phases). Comparison between the unimanual phases and the bimanual phase give more of an indication of the impact of differing conditions than of change or improvement in performance itself. Hence, the current study originally aimed to assess the difference in performance between the unimanual trials.

Furthermore, a tentative suggestion is that, in healthy participants, the addition of visual feedback might cause more disruption because they are accustomed to operating 'normally', that is, having congruent visual/motor feedback. As such, observing incongruent feedback, particularly a minimal amount that might be difficult to ignore/overcome as in bimanual trials, might cause more interference in the sensorimotor process.

It is possible that implementing a similar format with a clinical sample might have differing effects. For example, in patients who are already struggling with a

mismatch between different modalities and learning to find ways of managing this, having the addition of visual information might be more likely to have a beneficial effect or less likely to cause a disruption. Indeed, previous studies on MT with stroke patients have utilised bimanual training with encouraging results (Yavuzer *et al.*, 2008, Summers *et al.*, 2007, *cited in Yavuzer et al.*, 2008). Yet, the extent of disruption might also vary depending on the type of condition MT is being used to treat. (In PLP, bimanual trials would clearly not be an option).

In addition to this, the results section demonstrated that there were a greater number of NRs in the Mirror Specs condition, particularly for the bimanual trials. A preliminary interpretation of this could be that participants were simply more easily confused or distracted when using the Specs than the Box and therefore missed the switch they intended to hit. This could be related to the influence of Specs on sensorimotor integration. Then again, as stated in the previous chapter, interpretation of NRs can only be speculative. We cannot be sure that they reflect accidental missing of the switch, momentary loss of concentration, or interpreted as potential correct responses or errors.

4.2.1.2 Post-hoc Analysis

Given the degree of difference between NRs in each Mirror Device condition, in order to verify the robustness of the finding of no significant effect of Device on Error Rates, an additional post-hoc analysis on Error Rates was conducted to include NRs as errors. The Repeated Measures ANOVA indicated no significant effect of Device and Phase on Error Rates and the results are presented in Appendix 20. Although this result provides a caveat to the original finding, it again fails to provide support for Hypothesis 1. The post-hoc result further supports the conclusion, however, that there was no significant difference between Error Rates under each Mirror Device condition, as described in the next section.

4.2.1.3 Summary

On the basis of the aforementioned results, it is difficult to make definitive assumptions about how, when or if participants adapted to the Mirror Device or to the task they were presented with. Ultimately, these points suggest participants could have adapted to the task in different ways, but taking into consideration the results for Hypothesis 2, they did so in a way that was similar under each Mirror Device condition.

4.2.2 Hypothesis 2

The results of the statistical analyses offer support for Hypothesis 2. As was predicted in Hypothesis 2, the difference between participant responses on Phases 1 and 3 did not differ significantly when wearing the Mirror Specs or the Mirror Box in terms of Reaction Times and Error Rates.

These results are interpreted to provide an indication that participants were equally as able to adapt to the Mirror Specs and complete the task well as they were when using the Mirror Box. Given that previous studies of Mirror Therapy indicate support for the efficacy of MT using Mirror Boxes in clinical settings, the results from this study suggest further research should investigate whether Mirror Specs may have a similar impact.

This suggestion is undoubtedly speculative and must be interpreted with caution, yet it supports the outcome of a previous study (Bultitude & Rafal, 2009) and previous literature has referred to the possibility that MT and prism adaptation may have similar underlying mechanisms (Holmes & Spence, 2006). The findings reported in this study consequently provide a further basis for prospective investigations.

The results of this study extend those cited in Bultitude & Rafal (2009). In the previous study, prism adaptation and MT with a Mirror Box were investigated in a case of CRPS. The prisms were effective at reducing pain and improving

functioning. However, the prisms appear to have been used in conjunction with the Mirror Box and it is therefore difficult to extrapolate the differential effects of each device. Yet, this finding in addition to the results presented here, provide an indication that implementation of Mirror Specs may produce facilitative outcomes.

4.2.2.1 Participant Comments

When considering these results and the possible interpretations of the data in terms of understanding the utility of Mirror Specs, it is perhaps useful to take into account the descriptive comments made by participants when using each device. This information could extend our understanding of participants' experiences of using each device.

It seems that participants experienced some unexpected mild, short-term unpleasantness, for example nausea and dizziness, when initially putting the on Mirror Specs and some found it disorienting. This is consistent with previous evidence of negative side effects when using the Mirror Box with lower-limb amputees (Casale, Damiani, & Rosati, 2009). In the previous study, the duration of symptoms was not reported, however in the current project, these symptoms did not seem to last and were largely only reported when initially putting on the Specs. Furthermore, although participants were advised they could discontinue at any point if they felt unwell, none did so.

It is also interesting that, during the unimanual phase, one participant commented on experiencing a "numb" hand, whilst another reported feeling as if they had a "dead hand". This information could be viewed as an indication that these participants experienced an appropriate 'illusion' of the hand whilst viewing the mirror image through the Mirror Specs. Similarly, when using the Mirror Box, participants reported feeling "weird" and disoriented, and another reported a experiencing a "paralyzed" hand, suggesting a similar experience.

Additional comments appear to link participants' experience to the issue of Body Image. Some participants expressed feeling as if the mirror image of the visible hand had become their own hand as well as forgetting what their actual, own hand looked like. This could be interpreted as an indication that, in some participants, there was a change in their sense of ownership of body parts linked to changes in visual image/feedback. This speculative suggestion links to previous work indicating the importance of a sense of ownership with the viewed limb (Tichelaar *et al.*, 2007; Holmes & Spence, 2006). In this study, this aspect of MT was not investigated directly and it is not therefore clear how many participants experienced this and how many did not, or simply did not report it.

4.2.2.2 Summary

The findings indicate that participants in this study did not differ significantly in their performance on the given task whilst using the Mirror Specs and Mirror Box. This indicates that further research is warranted to provide support for the suggestion that Mirror Specs might provide an effective addition to rehabilitation treatment for conditions such as PLP.

4.2.3 Hypothesis 3

One significant correlation was detected between the measures of imagery ability and differences between Phases 1 and 3 on the Finger Tapping Task. This information indicates that individual imagery abilities did not influence how participants performed the task when using each Mirror Device. This is true for both Visual and Motor Imagery abilities. Hypothesis 3 is not therefore upheld.

With reference to the only significant relationship between imagery measures and adaptation scores, there is no clear explanation as to why participants were slower at responding on the Haptic Task as they got faster on the Finger Tapping Task whilst

using the Mirror Box. However, given the number of variables entered into the correlation matrix, this might have generated a false-positive result (or Type 1 Error) and may be a spurious correlation.

With regards to relationships between the measures of imagery themselves, the findings regarding visual imagery abilities support previous research. The negative correlations between VVIQ Open and Closed scores, and SUIS are consistent with previous studies indicating vivid imagery ability (low VVIQ scores) with high spontaneous use of imagery (high SUIS scores) (such as Reisberg, Pearson & Kosslyn, 2003). Similarly, previous research has found a relationship between high levels of Visual and Motor Imagery (e.g. Callow & Hardy, 2004).

Finally, it is interesting to note that one participant commented on attempting to create an image of the invisible hand moving, presumably as a method of coping with the mismatch.

4.2.3.1 Summary

This study did not find any clinically significant relationships between imagery abilities and changes in performance on the current visuomotor task.

4.3 Clinical Implications

This study found no significant differences in the way that healthy participants were able to adapt to, or manage a visuomotor task when using, both the Mirror Box and Mirror Specs. The implication is that future studies should replicate similar findings in patients with conditions such as phantom limb pain/sensation, CRPS or stroke (as is now underway). Such findings could strengthen the proposal that Mirror Specs could be employed in clinical settings as a feasible, practical alternative to the Mirror Box. It may also, therefore, function as a useful addition to multi-disciplinary

interventions for such conditions. The present study highlights some considerations for this future research.

The immature state of the research and evidence base for MT, as it stands, is acknowledged however. It is therefore advised that any implementation of Mirror Specs in clinical settings should take into account the issues, as described in previous chapters, surrounding the best method of assessing those who might be most likely to benefit from the therapy. Future use of MT should also assess how MT is implemented (that is, the protocols used) and how outcomes are measured. These outcomes should be assessed not just in the short-term but involve long-term follow-up of continued effects. This is discussed in more detail in the forthcoming section regarding future research. Indeed, research using appropriate implementation and sound methodology might add the current literature regarding MT with a Mirror Box.

If appropriate implementation of the Mirror Specs is subsequently achieved, this device could, as previously stated, offer an addition to multi-disciplinary approaches to treating pain and stroke etc. This could allow patients to perform MT at home regularly in order to improve symptoms. This might also facilitate, alongside psychological intervention, a sense of control over circumstances. Such treatment could also allow for cost-effective treatment in healthcare settings.

4.4 Methodological Considerations

4.4.1 Strengths and Limitations

A number of strengths and limitations in this study were taken into consideration when making the previous interpretations of the results.

4.4.1.1 Sample Size and Power

The study had a sufficient number of participants to meet statistical power to conduct ANOVAs.

4.4.1.2 Exclusion Criteria

Although the inclusion criteria were defined as ‘healthy’ volunteers the exclusion criteria did not specifically state that individuals with a previous history of psychiatric or brain injury should be excluded, as has been stated in previous studies (Amedi *et al.*, 2005, for example). Other potential exclusion criteria could have omitted individuals with previous or current history of drug or alcohol abuse. Both factors might have influenced the ability to respond quickly and accurately on the Finger Tapping Task, however, there was no evidence of this during testing.

4.4.1.3 Sample bias

In addition, as described previously, the sample included a majority of female psychology students and, due to the incentive of course credits, many were in their first or second year of undergraduate study. One possible factor influencing participation was that the majority of students took part in order to gain mandatory course credits, hence creating a potential bias in their completion of the task. Whilst many appeared interested in the study, it is possible that some took part in order to gain credits rather than to complete the experiment efficiently. Furthermore, as psychology students, they might also have been familiar with completing cognitive or visuomotor tasks. Yet, despite this, participants were naive to the hypothesised outcome of this novel task, which limits the possibility of previous experience influencing their performance in the current study.

In addition, several previous studies have included only right-handed participants (Matthys, *et al.*, 2009), which was not the case in this study. Theoretically, this could have created difficulties for right-handed participants in the left-handed tasks and

vice versa in that their ability to respond accurately and quickly may have been reduced. Conversely, the counterbalancing element to the running order should have offset any potential effect, as there should have been an equal number of participants completing the task with their dominant hand in each Mirror Device condition.

4.4.1.4 The Mirror Devices

This study observed that when using the Mirror Box participants had visual feedback of two hands moving whereas they had visual feedback of only one hand moving when using the Mirror Specs. This could have influenced, for example, how well participants identify with the limb they could see. Hypothetically, it may be more realistic to observe two moving hands (as indicated by one participant comment), which might influence how participants adapt to each device. Yet, the findings presented here suggest this did not cause a significant difference to participants when using the current task. The difference is however noted.

4.4.1.5 Finger Tapping Task

This study included a task was designed specifically to generate sensorimotor adaptation/transformation. A subsequent strength of this study was the time taken to design a task that would be likely to capture an effect of adaptation to Body Schema whilst using Mirror Devices. Extensive piloting was performed in order to provide the optimal conditions capturing the effect of the Mirror Devices, including appropriate auditory cue and the necessary number of trials.

4.4.1.6 Questionnaires

As has previously been highlighted (Mast *et al.*, 2003; Amedi *et al.*, 2005), the VVIQ is a subjective measure of participants' ability to form visual images and therefore relies on the completion of the questionnaire as honestly and accurately as possible. It is therefore also open to participant bias for example and the same might be true

for the SUIS. This subjective bias was considered when making interpretations about participants' true ability to form mental images in this study.

4.4.1.7 Haptic Task

The responses on this task were based on self reports rating the ability to form vivid motor images and as such are open to subjective bias and inaccurate reporting. The task is also dependent on participants' familiarity of the words presented to them. The researcher was careful to ensure all participants had the opportunity to declare if they were unfamiliar with a word. This was only reported on one occasion and was dealt with by giving a brief outline of the meaning of the word. Attention was paid to minimise the risk of giving a description that might influence the response.

4.4.1.8 Descriptive Information

Due to the fact that this study was not designed to analyse qualitative information, 'interpretations' made on the basis of participant comments, whilst potentially adding to the understanding of experiences during the study, can only be speculative and should be received with caution. It is difficult to establish whether all participants had different experiences of completing the task, for example, and of using the Mirror Devices, or if they employed different strategies or experienced changes in Body Image. Furthermore, some participants may not have experienced these symptoms, or indeed some participants merely may have not reported them.

4.5 Future Research

As previously stated, other clinical trials of the Mirror Specs are now in progress and the results and discussion points within this study suggest further options for the design of future research with the Mirror Specs.

Firstly, in terms of identifying participant samples, the literature suggests that a detailed assessment of clinical presentation, including type, severity and duration of illness, should be undertaken in order to identify those who may be most likely to benefit from intervention. This could involve consideration of whether individuals maintain a sense of ownership of body part(s), as indicated by Tichelaar *et al.*, (2007). Given the absence of any relationship between imagery abilities and performance on the task using both Mirror Devices, the current study indicates that investigating imagery abilities as a selection factor for MT might not be a useful when assessing who may benefit most from intervention.

In addition to clinical samples with clinical patients, future research could perhaps include male participants and healthy individuals who are not experienced in participating in such experiments (such as psychology students). This information could be used to compare and contrast the performance of a male versus a female population. It could also provide a comparison of the performance of healthy individuals who are not familiar with completing cognitive/visuomotor tasks and would therefore be naive to the nature of the task.

With respect to previous discussion of bimanual versus unimanual trials, future research could include a design involving all unimanual or all bimanual trials to investigate how participants' responses changed over 4 phases of exactly the same task completed in exactly the same manner. An interesting further investigation might involve an extended version of the procedure reported here, for example, how participants might perform during a second bimanual task whilst wearing the Mirror Devices. The current study did not include this due to the length of time of the experiment and the potential for fatigue.

In addition, future research might investigate implementing the Mirror Specs with a patient population, such as Chronic Regional Pain Syndrome (CRPS), completing both bimanual and unimanual trials, to investigate any differences between using one limb or both limbs during MT. This would therefore assess the effect of having two potential sources of sensory input versus visual feedback alone. The presence of any

differential effects of these conditions during Mirror Specs Therapy and Mirror Box Therapy would also be a worthwhile investigation. On a similar note, it could also be interesting to examine, more specifically, participant responses regarding having visual feedback of two moving limbs (as with the Mirror Box) and only one moving limb (as with the Mirror Specs).

The addition of a qualitative aspect to future research designs could also investigate and analyse, with specific intent, participant comments and experiences whilst using the Mirror Devices or on a specified task, more rigorously.

To reduce the potential for practice effects, future designs could employ a Between Subjects design with participants completing a task using only one device. The addition of a time gap between using each Mirror Device might also be useful. In addition, further studies could examine the use of these devices over a greater number of trials and over an extended period of time, for example, 2-3 weeks as has been successfully implemented in previous studies (Sekiyama, 2006).

Future investigations, as previously described, should also focus on establishing an optimal method of implementing MT, both with the Mirror Box and Mirror Specs. Such investigations should pay attention to establishing, for example, the appropriate duration of MT, in terms of length of and number of sessions, and the movements undertaken, in relation to the presenting condition of the participant. Given the evidence of Mirror Box Therapy combined with imagery (Moseley G. L., 2006), Mirror Therapy using the Mirror Specs combined with imagery could also be a beneficial method of implementation that would be worthwhile to investigate. Longer-term follow-up (for example, longer than 6 months, as has often previously been the case) would also provide an indication of the extent of lasting positive (e.g. Cacchio *et al.*, 2009; Yavuzer *et al.*, 2008) outcomes for MT with Mirror Specs.

Finally, the nature and extent of negative side effects of both MT with the Mirror Box and Mirror Specs should be investigated more thoroughly. It is possible that the

type and duration of negative side effects may differ depending on the participant sample MT is being used with or how it is implemented. Therefore, research should pay attention to any variation in reported symptoms in different participant samples and differing methods of MT implementation. Further insight into these symptoms might allow for methods of reducing negative outcomes when implementing Mirror Specs Therapy.

4.6 Summary and Conclusions

In conclusion, this study aimed to assess whether Mirror Specs could allow the same level of adaptation to reversed vision, and modification to visuomotor information, as the Mirror Box in healthy participants. It also aimed to investigate any relationship between this ‘adaptation’ and underlying imagery abilities.

The findings suggest participants were able to complete the novel sensorimotor task when using the Mirror Specs and Mirror Box in a similar way. There was no relationship between this and underlying imagery abilities.

The present study adds weight to the notion that the Mirror Specs might operate in a similar manner to the Mirror Box and subsequent research should investigate the possibility they might provide similar therapeutic value. Whilst suggesting this, a number of limitations to the sample and measures used are acknowledged by the researcher.

In addition, a number of recommendations are made for future research to investigate this notion more thoroughly, in a variety of patient samples and using comparable measures. Research also needs to investigate appropriate protocols for intervention to elucidate the optimal method of implementing MT in this format. Negative effects following use of the Mirror Specs should also be investigated.

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Appendices

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Appendix 1 Glossary of Terms

Definition of important terms.

Bilateral/bimanual: "applying to both sides of the body" (Kolb & Wislaaw, 2009, p G-5); using both hands.

Graded Motor Imagery Programme (GMIP): a combination of MT and Imagery involving three stages of treatment, the final involving MT.

Homunculus – meaning 'little human'. Map of representations of the "relative sensitivity of body parts" in the human cortex (Kolb & Wishaw, 2009, p.215)

Kinaesthetic feedback: feedback about the "perception of movement or position of the limb and body"(Kolb & Wishaw, 2009, p.G-18)

Mirror Box: a large wooden box with a mirror placed in the centre. The mirror is two sided so that an image can be generated on both the left and the right hand side. There is no roof to the box so that participants can see their hands inside the box. On the side facing participants, there are two holes so that participants can place each hand into the box at each side of the mirror.

Mirror Therapy: a therapeutic technique that relies on visual image of a moving limb provided through a mirror. It involves placing a limb (e.g. a right arm) in front of a mirror and observing the subsequent mirror image of that limb moving as if it were the opposite limb (e.g. the left arm). This creates an 'illusion' of two limbs being present and moving at once. Traditionally, this has involved using a Mirror Box.

Mirror Specs: plastic glasses with a prism attached. They are reversible in that they can be turned upside down in order to be used for left and right hands i.e. if the prism is placed on the left hand side of the participant's head, they are able to see an image of their right hand and the opposite is true if the prism is rotated so that the prism was on the right hand side. Only the eye that the prism is placed on is visible, the other is covered so that the participants cannot see their 'real' hand, only the mirror image of the hand.

Motor feedback: refers to information about the movement of a limb.

Motor homunculus: Map of representations of the relative sensitivity of body parts in the Primary Motor Cortex.

Motor Imagery: “ a covert cognitive process of imagining a movement of your own body (-part) without actually moving that body part”(as cited in de Vries & Mulder, 2007, p.6).

Pain of Predominantly Neuropathic Origin (POPNO): involving neuropathic pain, that is, pain that is associated with damage to the nervous system (Bogduk & Merskey, 1994)

Parietal Lobe: This region of the brain has an important functional role in integrating sensory information to generate a consistent picture of the surrounding world and in visuospatial processing. It integrates information about what and where an object is from the ventral and dorsal pathways to facilitate coordination of movements in response to objects in the environment (Kolb & Wishaw, 2009).

Plasticity: involves the ability of the brain to modify or adapt and involves the reorganisation of neural connections ; “ The ability of neurons to form new connections; the ability of the brain to change in various ways to compensate for the loss of function due to damage” (Kolb & Wishaw, 2009, p. G-25)

proprioception: refers to feedback about the "position and movement of the body and limbs".(Kolb & Wishaw, 2009, p. G-27)

proprioceptive feedback: regarding "sensory stimuli coming from the muscles and tendons" (Kolb & Wishaw, 2009, p. G-27).

Primary Motor Cortex: located in the posterior part of the frontal lobes and, in conjunction with the Premotor Cortex, is involved in planning and executing movements (Kolb & Wishaw, 2009).

Recalibration: involves the re-adjustment of for example a limb to a different position.

Sensory homunculus: Map of representations of the relative sensitivity of body parts in the somatosensory cortex.

Sensorimotor Transformation: – "neural calculations that integrate the movements of different body parts with the sensory feedback of what movements are actually being made and the plans to make movements. Sensorimotor transformation depends on both movement-related and sensory-related signals produced by cells in the posterior parietal cortex” Kolb & Wishaw, 2009, p. G-30).

Somatosensory cortex: forms part of the parietal lobe. Changes in the organisation of somatosensory cortex have increased the understanding of chronic pain conditions including PLP. The somatosensory cortex is involved in the process of receiving and integrating sensory information, such as information about touch, pain and temperature and representing body parts (Holmes & Spence, 2006).

Unimanual/unilateral: involving movement of one hand only.

Visual capture: Importance or dominance of visual information over other sensory modalities such as touch, and therefore the role of 'visual capture'. Involves the effect of vision upon the 'felt' location of a body part (Holmes & Spence, 2006)

Visual Imagery: "evoking or generating images not directly observed....seeing with the mind's eye"(Bertolo, 2005)

Appendix 2 Mirror Box



Appendix 3 Mirror Specs



Appendix 4 Summary of Studies investigating MT with Pain.

Author	Sample	Methods	Main Finding	Weaknesses	Relevance
Ramachandran (1993b)	2 cases of phantom limbs.	Bilateral mirror-symmetric movements (Clenching/unclenching fist) in Mirror Box.	Perceived 'movement' of phantom and associated sense of control.	Single n results less open to generalising to wider samples.	Initial indication of benefit of MT, instigated further research.
Ramachandran & Rogers-Ramachandran, (1996)	Series of 10 Case studies.	Unspecified symmetric movement using Mirror Box, eyes open/closed.	Reduction in pain in 4/10 cases , altered phantom sensation in 6/10 cases..	Length of MT session not reported.	Introduction of MT as therapeutic tool, instigated further research.
McCabe <i>et al.</i> (2003)	Case studies with 8 patients with CRPS.	6 weeks of MT, congruent flexion-extension movements of both limbs. 10 minutes max.	Reduction in pain in early CRPS (<8wks) and stiffness in intermediate CRPS (<1yr). No effect on chronic CRPS.	Small sample limits generalisability	MT is more effective for early to intermediate CRPS.
Mac Lachlan <i>et al.</i> (2004)	Case study with lower limb PLP.	MT in Clinical setting and at home. 10 exercises repeated 10 times in front of mirror.	Decreased PLP, increased sense of motor control, altered experience of phantom.	Single case limits generaliseability	Initial evidence of MT efficacy in lower-limb PLP.
Tichelkar <i>et al.</i> , (2007)	3 cases of CRPS.	MT combined with CBT, 4-6 weeks, 3-5x5minutes daily, making small movements.	Improvement in pain and walking in case 1, improvement in pain only in case 2, no improvement in case 3.	Small sample, mixed results.	Tentative evidence of efficacy of MT combined with CBT.

Author	Sample	Methods	Main Finding	Weaknesses	Relevance
Brodie <i>et al.</i> , (2007)	RCT, 80 lower limb amputees.	One session of MT or control (viewing movement of intact limb only), 10 movements 10 times.	MT increased phantom limb movement. Equal reduction in severity of phantom pain and sensation.	Nature of 'movements' in MT not reported.	Highlights importance of assessing different aspects of phantom limbs.
Chan <i>et al.</i> , (2007)	RCT, 22 lower limb amputees.	Mirror, imagery or control intervention. 4 weeks of 15 minutes daily.	Reduction in pain in all patients who received MT, 2 reductions and increases in pain in imagery group.	Absence of Follow up.	MT is more effective than Imagery.
Sumitani <i>et al.</i> , (2008)	22 individuals with chronic pain including PLP.	Daily MT, 10 mins, flexion-extension movements at patients' discretion. Assessed by interview.	MT more effective at reducing 'deep pain' i.e. crushing, clenching pain than superficial pain i.e. shooting or burning pain..		MT applied to specific types of pain may be more beneficial.

Author	Study/Sample	Methods	Main Finding	Weaknesses	Relevance
Dannall (2009)	Case study with lower limb amputee. Follow-up at 4 mths.	Daily MT, 1 mth in domestic setting. Unstructured protocol, 20-30 minutes, 2-3xweek, relaxation training.	Extinction of phantom pain, reduction in impact of pain, increased sense of control, maintained at 4 mths.	Small sample. Unstructured protocol. No assessment of differential outcomes of MT and relaxation.	MT can be successfully applied in a domestic setting.
Hussey-Anderson <i>et al.</i> , (2009)	Treatment intervention, 15 lower-limb amputees.	MT moving intact foot in mirror, 15 mins daily, 4 wks.	Reduction in pain, particularly for shooting, stabbing, sharp pain.	No control group. Details of MT movements is lacking.	Suggests that MT may be more effective for certain types of pain, implications for assessment protocols.
Cacchio <i>et al.</i> , (2009)	RCT, 48 patients with CRPS following unilateral stroke. 6 mth follow-up.	Intervention: 30-60 mins MT, 4 wks, flexion-extension of upper limb. Control: same intervention using covered mirror.	Reduced pain, improved functioning in Mirror group only. Results maintained at 6 mth follow-up.		More robust evidence for MT for CRPS following stroke.
Casale <i>et al.</i> , (2009)	Retrospective Review, 33 patients with phantom limbs.	Review of patients who had taken part in MT interventions. Data on adverse effects of MT was collected via reports in clinical diaries and	19 out of 33 experienced 'negative' outcomes including confusion and dizziness.	Retrospective method based on subjective reporting lacks rigorous, assessment/screening measures potential	Provides indication of potential adverse affects of MT for consideration in future studies.

Appendix 5 Summary of Studies examining MT with stroke patients

Author	Sample	Methods	Outcome	Limitations	Relevance
Altschuler <i>et al.</i> (1999)	Placebo-controlled pilot stud with 9 stroke Patients (>6mths post Stroke).	MT 4 wks, 15 mins per day, twice a day, 6 days a week. Bilateral upper limb movements.	Improvement in motion of arm movement. Moderate recovery in 3 patients, mild in 2 and none in 3		Provides preliminary findings in support of MT.
Sathian <i>et al.</i> (2000)	Single Case study with stroke patient.	2 weeks of MT involving bimanual movements.	Improvements in grip strength.	Single case study limits generalisability	Preliminary evidence of utility of MT in stroke rehabilitation.
Stevens & Stoykov, (2003)	Case series of MT with 2 stroke patients. Time following - = 14 mths and 6yrs, 2mths. 3 mth follow-up.	Imagery Task, presenting computer-generated arm/wrist movements. Mirror box Task moving functional limb in front of mirror. Therapy = 1 mth.	Improvement in grip strength and wrist extension. Improvement evident at 3 mth follow-up, particularly for pt 1.	Small numbers limits generalisability.	Indication of utility of early intervention using MT.
Stevens & Stoykov, (2004)	Case Study of upper-extremity hemiparesis 1 yr, 3 mths post-Stroke.	MT , 35 minutes, 3 times a week, 3 weeks. Finger Tapping, wrist flexion-extension movements.	Improved function of the affected limb.	Single N limits generalisability. No follow-up of long-term effects.	Indication of efficacy of MT in Stroke.

Author	Sample	Methods	Outcome	Limitations	Relevance
Sutbeyaz <i>et al.</i> (2007)	RCT, 40 stroke Patients, < 12 mths post-stroke. Lower limb paralysis. 6 mth follow-up	4 weeks of MT for 2-5 hours a day, 5 days a week. Flexion movements of ankle. Additional physiotherapy.	Improvement in motor functioning in hand, continued at follow-up.	No differential outcomes for MT and physiotherapy.	Robust evidence of MT efficacy sustained in lower-limb stroke.
Yavuzer <i>et al.</i> , (2008)	RCT. 40 stroke patients with upper limb hemiparesis.. <12mth post-stroke. 6 mth follow-up.	In addition to conventional Therapy, 30 mins of MT(Flexion/extension movements of wrist ,finger of functioning limb). 5 sessions per week, 4 weeks.. Control group using covered mirror	Improvements in range of movement and hand related functioning. Improvements maintained at 6 mth follow-up.	Differential effects of MT and conventional therapy not considered.	Robust evidence for efficacy of MT, in addition to conventional therapy, sustained in upper-limb hemiparesis following stroke.
Dohle <i>et al.</i> (2008)	RCT. 36 patients, < 8 wks post-stroke, first stroke, in region of middle cerebral artery)	6 weeks of 30 minutes of MT, 5 times per week.	Improvement in sensory and attentional deficits, hemineglect.	Potential for spontaneous recovery versus effect of MT.	Evidence of utility of early intervention of MT in stroke.

Appendix 6 Summary of Studies investigating Imagery Therapy

Author	Study type/Sample	Methods	Outcome	Weaknesses	Relevance
Moseley, (2006)	RCT. 51 patients with PLP or CRPS.	Graded Motor Imagery Programme inc. Imagined and Mirror Movements	Pain reduced, functioning improved. Measured by McGill Pain Qu. Improvements maintained a 6 mth follow-up.	.	Evidence of efficacy of combined MT and imagery approach
Gaggioli, Meneghini, Morganti, Alcaniz, & Riva (2006)	Case Study, upper-limb paresis following subcortical ischemic stroke 13 mths post-stroke).	Phase 1: Mental Practice using computer assisted visual mirror. ½ hr. 3 times a wk over 4 wks. Phase 2: 1 mth. Use of portable computer device at home (in addition to ½ hr physical therapy).	Functional improvement in paretic limb following inpatient intervention, modest improvement after home rehabilitation.	No control condition. Differential outcomes of intervention and physical therapy not reported. Questionable generalisability.	Indication of computer-based implementation of Imagery. Emphasises importance of practice of imagery techniques at home
Sharma, Pomeroy, & Baron, (2006)	Review of methodological issues in applying	Systematic review of available studies on Motor Imagery.	Encouraging effects of Motor Imagery following stroke.		Highlights difficulties with screening process.

Author	Study type/Sample	Methods	Outcome	Weaknesses	Relevance
Page <i>et al.</i> , 2007	RCT, 32 stroke patients (ave. 3.6yrs post stroke).	Mental imagery therapy, 30 mins, 2xper wk, 6 wks, mental practice of activities of daily living. Control: relaxation therapy.	In imagery group, significant reductions in impairment of affected arm, increase in movement. No significant change in control group.	Location of brain injury and variance in duration of impairment not reported.	Robust evidence of efficacy of imagery with stroke.
Chan <i>et al.</i> , (2007)	RCT, 22 lower limb amputees	Mirror, imagery or control intervention. 4 weeks of 15 minutes daily	Reduction in pain in all patients following MT, 2 reductions and 3 increases in pain in imagery group.	No follow-up. Duration/characteristics of pain not assessed.	Indication that MT is more effective than Imagery
MacIver <i>et al.</i> , (2008)	13 upper-limb amputees with PLP. Duration of pain = 3 to 51 yrs.	6 (40 min)sessions of relaxation therapy and imagery of limb moving or resting. . Also practiced daily at home.	Reduction in pain, inc. exacerbations of over 50%, with reduction in associated cortical reorganisation .	Different effects of relaxation and imagery not assessed.	Imagery leads to reduction in pain, cortical reorganisation in PLP.
Zimmermann-Schlatter <i>et al.</i> , (2008)	Review of Motor Imagery research in Stroke.	Systematic Review of available literature.	Evidence indicates 'modest' support for imagery. Highlighted methodological weaknesses, small samples, lack of standardised protocols.		Indicates only 'modest' evidence for imagery alone.

Appendix 7 Body Schema Definition

The notion of Body Schema defined as the internal, neural representation of body parts can be viewed as distinct from the concept of Body Image, which can be defined as one's experience of one's body or conscious awareness (Schilder, 1935). Thus, the latter involves a conscious process and 'the way one's body *feels* to its owner' (Lotze & Moseley, 2007), while the former implies an unconscious process.

Holmes & Spence (2006) however refer to the possibility that the two concepts are linked i.e. that a change in Body Image, and identification with a new object/body part, is accompanied by a change in the Body Schema, the internal representation involved in sensorimotor coordination.

In addition, Tsakiris (2010) recently proposed a neurocognitive model of 'body ownership' that involves 3 elements. I) A pre-existing model of the body, ii) 'anatomical representation' of the body that controls incoming sensory information and that contributes to recalibration of visual and motor systems iii) the subsequent 'transfer of tactile sensation'.

It is important to note the difference between this representation of body parts involving integration of sensory input/transformation (or a functional representation) as opposed to the cortical representation that is part of the homunculus previously described. There is little information about the neural substrates of the Body Schema (Sekiyama, 2006) but it is thought that it is involved in coordinating different modalities (i.e. vision, touch) through coordinating regions of the somatosensory maps, as described earlier, and as such it is linked to the body's sensorimotor control areas (Kinsbourne, 2002).

Appendix 8 Ethical Approval Letters



Fife



Forth Valley



Tayside

Fife, Forth Valley & Tayside Research Ethics Service

Tayside Committee on Medical Research Ethics B

Research Ethics Office

Residency Block

Level 2

Ninewells Hospital & Medical School

DUNDEE

DD1 9SY

Ms Joanna L. Walker
Trainee Clinical Psychologist
Clinical Health Psychology
Level 6, South Block
Ninewells Hospital
Dundee
DD1 9SY

Date: 18 March 2009
Your Ref:
Our Ref: LR/09/S1402/16
Enquiries to: Mrs Lorraine Reilly
Extension: Ninewells extension 40099
Direct Line: 01382 740099
Email: Lorraine.reilly@nhs.net

Dear Ms Walker

Full title of study: Do Mirrors Specs produce a similar imagery ability to the Mirror Box?
REC reference number: 09/S1402/16

The Research Ethics Committee reviewed the above application at the meeting held on 13 March 2009. Thank you and your supervisor for attending to discuss the study.

Ethical opinion

The members of the Committee present gave a favourable ethical opinion of the above research on the basis described in the application form, protocol and supporting documentation, subject to the conditions specified below.

Conditions of the favourable opinion

The favourable opinion is subject to the following conditions being met prior to the start of the study.

You clarified the following points:

- Regarding A60 on the application form – you clarified that there would be a sample size of 40 participants with 20 in each group and they would all use the device, 20 to use device and then without and vice-versa.

Please clarify the following points in letter form and submit revised Participant Information Sheet and Questionnaires with version number and full date:

1. Regarding application form:

- A31 states there is no deadline for participants to decide if they wish to take part in the study or not, please clarify?
- Regarding A36 – please give further details regarding use of NHS computers.



2. Regarding Participant Information Sheet:

- Please print on departmental/University headed paper and include subject headings.
- Please adapt and include the student introductory paragraph:

'My name is and I am a (.....student or as appropriate) at the (University of Edinburgh or as appropriate). I am required to undertake a project as part of my course and invite you to take part in the following study. However, before you decide to do so, I need to be sure that you understand firstly why I am doing it, and secondly what it would involve if you agreed. I am therefore providing you with the following information. Please read it carefully and be sure to ask any questions you might have and, if you want, discuss it with others including your friends and family. I will do my best to explain the project to you and provide you with any further information you may ask for now or later.'

- Please explain a bit about the background and the reason for carrying out the study including what a computer image is.
- The £5 paid to participants for taking part is on the advert but should also be included in the Participant Information Sheet.
- Please adapt and insert standard complaints paragraph:

'You do not have to take part in this project and, even if you do, you are free to withdraw at any time without having to give me any explanation. If you do not take part or if you withdraw, this will have no effect at all on the treatment you receive now or in the future or your relationship with the staff who look after you.'

3. Regarding Questionnaires:

- These are devised more for amputees rather than healthy volunteers please make more reference to healthy volunteers.
- Please clarify as there is a questionnaire on mirror devices but not one on mirror specs.

Management permission or approval must be obtained from each host organisation prior to the start of the study at the site concerned.

Management permission at NHS sites ("R&D approval") should be obtained from the relevant care organisation(s) in accordance with NHS research governance arrangements. Guidance on applying for NHS permission is available in the Integrated Research Application System or at <http://www.rdforum.nhs.uk>.

Ethical review of research sites

The favourable opinion applies to the research sites listed on the attached form.

Approved documents

The documents reviewed and approved at the meeting were:



Document	Version	Date
Clinical Supervisor CV - Sara Joice		17 February 2009
Supervisor CV - David Gillanders		23 February 2009
Participant Consent Form	2	24 February 2009
Participant Information Sheet	2	15 February 2009
Letter of invitation to participant		
Advertisement	1	19 February 2009
Questionnaire: Vividness of Visual Imagery Questionnaire - VVIQ		
Questionnaire: Imagery Evaluation Form		18 February 2009
Questionnaire: Spontaneous Use of Imagery Scale - SUIIS		
Letter from Sponsor		17 February 2009
Covering Letter		17 February 2009
Protocol	1	18 February 2009
Investigator CV		19 February 2009
Application		19 February 2009
Letter from College of Humanities and Social Science		04 February 2009
Letter re Insurance/Indemnity Policy - Renewal Date 01/08/2009		

Membership of the Committee

The members of the Ethics Committee who were present at the meeting are listed on the attached sheet.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

After ethical review

Now that you have completed the application process please visit the National Research Ethics Website > After Review

You are invited to give your view of the service that you have received from the National Research Ethics Service and the application procedure. If you wish to make your views known please use the feedback form available on the website.

The attached document "After ethical review – guidance for researchers" gives detailed guidance on reporting requirements for studies with a favourable opinion, including:

- Notifying substantial amendments
- Progress and safety reports
- Notifying the end of the study

The NRES website also provides guidance on these topics, which is updated in the light of changes in reporting requirements or procedures.

We would also like to inform you that we consult regularly with stakeholders to improve our service. If you would like to join our Reference Group please email referencegroup@nres.npsa.nhs.uk.



09/S1402/16

Please quote this number on all correspondence

Yours sincerely



for **Dr Margaret A R Thomson**
Chair

Email: ethicshelpline.tayside@nhs.net

Enclosures: List of names and professions of members who were present at the meeting and those who submitted written comments
"After ethical review – guidance for researchers
Site approval form (SF1)

Copy to: Mrs Elspeth Currie, Research Governance Manager, University of Edinburgh
NHS Tayside R&D office



Tayside Committee on Medical Research Ethics B
Attendance at Committee meeting on 13 March 2009

Committee Members:

Name	Profession	Present	Notes
Dr Margaret A R Thomson	Consultant in Obstetrics & Gynaecology	Yes	Chair
Dr Lloyd Carson	Lecturer in Psychology	Yes	
Mrs Carolyn Donnelly		Yes	
Mrs Jacqueline Dunlop	Macmillan Genetic Counsellor	Yes	
Mrs Sandra Forbes	Lecturer in Nursing	No	Vice-chair, Apologies given
Professor David Levison	Professor of Pathology and Head of Tayside Tissue Bank	Yes	
Dr Carol MacMillan	Consultant in Intensive Care Medicine & Anaesthesia	Yes	Alternate Vice-chair
Dr Robert Martin	GP Member	Yes	
Mr Charles McMurray	Retired NHS Manager	No	Apologies given
Dr Simon Ogston	Lecturer	Yes	
Mrs Patricia Robb	Retired RGN	Yes	
Mrs Anne Simpson	Retired Community Nurse	Yes	
Dr Wendy B Stevenson	Retired	Yes	
Mr Peter Withers	Retired	Yes	

Also in attendance:


Name	Position (or reason for attending)
Ms Caroline Ackland	Scientific Officer
Mrs Lorraine Reilly	Co-ordinator Committee B



Tayside Committee on Medical Research Ethics B

LIST OF SITES WITH A FAVOURABLE ETHICAL OPINION

For all studies requiring site-specific assessment, this form is issued by the main REC to the Chief Investigator and sponsor with the favourable opinion letter and following subsequent notifications from site assessors. For issue 2 onwards, all sites with a favourable opinion are listed, adding the new sites approved.

REC reference number:	09/S1402/16	Issue number:	1	Date of issue:	18 March 2009
Chief Investigator:	Ms Joanna L. Walker				
Full title of study:	Do Mirrors Specs produce a similar imagery ability to the Mirror Box?				
This study was given a favourable ethical opinion by Tayside Committee on Medical Research Ethics B on 13 March 2009. The favourable opinion is extended to each of the sites listed below. The research may commence at each NHS site when management approval from the relevant NHS care organisation has been confirmed.					
Principal Investigator	Post	Research site	Site assessor	Date of favourable opinion for this site	Notes ⁽¹⁾
Ms Joanna L. Walker	Trainee Clinical Psychologist	University Of Dundee	Tayside Committee on Medical Research Ethics B	18/03/2009	
Approved by the Chair on behalf of the REC:  (delete as applicable) (Signature of Chair/Co-ordinator) Mrs. Lorraine Kelly (Name)					

(1) The notes column may be used by the main REC to record the early closure or withdrawal of a site (where notified by the Chief Investigator or sponsor), the suspension of termination of the favourable opinion for an individual site, or any other relevant development. The date should be recorded.





Fife



Forth Valley



Tayside

Fife, Forth Valley & Tayside Research Ethics Service

Tayside Committee on Medical Research Ethics B

Research Ethics Office
School of Nursing & Midwifery
Residency Block
Level 2
Ninewells Hospital & Medical School
DUNDEE
DD1 9SY

Ms Joanna L. Walker
Trainee Clinical Psychologist
Clinical Health Psychologist
Level 6, South Block
Ninewells Hospital & Medical School
Dundee
DD1 9SY

Date: 29 April 2009
Your Ref:
Our Ref: LR/DL/09/S1402/16
Enquiries to: Mrs Lorraine Reilly
Extension: Ninewells extension 40099
Direct Line: 01382 740099
Email: Lorraine.reilly@nhs.net

Dear Ms Walker

Full title of study: Do Mirrors Specs produce a similar imagery ability to the Mirror Box?
REC reference number: 09/S1402/16
Protocol number: 1

Thank you for your email of 29 April 2009. I can confirm the REC has received the documents listed below as evidence of compliance with the approval conditions detailed in our letter dated 13 March 2009. Please note these documents are for information only and have not been reviewed by the committee.

Documents received

The documents received were as follows:

Document	Version	Date
Participant Information Sheet	3	28 April 2009
Response to Request for Further Information		29 April 2009
Questionnaire: Mirror Device Evaluation	2	04 April 2009
Consent Form	2	15 February 2009

09/S1402/16 Please quote this number on all correspondence

Yours sincerely

**Mrs Diane Leonard
Administrative Assistant**

Copy to: Mrs Elspeth Currie, Research Governance Manager, University of Edinburgh
NHS Tayside R&D Office



EC/LH

27 March 2009

Ms Joanna Walker
Trainee Clinical Psychology
Level 6, South Block
Ninewells Hospital & Medical School
DUNDEE
DD1 9SY

Dear Ms Walker,

NHS TAYSIDE MANAGEMENT/GOVERNANCE APPROVAL

R&D Project ID: 2009GM01

Title: Do Mirror Specs Produce A Similar Imagery Ability to the Mirror Box?

Ethics Ref: 09/S1402/16 Ethics Approval Date: 18/13/09

Funder: Unfunded

Sponsor: University of Edinburgh

NHS Support Costs: NIL

The above project has been registered on the NHS Tayside R&D database, as required by the Research Governance Framework. Full ethics approval has been obtained and there are no local NHS Support Costs associated with this research project.

NHS Tayside has no objection to the project proceeding, provided all necessary approvals are in place and all amendments to the protocol, personnel involved and funding be notified to the R&D Office and all appropriate personnel.

It is important to note that all research must be carried out in compliance with the Research Governance Framework for Health & Community Care, GCP and the new EU Clinical Trials Directive (for clinical trials involving investigational medicinal products).

Kind Regards



Elizabeth Coote
Non-Commercial
R&D Manager

NOTE: This project is subject to a collaboration agreement which is about to be finalised

c.c. Mrs Lorraine Reilly (Assistant Administration Manager, NHS Tayside)
Elspeth Currie (Research Governance Manager, University of Edinburgh)
Dr David Gillanders (Lecturer in Clinical Psychology, University of Edinburgh)
Dr Lorna Talbot (Head of IPR & Enterprise Management, NHS Tayside)
Dr Nigel Mclean (SHIL)



East of Scotland Research Ethics Service

Tayside Committee on Medical Research Ethics B
Research Ethics Office
Residency Block
Level 2
Ninewells Hospital & Medical School
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DD1 9SY

Ms Joanna L. Walker
Trainee Clinical Psychologist
Clinical Health Psychology
Level 6, South Block
Ninewells Hospital
Dundee
DD1 9SY

Date: 31 August 2009
Your Ref:
Our Ref: LR/09/S1402/16
Enquiries to: Mrs Lorraine Reilly
Extension: Ninewells extension 40099
Direct Line: 01382 740099
Email: Lorraine.reilly@nhs.net

Dear Ms Walker

Full title of study: Do Mirrors Specs produce a similar imagery ability to the Mirror Box?
REC reference number: 09/S1402/16
Amendment number: 01
Amendment date: 24 August 2009

The above amendment was reviewed at the meeting of the Sub-Committee held on 27 August 2009 and by the vice-chair in correspondence.

Ethical opinion

The members of the Committee taking part in the review gave a favourable ethical opinion of the amendment on the basis described in the notice of amendment form and supporting documentation with the following conditions.

1. Please send short CV's for Dr Keehner and Dr Fischer for our records.
2. Please clarify start date as you state planned start date August 2009.

Approved documents

The documents reviewed and approved at the meeting were:

Document	Version	Date
Running Order Sheet	1	24 August 2009
Participant Signature Sheet		
Instruction Script	1	24 August 2009
Participant Consent Form	4	18 August 2009
Participant Information Sheet: Healthy Volunteers	4	18 August 2009
Questionnaire	VVIQ V3	24 August 2009



Questionnaire	SUIS V3	24 August 2009
Covering Letter		24 August 2009
Protocol	2	21 August 2009
Notice of Substantial Amendment (non-CTIMPs)	01	24 August 2009

Membership of the Committee

The members of the Committee who took part in the review are listed on the attached sheet.

R&D approval

All investigators and research collaborators in the NHS should notify the R&D office for the relevant NHS care organisation of this amendment and check whether it affects R&D approval of the research.


Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

09/S1402/16

Please quote this number on all correspondence

Yours sincerely



**Mrs Lorraine Reilly
Committee Co-ordinator**

Enclosures: List of names and professions of members who took part in the review

Copy to: Mrs Elspeth Currie, Research Governance Manager, University of Edinburgh
NHS Tayside R&D office



Tayside Committee on Medical Research Ethics B

**Attendance at Sub-Committee of the REC meeting on 27 August 2009 and
written comments received on 28 August 2009**

Name	Profession	Capacity
Mrs Jacqueline Dunlop	Macmillan Genetic Counsellor	Expert

Also in attendance:

Name	Position (or reason for attending)
Mrs Lorraine Reilly	Co-ordinator Committee B

Written comments received on 28 August 2009 from:

Name	Position
Dr Carol MacMillan	Consultant in Intensive Care Medicine & Anaesthesia





East of Scotland Research Ethics Service

Tayside Committee on Medical Research Ethics B

Research Ethics Office
Residency Block
Level 2
Ninewells Hospital & Medical School
DUNDEE
DD1 9SY

Ms Joanna L. Walker
Trainee Clinical Psychologist
Clinical Health Psychology
Level 6, South Block,
Ninewells Hospital & Medical School
Dundee DD1 9SY

Date: 02 September 2009
Your Ref:
Our Ref: LR/DL/09/S1402/16
Enquiries to: Mrs Lorraine Reilly
Extension: Ninewells extension 40099
Direct Line: 01382 740099
Email: Lorraine.reilly@nhs.net

Dear Ms Walker

Full title of study: Do Mirrors Specs produce a similar imagery ability to the Mirror Box?
REC reference number: 09/S1402/16
Protocol number: 1

Thank you for your Email dated 01 September 2009.. I can confirm the REC has received the documents listed below as evidence of compliance with the approval conditions detailed in our letter dated 13 March 2009. Please note these documents are for information only and have not been reviewed by the committee.

Documents received

The documents received were as follows:

Document	Version	Date
CV - Dr Madeleine Keehner		
CV - Dr Martin Fischer		01 September 2009

You should ensure that the sponsor has a copy of the final documentation for the study. It is the sponsor's responsibility to ensure that the documentation is made available to R&D offices at all participating sites.

09/S1402/16 Please quote this number on all correspondence

Yours sincerely

**Mrs Lorraine Reilly
Committee Co-ordinator**

Copy to: Mrs Elspeth Currie, Research Governance Manager, University of Edinburgh
NHS Tayside R&D Office





Fife

Amended



Forth Valley



Tayside

East of Scotland Research Ethics Service

Tayside Committee on Medical Research Ethics B

Research Ethics Office
Residency Block
Level 2
Ninewells Hospital & Medical School
DUNDEE
DD1 9SY

Ms Joanna L. Walker
Trainee Clinical Psychologist
Clinical Health Psychology
Level 6, South Block,
Ninewells Hospital & Medical School
Dundee DD1 9SY

Date: 22 September 2009
Your Ref:
Our Ref: LR/09/S1402/16
Enquiries to: Mrs Lorraine Reilly
Extension: Ninewells extension 40099
Direct Line: 01382 740099
Email: Lorraine.reilly@nhs.net

Dear Ms Walker

Full title of study: Do Mirrors Specs produce a similar imagery ability to the Mirror Box?
REC reference number: 09/S1402/16
Protocol number: 2
Amendment number: 1
Amendment date: 24 August 2009

Thank you for your Email dated 01 September 2009. I can confirm the REC has received the documents listed below as evidence of compliance with the approval conditions detailed in our letter dated 31 August 2009. Please note these documents are for information only and have not been reviewed by the committee.

Documents received

The documents received were as follows:

Document	Version	Date
CV - Dr Madeleine Keehner		
CV - Dr Martin Fischer		01 September 2009

You should ensure that the sponsor has a copy of the final documentation for the study. It is the sponsor's responsibility to ensure that the documentation is made available to R&D offices at all participating sites.

09/S1402/16 Please quote this number on all correspondence

Yours sincerely

L. Reilly
Mrs Lorraine Reilly
Committee Co-ordinator

Copy to: Mrs Elspeth Currie, Research Governance Manager, University of Edinburgh
NHS Tayside R&D Office





EC/LH

24 September 2009

Ms Joanna Walker
Trainee Clinical Psychologist
Clinical Health Psychology
Level 6, South Block
Ninewells Hospital and Medical School
DUNDEE
DD1 9SY

Dear Ms Walker,

ACCEPTANCE OF AMENDMENT LETTER

Tayside R&D Project ID: 2009GM01

Title: How do healthy participants adapt to reversed vision generated when using binocular Specs? An investigation into mirror devices, adaptation to body schema and imagery ability in healthy participants.

Main REC Ref: 09/S1402/16

Chief Investigator: Ms Joanna Walker

Amendment Number: 1

Amendment Dates: 24/08/09

Thank you for submitting the above Substantial Amendment for review by the R&D Office here in NHS Tayside. Following my assessment of the proposed changes I am pleased to confirm that NHS Tayside has no objection to these being implemented locally.

I thank you for keeping the R&D Office informed of the study progress.

Kind Regards

A handwritten signature in blue ink that reads 'Lindsay Hogg'.

Lindsay Hogg
Non-Commercial R&D Administrator



East of Scotland Research Ethics Service

Tayside Committee on Medical Research Ethics B

Research Ethics Office

Residency Block

Level 2

Ninewells Hospital & Medical School

DUNDEE

DD1 9SY

Ms Joanna L. Walker
Trainee Clinical Psychologist
Clinical Health Psychology
Level 6, South Block
Ninewells Hospital
Dundee
DD1 9SY

Date: 08 December 2009
Your Ref:
Our Ref: LR/09/S1402/16
Enquiries to: Mrs Lorraine Reilly
Extension: Ninewells extension 40099
Direct Line: 01382 740099
Email: Lorraine.reilly@nhs.net

Dear Ms Walker

Full title of study: Do Mirrors Specs produce a similar imagery ability to the Mirror Box?
REC reference number: 09/S1402/16
Amendment number: 02
Amendment date: 03 December 2009

The above amendment was reviewed on 07 December 2009 by the Sub-Committee in correspondence.

Ethical opinion

The members of the Committee taking part in the review gave a favourable ethical opinion of the amendment on the basis described in the notice of amendment form and supporting documentation.

Approved documents

The documents reviewed and approved at the meeting were:

Document	Version	Date
Letter		02 December 2009
Instruction Script	2	02 December 2009
Participant Information Sheet	5	03 December 2010
Protocol	3	02 December 2009
Notice of Substantial Amendment (non-CTIMPs)	02	03 December 2009

Membership of the Committee

The members of the Committee who took part in the review are listed on the attached sheet.



R&D approval

All investigators and research collaborators in the NHS should notify the R&D office for the relevant NHS care organisation of this amendment and check whether it affects R&D approval of the research.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

09/S1402/16 Please quote this number on all correspondence

Yours sincerely



**Mrs Lorraine Reilly
Committee Co-ordinator**

- Enclosures: List of names and professions of members who took part in the review
- Copy to: Mrs Elspeth Currie, Research Governance Manager, University of Edinburgh
NHS Tayside R&D office

09/S1402/16	09/S1402/16	09/S1402/16	09/S1402/16
09/S1402/16	09/S1402/16	09/S1402/16	09/S1402/16
09/S1402/16	09/S1402/16	09/S1402/16	09/S1402/16
09/S1402/16	09/S1402/16	09/S1402/16	09/S1402/16





Tayside Committee on Medical Research Ethics B

Sub-Committee of the REC correspondence received 07 December 2009

Comments received from:

Name	Position
Mrs Sandra Forbes	Lecturer in Nursing, Chair
Dr Carol MacMillan	Consultant in Intensive Care Medicine & Anaesthesia, Vice-chair

In attendance:

Name	Position (or reason for attending)
Mrs Lorraine Reilly	Co-ordinator Committee B





EC/LH

09 December 2009

Ms Joanne Walker
Trainee Clinical Psychologist
Clinical Health Psychology
Level 6, South Block
Ninewells Hospital and Medical School
DUNDEE
DD1 9SY

Dear Ms Walker,

ACCEPTANCE OF AMENDMENT LETTER

Tayside R&D Project ID: 2009GM01

Title: How do healthy participants adapt to reversed vision generated when using Mirror Specs? An investigation into mirror devices, adaptation to body schema and imagery ability in healthy participants.

Main REC Ref: 09/S1402/16

Chief Investigator: Ms Joanna Walker

Amendment Number: 2

Amendment Date: 03/12/09

Thank you for submitting the above Substantial Amendment for review by the R&D Office here in NHS Tayside. Following my assessment of the proposed changes I am pleased to confirm that NHS Tayside has no objection to these being implemented locally.

I thank you for keeping the R&D Office informed of the study progress.

Kind Regards

A handwritten signature in blue ink that reads 'Lindsay Hogg'.

Lindsay Hogg
Non-Commercial R&D Administrator



Fife



Forth Valley



Tayside

East of Scotland Research Ethics Service

Tayside Committee on Medical Research Ethics B

Research Ethics Office
Residency Block
Level 2
Ninewells Hospital & Medical School
DUNDEE
DD1 9SY

Ms Joanna L. Walker
Trainee Clinical Psychologist
Clinical Health Psychology
Level 6, South Block
Ninewells Hospital
Dundee
DD1 9SY

Date: 09 February 2010
Your Ref:
Our Ref: LR/09/S1402/16
Enquiries to: Mrs Lorraine Reilly
Extension: Ninewells extension 40099
Direct Line: 01382 740099
Email: Lorraine.reilly@nhs.net

Dear Ms Walker

Full title of study: Do Mirrors Specs produce a similar imagery ability to the Mirror Box?
REC reference number: 09/S1402/16
Amendment number: 03
Amendment date: 04 February 2010

The above amendment was reviewed by the Sub-Committee in correspondence.

Ethical opinion

The members of the Committee taking part in the review gave a favourable ethical opinion of the amendment on the basis described in the notice of amendment form and supporting documentation.

- Dr Simon Ogston, Statistician member pointed out that you should be able to calculate the power of the study for the revised numbers, using the Gpower program you used previously.

Approved documents

The documents reviewed and approved at the meeting were:

Document	Version	Date
Protocol	4	04 February 2010
Notice of Substantial Amendment (non-CTIMPs)	03	04 February 2010

Membership of the Committee

The members of the Committee who took part in the review are listed on the attached sheet.



R&D approval

All investigators and research collaborators in the NHS should notify the R&D office for the relevant NHS care organisation of this amendment and check whether it affects R&D approval of the research.

Statement of compliance

The Committee is constituted in accordance with the Governance Arrangements for Research Ethics Committees (July 2001) and complies fully with the Standard Operating Procedures for Research Ethics Committees in the UK.

09/S1402/16

Please quote this number on all correspondence

Yours sincerely



Mrs Lorraine Reilly
Committee Co-ordinator

Enclosures: List of names and professions of members who took part in the review

Copy to: Mrs Elspeth Currie, Research Governance Manager, University of Edinburgh
NHS Tayside R&D office



Tayside Committee on Medical Research Ethics B

Sub-Committee of the REC meeting in correspondence on 08 February 2010

Written comments received from:

Name	Profession	Notes
Mrs Sandra Forbes	Lecturer in Nursing	Chair
Dr Carol MacMillan	Consultant in Intensive Care Medicine & Anaesthesia	Vice-chair
Dr Simon Ogston	Lecturer	

Also in attendance:

Name	Position (or reason for attending)
Mrs Lorraine Reilly	Co-ordinator Committee B





EC/LH

10 February 2010

Ms Joanna Walker
Trainee Clinical Psychologist
Clinical Health Psychology
Level 6, South Block
Ninewells Hospital and Medical School
DUNDEE
DD1 9SY

Dear Ms Walker,

ACCEPTANCE OF AMENDMENT LETTER

Tayside R&D Project ID: 2009GM01

**Title: How do healthy participants adapt to reversed vision generated when using Mirror Specs?
An investigation into mirror devices, adaptation to body schema and imagery ability in healthy participants.**

Main REC Ref: 09/S1402/16

Chief Investigator: Ms Joanna Walker

Amendment Number: 03

Amendment Date: 04/02/10

Thank you for submitting the above Substantial Amendment for review by the R&D Office here in NHS Tayside. Following my assessment of the proposed changes I am pleased to confirm that NHS Tayside has no objection to these being implemented locally.

I thank you for keeping the R&D Office informed of the study progress.

Kind Regards

A handwritten signature in black ink that reads 'Lindsay Hogg'.

Lindsay Hogg
Senior Non-Commercial R&D Administrator

Appendix 9 Recruitment Poster



**Would you like to be involved in some exciting
new research?**

And be paid £5 for your participation?

I am a Trainee Clinical Psychologist completing my Doctoral Thesis and am looking for participants to volunteer in my Study.

I am investigating an exciting new device called 'Mirror Specs'. The study will involve completing a computer programme, involving hand movements and answering some questionnaires.

Participation will not involve any unpleasant procedures and is voluntary. So I am looking for anyone who might be interested in volunteering to get in touch for more information.

Contact me, Joanna Walker at,

Clinical Health Psychology Department, Level 6, South Block, Ninewells Hospital,

Dundee. Tel: 01382 740406 Email: joanna.walker3@nhs.net ***

Appendix 10 Participant Invitation Letter

Dear Participant,

My name is Joanna Walker and I am currently completing post-graduate training in Clinical Psychology at the University of Edinburgh. As part of my training, I am carrying out a research project and I am writing to invite you to take part in my study. I have enclosed an information sheet, providing details of any involvement in the study, and a consent form. Before you decide whether to take part or not, it is important that you understand why the research is being done and what you will be required to do.

Please read the information sheet carefully and if you have any queries, please contact myself or my supervisor. Contact details can be found at the end of the information sheet.

If you agree to take part, please complete the consent form. I will subsequently sign it and we can arrange a time for you complete the materials.

Please note that your decision to take part or not will not affect the current or future service that you receive from the NHS in any way, and will not affect your studies at the University of Dundee.

Many thanks for reading this information and, if you agree, for helping with my research project.

Yours Sincerely,

Joanna Walker
Trainee Clinical Psychologist

Appendix 11 Participant Information Sheet

MIRROR SPECS PROJECT: **HEALTHY VOLUNTEER INFORMATION SHEET**

My name is Joanna Walker and I am a Trainee Clinical Psychologist at the University of Edinburgh. I am required to undertake a research project as part of my course and invite you to take part in the following study. However, before you decide whether or not you wish to participate, I need to be sure that you understand firstly why I am doing it, and secondly what it would involve if you agreed. I am therefore providing you with the following information. Please read it carefully and be sure to ask any questions you have, and, if you want, discuss it with others including friends and family. I will do my best to explain and to provide any further information you may ask for now or later. You do not have to make an immediate decision.

BACKGROUND TO THE PROJECT

In this project, we are investigating what it feels like to use different mirror devices i) the mirror box and ii) mirror specs. A mirror box is a wooden box with a mirror that divides it into two sections. Mirror specs are ordinary spectacles or glasses (or your prescription specs, if you wear them) with a mirror prism attached to them. Both devices reflect the observed image so that, for example, if you view your right hand via the mirror it will look like your left hand.

The mirror box has been found to help reduce pain in people who have phantom limb pain following amputation. There is also evidence it can aid rehabilitation following stroke. This study is part of three studies investigating whether the mirror specs produce a similar effect. This study investigates their use with healthy participants.

WHAT DOES THE PROJECT INVOLVE?

As part of this study, we are interested to find out what it feels like to complete a computer task involving hand movements when using the mirror box and specs. During the computer task you are presented with an auditory cue and asked to make some finger tapping movements. You will be wearing switches that will be attached to your fingertips and these will record your responses. You will be asked to

complete the task whilst looking through the mirror specs or using the mirror box. Several cues are presented and we record how accurately you respond and how long it takes you to do this. On some trials you will complete this task using both hands. On other trials you will use only one hand. We are interested in how each device affects your ability to complete the task.

You also will be asked to complete a brief imagery task, which involves making comparisons between two objects and three questionnaires, which ask you in more detail about what it was like to use the mirror device and about how well you can form mental images. We expect it will take around 1 hour to complete everything. You will have the choice of being paid £5 or receiving course credits for taking part in this study.

WHAT ARE THE DISCOMFORTS OR RISKS?

We do not expect this process will involve any discomfort or side effects in any way and there will always be a facilitator available to provide information if need be.

WHAT WILL HAPPEN TO THE INFORMATION YOU COLLECT ABOUT ME?

You have been asked to participate because we want to know how it feels to healthy individuals when using the mirror specs. We are asking people who are students in the College of Medicine, Nursing & Dentistry and the School of Psychology and we are aiming to have around 40 people participate. We hope the information provided in this study will help provide more information on imagery abilities and the mirror devices.

Your responses on the computer programme and the information contained in the questionnaires will be remain confidential and will be used to as part of a University of Edinburgh Doctoral Thesis. You will be assigned a participant number, which will be used on all materials instead of names etc. and all data collected will be stored securely in the School of Psychology, University of Dundee. The results will be collated, analysed and will be made available to participants via a poster presentation displayed in the School of Nursing/ Medical School. You will also be given contact information so that you can get in touch with the facilitators to find out the results of the study if you wish to.

WHAT ARE MY RIGHTS?

Participation in this study is entirely voluntary. You do not have to take part, and if you do, you are free to withdraw at any time without having to give a reason. If you do not take part or if you withdraw, this will have no effect at all on the treatment you receive now or in the future or your relationship with staff who look after you. The Tayside Committee on Medical Research Ethics, which has responsibility for scrutinising all proposals for medical research on humans in Tayside, has examined the proposal and has raised no objections from the point of view of medical ethics. It is a requirement that your records in this research, together with any relevant medical records, be made for scrutiny by NHS Tayside and the Regulatory Authorities, whose role it is to check that research is properly conducted and the interests of those taking part are adequately protected.

Thank you for taking the time to read this Information Sheet and for considering taking part in this study.

Contact details:

J Walker: Department of Clinical Psychology/Pain Clinic, Ninewells Hospital,
Dundee. Tel: 01382 740406.

Email: joanna.walker3@nhs.net

Drs Madeleine Keehner and Dr Martin Fischer, Lecturers in Psychology, School of
Psychology, University of Dundee, Dundee, DD1 4HN, Tel:01382 344000

Appendix 12 Consent Form

'How do Healthy Participants adapt to reversed vision generated when using Mirror Specs? An investigation into mirror devices, adaptation to body schema and imagery ability in healthy participants'

Joanna Walker (Principal Researcher)

I have read the attached Information Sheet about the Mirror Specs Study and would like to participate in this study.

Please initial box

I have been given an explanation of what my involvement in the study will be and I understand what participation in this study involves.

I understand that my participation is voluntary and I have the right to withdraw from the study at any time, if I wish without explanation, without any medical care or legal rights being affected.

I understand that all data produced will remain confidential and the information I provide will be unidentifiable if published and disseminated to other bodies.

I hereby give my consent to participate in the Mirror Specs Study.

Name of participant:

Date:

Signature:

Name of person taking consent(Principal Investigator):

Date;

Signature:

Appendix 13 Task Instruction Script

During this experiment, I will be asking you to make some finger tapping movements in response to an auditory cue. You will be wearing these switches on your hands whilst you do this. Before we go any further, let's put these on your fingers (*experimenter attaches switches - check the correct switches are on the correct fingers and correct hand.*)

You will **hear 4 different tones** that correspond to each of your 4 fingers and when you hear each tone you should tap the corresponding finger with your thumb as quickly as you can. Here is an example, if you hear tone 1 (**experimenter plays tone**), you should tap your index finger with your thumb as fast as possible.

Different tones will be presented in a random order and there will be a gap between each one. **I will play each tone to show you which tone corresponds to which finger** (*experimenter plays each of the 4 tones and tells participant which finger it corresponds to*).

In some blocks, you will do this with both hands, and in other blocks of trials you will do this with just one hand. I will tell you before each block of trials whether you should use one hand or both.

You should make sure that you hit the switch that is on each thimble and you should do this as quickly and accurately as you can. As you hit the switch it will record your response and measure how long it takes you to respond.

You will do this task during 3 phases of trials but first we will do some practice trials to make sure you understand the task and you are familiar with which tones correspond to each finger. I will play a tone and you should respond accordingly.

Remember, try to tap the relevant finger as quickly as possible and make sure you hit the switch each time. Are you ready? Here we go...

3, 2, 4, 1, 3, 1, 4, 2, (*Experimenter plays **the tones** with pauses in between. She corrects any incorrect responses. Repeat practice trials until the participant can do the entire sequence with no errors*).

You will perform this task wearing the Mirror Specs or looking into Mirror Box. When you use each mirror device you will be able to see one hand reflected in the

mirror, while the other hand will be obscured from view by the mirror. In each block of trials I will tell you which hand will be visible. Let's start the first set of trials.
*(Note to Experimenter: For Mirror Specs **LEFT XP**, Prism should be situated on the **RIGHT** hand side. For Mirror Specs **RIGHT XP**, Prism should be situated on the **LEFT** hand side)*

Mirror specs instructions: Set-up & practice

Now I am going to ask you to do some practice trials. This is to familiarize you with how the voice commands will sound and get your responses up to speed. **The computer will play the tones one at a time and you must tap the relevant finger** with your thumb as quickly as you can. Do this with both of your hands. Ready? Here we go.

[Begin practice trials in Superlab.]

Mirror specs instructions: Phase 1

Good. Now we are ready to begin the real experimental task.

Please put on these specs with the prism on the [left / right]. Now raise both hands and adjust their position in front of you until you can clearly see one of them through the specs. Make sure the position of your two hands matches, in other words, your two hands should be at the same height and the same distance from your body. Your invisible hand should feel to be in the same position as your visible hand. Wiggle the fingers on both hands to make sure you are happy with the view you have. Can you see your hand clearly? Good.

In this first set of trials, you will hear **the same tones played in a random order**. Your task is to tap your fingers using **ONLY** the hand that you cannot see directly at the moment, in other words, do this with **ONLY** your [left / right] hand *[experimenter should identify the hand to be used by name]*. Your visible hand should remain still. While you are doing this, look at the hand you can see through the specs. Remember to respond as fast as you can, as we will be recording the speed of your responses. Do you understand? OK, let's start. Are

Mirror box instructions: Set-up & practice

Now I am going to ask you to do some practice trials. This is to familiarize you with how the voice commands will sound and get your responses up to speed. **The computer will play the tones one at a time and you must tap the relevant finger** with your thumb as quickly as you can. Do this with both of your hands. Ready? Here we go.

[Begin practice trials in Superlab.]

Mirror box instructions: Phase 1

Good. Now we are ready to begin the real experimental task.

Please look into the mirror box. Now place both hands either side of the mirror and adjust their position until you can clearly see one of them reflected in the mirror. Make sure the position of your two hands matches, in other words, your two hands should be at the same height and the same distance from your body. Your invisible hand should feel to be in the same position as your visible hand. Wiggle the fingers on both hands to make sure you are happy with the view you have. Can you see your hand clearly? Good.

In this first set of trials, **you will hear the same tones played in a random order**. Your task is to tap your fingers using **ONLY** the hand that you cannot see directly at the moment, in other words, do this with **ONLY** your [left / right] hand *[experimenter should identify the hand to be used by name]*. Your visible hand should remain still. While you are doing this, look at the hand you can see in the mirror. Remember to respond as fast as you can, as we will be recording the speed of your responses. Do you understand? OK let's start. Are you ready?

Mirror specs instructions: Phase 2

Now reposition your hands as before and make sure you can see one hand clearly in your view through the specs. Next we are going to do the same thing, but this time you will do the movements simultaneously with BOTH hands. Do you understand? Look at your hand in the specs, as before, while you are doing the movement, and remember to respond as quickly as possible. Ready? Here we go.

[Begin experimental trials in Superlab for the non-visible hand]

Good, take a break.

Mirror specs instructions: Phase 3

Now reposition your hands as before and make sure you can see one hand clearly in your view through the specs. Next we are going to do the same thing, but this time you will do the movements with ONE hand, just as you did before. You should use ONLY the hand that you cannot see directly at the moment, in other words, do this with ONLY your [left / right] hand *[experimenter should identify the hand to be used by name]*. Your visible hand should remain still. Do you understand? Look at the reflection of your hand in the specs, as before, while you are doing the movement, and remember to respond as quickly as possible, as we will be recording your speed. Ready? Here we go.

[Begin experimental trials in Superlab for the non-visible hand]

Well done, that is the end of this phase of the experimental task. Take a break.

[If this is the first set they have done, say:]

Next, we will repeat the same sets of trials but this time you will view your hand using the mirror box.

Mirror box instructions: Phase 2

Now reposition your hands as before and make sure you can see one hand clearly reflected in the mirror. Next we are going to do the same thing, but this time you will do the movements simultaneously with BOTH hands. Do you understand? Look at your hand in the mirror, as before, while you are doing the movement, and remember to respond as quickly as possible. Ready? Here we go.

[Begin experimental trials in Superlab for the non-visible hand]

Good, take a break.

Mirror box instructions: Phase 3

Now reposition your hands as before and make sure you can see one hand clearly in your view through the specs. Next we are going to do the same thing, but this time you will do the movements with ONE hand, just as you did before. You should use ONLY the hand that you cannot see directly at the moment, in other words, do this with ONLY your [left / right] hand *[experimenter should identify the hand to be used by name]*. Your visible hand should remain still. Do you understand? Look at the reflection of your hand in the mirror, as before, while you are doing the movement, and remember to respond as quickly as possible, as we will be recording your speed. Ready? Here we go.

[Begin experimental trials in Superlab for the non-visible hand]

Well done, that is the end of this phase of the experimental task. Take a break.

[If this is the first set they have done, say:]

Next, we will repeat the same sets of trials but this time you will view your hand using the mirror specs.

Appendix 14 VVIQ

VIVIDNESS OF VISUAL IMAGERY QUESTIONNAIRE (VVIQ)

TOTAL SCORES

(a) Eyes open =

(b) Eyes closed =

Total (a + b) =

Code:

Age:

Male or Female:

Occupation (if student, then give course of study and stage reached):

Visual imagery refers to the ability to visualize, that is, the ability to form mental pictures, or to "see in the mind's eye". Marked individual differences have been found in the strength and clarity of reported visual imagery and these differences are of considerable psychological interest.

The aim of this test is to determine the vividness of your visual imagery. The items of the test will possibly bring certain images to your mind. You are asked to rate the vividness of each image by reference to the 5-point scale given below. For example, if your image is "vague and dim" then give it a rating of 4. After each item write the appropriate number in the box provided. The first box is for an image obtained with your eyes open and the second box is for an image obtained with your eyes closed. Before you turn to the items on the next page, familiarize yourself with the different categories on the rating scale. Throughout the test, refer to the rating scale when judging the vividness of each image. Try to do each item separately, independent of how you may have done other items.

Complete all items for images obtained with the eyes open and then return to the beginning of the questionnaire and rate the image obtained for each item with your eyes closed. Try and give your "eyes closed" rating independently of the "eyes open" rating. The two ratings for a given item may not in all cases be the same.

Rating Scale

The image aroused by an item might be:

- Perfectly clear and as vivid as normal vision **rating 1**
- Clear and reasonably vivid **rating 2**
- Moderately clear and vivid **rating 3**
- Vague and dim **rating 4**
- No image at all, you only "know" that you are thinking of an object **rating 5**

.....

In answering items 1 to 4, think of some relative or friend whom you frequently see (but who is not with you at present) and consider carefully the picture that comes before your mind's eye.

Clear & Vivid	Clear & Reasonably Vivid	Moderately Clear & Vivid	Vague & Dim	No image at all
1	2	3	4	5

Eyes Eyes
Open closed

- 1 The exact contour of face, head, shoulders and body.
- 2 Characteristic poses of head, attitudes of body etc.
- 3 The precise carriage, length of step, etc. in walking.
- 4 The different colours worn in some familiar clothes.

.....

Clear & Vivid	Clear & Reasonably Vivid	Moderately Clear & Vivid	Vague & Dim	No image at all
1	2	3	4	5

Visualise the rising sun. Consider carefully the picture that comes before your mind's eye.

Eyes Eyes
Open closed

- 5 The sun is rising above the horizon into a hazy sky
- 6 The sky clears and surrounds the sun with blueness
- 7 Clouds. A storm blows up, with flashes of lightening
- 8 A rainbow appears

.....

Clear & Vivid	Clear & Reasonably Vivid	Moderately Clear & Vivid	Vague & Dim	No image at all
1	2	3	4	5

Think of the front of a shop which you often go to. Consider the picture that comes before your mind's eye.

Eyes Eyes
Open closed

- 9** The overall appearance of the shop from the opposite side of the road
- 10** A window display including colours, shape and details of individual items for sale.
- 11** You are near the entrance. The colour, shape and details of the door.
- 12** You enter the shop and go to the counter. The counter assistant serves you. Money changes hands.

Clear & Vivid	Clear & Reasonably Vivid	Moderately Clear & Vivid	Vague & Dim	No image at all
1	2	3	4	5

Finally, think of a country scene which involves trees, mountains and a lake. Consider the picture that comes before your mind's eye.

Eyes Eyes
open Closed

- 13** The contours of the landscape
- 14** The colour and shape of the trees
- 15** The colour and shape of the lake
- 16** A strong wind blows on the tree and
on the lake causing waves

.....

Appendix 15 SUIS

SPONTANEOUS USE OF IMAGERY SCALE (SUIS)

From Reisberg, D., Pearson, D.G., & Kosslyn, S.M. (2003). Intuitions and Introspections about Imagery: The Role of Imagery Experience in Shaping an Investigator's Theoretical Views. *Applied Cognitive Psychology*, 17, 147-160.

Please read each of the following descriptions and indicate the degree to which each is appropriate for you. Do not spend a lot of time thinking about each one, but respond based on your thoughts about how you do or do not perform each activity. If a description is always completely appropriate, please write "5"; if it is never appropriate, write "1"; if it is appropriate about half of the time, write "3"; and use the other numbers accordingly.

Never	Occasionally	Half the Time	Most of the Time	Always
1	2	3	4	5

_____ a. When going to a new place, I prefer directions that include detailed descriptions of landmarks (such as the size, shape and color of a gas station) in addition to their names.

_____ b. If I catch a glance of a car that is partially hidden behind bushes, I automatically "complete it," seeing the entire car in my mind's eye.

_____ c. If I am looking for new furniture in a store, I always visualize what the furniture would look like in particular places in my home.

_____ d. I prefer to read novels that lead me easily to visualize

where the characters are and what they are doing instead of novels that are difficult to visualize.

_____ e. When I think about visiting a relative, I almost always have a clear mental picture of him or her.

_____ f. When relatively easy technical material is described clearly in a text, I find illustrations distracting because they interfere with my ability to visualize the material.

_____ g. If someone were to tell me two-digit numbers to add (e.g., 24 and 31), I would visualize them in order to add them.

_____ h. Before I get dressed to go out, I first visualize what I will look like if I wear different combinations of clothes.

_____ i. When I think about a series of errands I must do, I visualize the stores I will visit.

_____ j. When I first hear a friend's voice, a visual image of him or her almost always springs to mind.

_____ k. When I hear a radio announcer or DJ I've never actually seen, I usually find myself picturing what they might look like.

_____ l. If I saw a car accident, I would visualize what had happened when later trying to recall the details.

Appendix 16 Running Order Sheet

Participant Number	Code	TRIAL ONE	TRIAL TWO
1		BOX LEFT	SPECS RIGHT
2		BOX RIGHT	SPECS LEFT
3		SPECS LEFT	BOX RIGHT
4		SPECS RIGHT	BOX LEFT
5		BOX LEFT	SPECS RIGHT
6		BOX RIGHT	SPECS LEFT
7		SPECS LEFT	BOX RIGHT
8		SPECS RIGHT	BOX LEFT
9		BOX LEFT	SPECS RIGHT
10		BOX RIGHT	SPECS LEFT
11		SPECS LEFT	BOX RIGHT
12		SPECS RIGHT	BOX LEFT
13		BOX LEFT	SPECS RIGHT
14		BOX RIGHT	SPECS LEFT
15		SPECS LEFT	BOX RIGHT
16		SPECS RIGHT	BOX LEFT
17		BOX LEFT	SPECS RIGHT
18		BOX RIGHT	SPECS LEFT
19		SPECS LEFT	BOX RIGHT
20		SPECS RIGHT	BOX LEFT
21		BOX LEFT	SPECS RIGHT
22		BOX RIGHT	SPECS LEFT
23		SPECS LEFT	BOX RIGHT
24		SPECS RIGHT	BOX LEFT
25		BOX LEFT	SPECS RIGHT
26		BOX RIGHT	SPECS LEFT
27		SPECS LEFT	BOX RIGHT
28		SPECS RIGHT	BOX LEFT
29		BOX LEFT	SPECS RIGHT
30		BOX RIGHT	SPECS LEFT
31		SPECS LEFT	BOX RIGHT
32		SPECS RIGHT	BOX LEFT
33		BOX LEFT	SPECS RIGHT
34		BOX RIGHT	SPECS LEFT
35		SPECS LEFT	BOX RIGHT
36		SPECS RIGHT	BOX LEFT
37		BOX LEFT	SPECS RIGHT
38		BOX RIGHT	SPECS LEFT
39		SPECS LEFT	BOX RIGHT
40		SPECS RIGHT	BOX LEFT

Appendix 17 NRs

NRs across All Phases for Mirror Specs and Mirror Box

	Phase 0(Practice)	Phase 1(unimanual)	Phase 2(bimanual)	Phase (unimanual)	Total
Mirror Specs	37	2	24	18	81
Mirror Box	14	4	14	2	34

Appendix 18 Total Scores for VVIQ/SUIS

	VVIQ Open	VVIQ Closed	SUIS
Total score	<u>42.34</u> (max = 80)	<u>36.91</u> max = 80	<u>40.01</u> max = 60
Range of ratings(min-max)	<u>(18-75)</u>	<u>(16-79)</u>	<u>(24-51)</u>

Appendix 19 Results of Correlations for Imagery Measures

In addition to the hypothesised correlations, significant correlations were found for the following imagery variables. The VVIQ Open scores correlated positively with VVIQ Closed ($r = .502$, $p < .01$, two-tailed), indicating that as VVIQ open scores increased (indicating low levels of vividness) so did the scores for VVIQ closed. VVIQ Open scores also correlated negatively with SUIS scores, ($r = -.375$, $p < .05$ two-tailed) indicating that as VVIQ scores increased (indicating low levels of vividness), SUIS scores decreased (indicating low level of spontaneous use of imagery), and negatively with Haptic Average Ratings ($r = -.436$, $p < .01$, two-tailed), therefore as Haptic Rating increased (indicating higher levels of haptic/motor imagery), VVIQ scores decreased (indicating high level of vividness of visual imagery).

The VVIQ Closed scores correlated negatively with SUIS, ($r = .563$, $p < .01$, two-tailed) indicating that as VVIQ Closed scores decreased (indicating high level of vividness of visual imagery), scores on the SUIS increased (indicating higher spontaneous use of imagery). VVIQ scores also correlated negatively with Haptic Average Rating ($r = -.453$, $p < .01$, two-tailed), indicating therefore that, as Haptic Ratings increased (indicating higher levels of haptic/motor imagery), VVIQ scores decreased (indicating high level of imagery).

Finally a significant positive correlation was also found between the SUIS and Haptic Average Rating ($r = .576$, $p < .01$, two-tailed) indicating that as SUIS scores increased (indicating higher spontaneous use of imagery), Haptic scores also increased (indicating higher levels of haptic/motor imagery).

Appendix 20 Post Hoc Analysis Result

The Post-hoc analysis on Error Rates included no responses as errors. The Repeated Measures ANOVA indicated no significant effect of Device on Error Rates ($F(1,43) = 3.959, p >.05$). In addition, however, no significant effect of Phase was detected for Error Rates ($F(1,43) = 3.727, p >.05$), indicating that there was no significant difference between Error Rates between Phase 1 and Phase 3. This provides a caveat to the previous result, however, it again provides no support for Hypothesis 1. Hypothesis 2 is again supported.