Not all left/right judgment tasks elicit motor imagery; experimental investigations comparing judgment and movement times

By

Matthew Taylor

A thesis submitted to the University of Birmingham for the degree of Master by Research

Motor Control and Rehabilitation Research Group

School of Sport, Exercise and Rehabilitation Sciences

College of Life and Environmental Sciences

University of Birmingham

July 2020

UNIVERSITY OF
BIRMINGHAM

University of Birmingham Research Archive

e-theses repository

This unpublished thesis/dissertation is copyright of the author and/or third parties. The intellectual property rights of the author or third parties in respect of this work are as defined by The Copyright Designs and Patents Act 1988 or as modified by any successor legislation.

Any use made of information contained in this thesis/dissertation must be in accordance with that legislation and must be properly acknowledged. Further distribution or reproduction in any format is prohibited without the permission of the copyright holder.

Abstract

Determining the laterality of an image depicting a disembodied hand (i.e. is it ‘left’ or ‘right’?) elicits motor imagery of the corresponding limb. In solving the task, we imagine our limb moving from its current position to the position shown in the image. This was most famously demonstrated by Parsons (1994) who showed that the time taken to make left/right judgments showed remarkable similarities with the time taken to move the limb to the same position.

Building on this established finding, the field of rehabilitation has adopted left/right judgment tasks (LRJTs) in the management of patients with chronic pain; the clinical value of the tasks residing in their ability to elicit motor imagery.

However, rather than limiting use to hand-based LRJTs, the field has developed new tasks involving different parts of the body and assumed that the same judgment process involving motor imagery occurs. Accordingly, LRJTs claiming to elicit motor imagery of the trunk, shoulder, neck and knee have been developed and are now sold commercially.

This thesis presents a series of experiments investigating the ability of different LRJTs to elicit motor imagery by building closely on Parsons’ (1994) influential study. It first examines a hand-based LRJT, replicating Parsons’ data for judgment and movement times (Chapter Two). Applying the same approach to a trunk-based LRJT revealed contrasting judgment and movement times; data were not consistent with the task eliciting motor imagery of trunk movements (Chapter Two). A second experiment examined judgment and movement times in response to shoulder-based images. Again, data were not consistent with shoulder-based LRJTs eliciting motor imagery of

shoulder movements (Chapter 3). A final experiment also examined judgment and movement times for a shoulder-based task, but this time using commercially available images. Data were again inconsistent with the task eliciting motor imagery of shoulder movements and also draws attention to other problems with the task (Chapter 4).

Together, findings in the thesis provide clear theoretical and applied messages. Data confirm the ability of hand-based LRJTs to elicit motor imagery and support their use in clinical practice. However, data provide no support for the ability of trunk-based and shoulder-based LRJTs to elicit motor imagery of the corresponding body parts. It concludes that these newer forms of LRJT should be withdrawn.

Acknowledgments

I would like to thank my supervisor Dr. David Punt for his continued support and enthusiasm for this project. And thanks to my friends and family for the love and support they have shown and the hard work they have put in to keep me (largely) sane whilst writing up this project.

Table of Contents

Chapter One: General Introduction

1.1 Introduction

Recognising an image of a hand as belonging to the left or right side of the body is an example of a left/right judgment task (LRJT). This particular form of the task has been shown to involve mental rotation of one's own limbs (Parsons, 1994). As one is not necessarily aware of making these mental rotations to solve the task, it is considered one that elicits *implicit* motor imagery (IMI). In more recent years, these tasks have been developed in other areas of the body such as the trunk (Bray and Moseley, 2011), knee (https://apps.apple.com/gb/app/recognise-knee/id1082943360), neck (Wallwork et al., 2013) and shoulder (Breckenridge et al., 2017) under the assumption that the same underpinning mechanisms are used (i.e. local IMI of the body part in question). This is an assumption that has been made without the same levels of rigorous testing that has been afforded to hand-based tasks.

1.2 The development of hand-based LRJTs.

Perhaps the most well-known LRJT is that of the hands. This involves presenting participants with an image of a hand and asking, "is this a left hand or a right hand?". This task was first investigated by Cooper and Shepard, (1975). Participants were shown line drawings of disembodied (cut at the wrist) hands presented with either the palm or the back of the hand facing the participant, and were presented in 0°, 60°, 120°, 180°, 240° and 300° orientations (i.e. 0° being fingers upright, 180° being fingers pointing downwards). The results showed that the further the presented hand was orientated away from 0°, the greater the participants' response times (RT). The authors of this study proposed that we solve the task by "moving a mental *phantom* of one of their own hands into the portrayed position and by then comparing its imagined appearance against the appearance of the externally presented hand." (Cooper and Shepard, 1975, p. 48).

This experiment was later developed by (Sekiyama, 1982). Here, participants were shown line drawings of disembodied hands in five different postures (see Fig. 1.1 for postures) and were rotated in 45° steps from 0° to 315°. This study once more showed an increase in RT with an increase in angular disparity. Sekiyama also developed the idea of "manageable directions" (Sekiyama, 1982, p. 91). This is the idea that movements which are harder to *physically* move into, also produce a longer *judgment* RT. For example, imagine looking at the palm of your right hand out in front of your face. Now imagine moving your hand clockwise to a four 'o' clock position. This is an impossible movement. In order to reach the target position of four 'o' clock, you instead rotate your hand in an anti-clockwise direction to get to the position. This movement requires you to move a greater distance than if the clockwise position was possible. Sekiyama (1982) suggests this movement pattern is preserved in imagined movements. Although in an abstract sense it is possible to imagine moving your arm clockwise to the four 'o' clock position; when completing these tasks, the mental transformation of your hand matches the time pattern of the physically possible movement, i.e. moving your hand through greater distance anti-clockwise (Parsons 1987b, Parsons 1994, Sekiyama 1982). Parsons (1987b) demonstrated this with LRJTs of disembodied hands and feet. The data showed that people took longer to *judge* the sidedness of the presented stimulus and to imagine moving to the same posture, when the presented stimulus had higher levels of awkwardness, e.g. were presented laterally away from the midline of the body. This finding is critical in supporting our understanding the hand-based LRJT as one where we are mentally reflecting our physical movement when completing it.

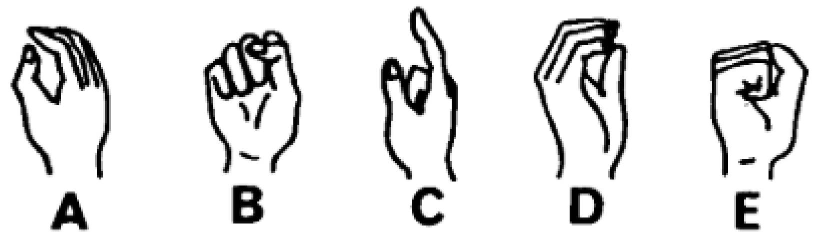


Fig. 1.1 showing the different postures used in Sekiyama (1982).

1.3 Evidence for hand-based LRJTs eliciting IMI

Parsons further developed work on hand-based LRJTs and conducted a later study that is pivotal to the idea of the hand-based task as one that elicits IMI. This study (Parsons, 1994) elegantly demonstrates the temporal regularity between the time taken to make a left/right judgment (LRJ) and the time taken to *physically* move to the same posture (see Fig 1.2). The study presents the idea that "one mentally simulates one's body movements by representing biomechanically accurate trajectories in a three-dimensional space with temporal dynamics comparable to real movement." (Parsons, 1994, p. 726). Parsons coined the term *"exact match confirmation"* (Parsons, 1994), p.730) which refers to the three-step process used to solve LRJTs of disembodied hands. Firstly, we make an initial 'best guess' of the handedness of the image presented to us based on its visual features. Secondly, we then mentally rotate our own corresponding hand so that it matches the same posture as the image presented. Finally, there is a confirmation process in which we compare the mentally rotated hand to the presented hand; if the two match we give our answer. If the two do not match, we then mentally rotate our other hand to confirm that the second hand is correct. Through in-depth study by (Parsons, 1987a, Parsons, 1987b, Parsons, 1994), it is thought that we do not use a disconfirmation strategy. For example, checking a dominant hand against the stimulus and inferring from a mismatch that it is the other hand would produce RT patterns with the non-dominant hand that reflected joint constraints of the dominant hand; this is not the case (Parsons, 1994).

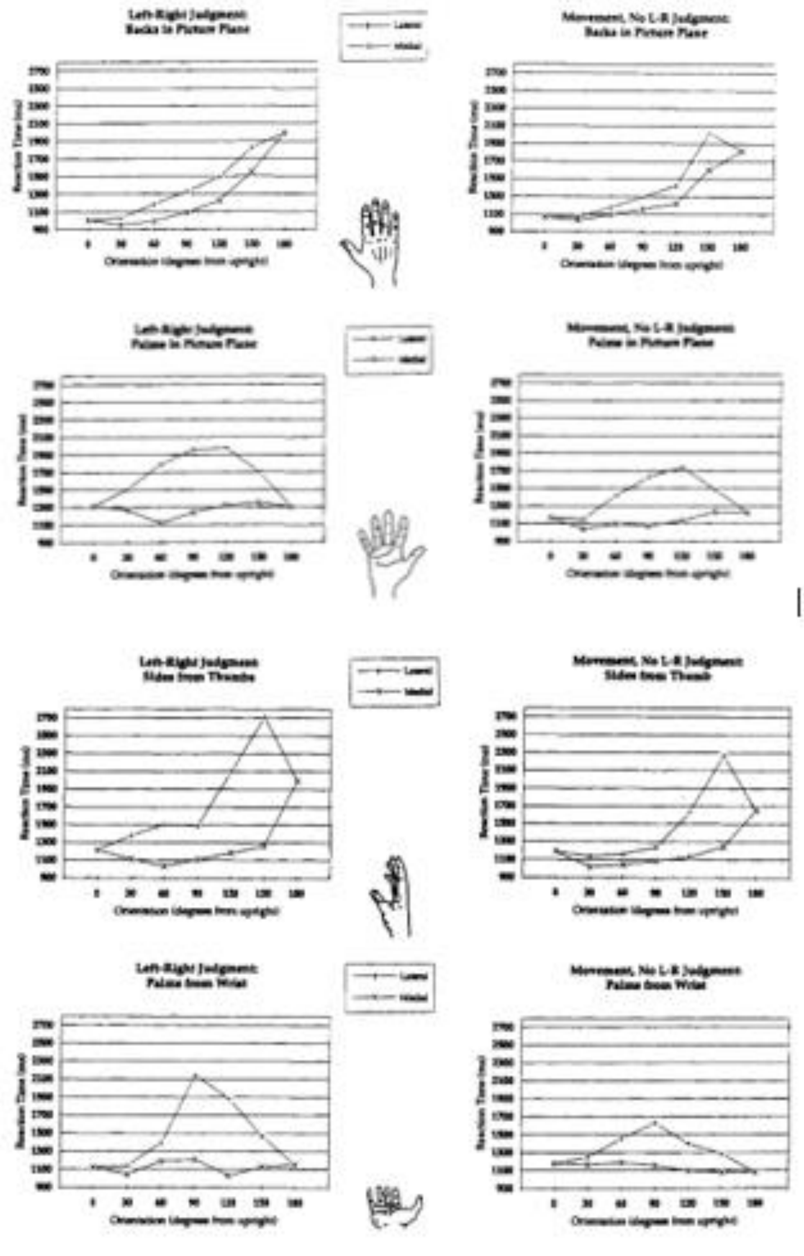


Fig 1.2. Shows the data taken from Fig. 3 Parsons, (1994 p.714-715). It shows the close relationship of the pattern of data from time taken to make a LRJ (on the left panels) and time taken to physically move to the same position (on the right panels).

Since this study there have been numerous other studies providing data consistent with the exact match confirmation hypothesis, both in psychological studies (Sirigu et al., 1996, Gentilucci et al., 1998, Schwoebel et al., 2001, Nico et al., 2004) and neuroimaging studies (Kosslyn et al., 1998, de Lange et al., 2006).

Further highlighting the motoric nature of the task, performance on a hand-based LRJT is modulated by participant posture. Sirigu and Duhamel (2001) demonstrated that performing a hand-based LRJT with hands behind the back led to significantly slower judgment times compared to when the hands were placed on the participant's lap. This finding that physical position of the hands modulates performance in a judgment task has been replicated several times (Shenton et al., 2004, Ionta and Blanke, 2009, Ionta et al., 2012) and shows that one's ability to complete the task is reliant on proprioceptive and efference copy information, two aspects that form the basis of our body schema representation (Shenton et al., 2004).

1.4 Body representations and their implications for LRJTs.

The brain holds various representations of our body and the world around it (Schwoebel and Coslett, 2005). These representations allow us to make sense of the interactions between our body and environment. For some of these representations, an anatomical basis exists, such as the motor cortex and somatosensory cortex (Kosslyn et al., 1998). One of these representations has already been touched upon; *body schema* (BSc). BSc is a dynamic coding of intrinsic positions of body parts (Buxbaum and Coslett, 2001) , and that relies on efference copy and proprioceptive information (Schwoebel and Coslett, 2005). Another of these representations is *body structural description* (BSD). This is a more general representation of a body that can be held for your own body and sustained for the processing of other peoples' bodies (see Corradi-Dell'Acqua and Rumiati, 2007 for a more in-depth review).

Research is ongoing but there has been evidence for these representations being functionally separate to one another. Schwoebel and Coslett (2005) compared the ability of stroke patients and unimpaired participants to undertake tasks that depend on either the BSc or the BSD. They also showed that deficits to BSD were associated with temporal brain lesions, and impairments to BSc were associated with lesions to the dorsal longitudinal fasciculus and/or the parietal lobes. This work is strengthened by *f*MRI investigations which have shown different neural correlates underpinning these different body representations (Corradi-Dell'Acqua et al., 2009). Together, these data are strongly suggestive of them being different and independent systems.

It is important to recognise this dissociation between the two body representations as it is so relevant to the mechanisms underpinning how different forms of LRJT are solved. As discussed earlier, *judgment* time for a hand-based LRJT is affected by the starting posture of the participant's own hands (Shenton et al., 2004, Ionta and Blanke, 2009) and there is a close temporal relationship between the *judgment time* and the time taken to move one's hand to the position shown (Parsons, 1987b, Parsons, 1994). Parsons (1987b) This shows that our ability to make mental transformations of the hand rely on a dynamic internal representation of hand position, which is derived from efference copy and proprioceptive information; in other words, undertaking a hand-based LRJT relies on BSc (Schwoebel and Coslett, 2005) and is fundamental to it being a process that elicits IMI.

In contrast, further study by Parsons (Parsons, 1987a) investigated a LRJT using stimuli containing a line drawing of a whole person presented in different orientations (see Fig 1.3), with one arm outstretched. Participants were asked to indicate which arm they thought was outstretched. The results showed that the RTs became slower the further the stimuli were orientated away from 0°. Unlike hand-based LRJTs, the direction of rotation (i.e. clockwise vs. anti-clockwise) did not influence the RTs. As part of the study, the author also asked participants for their introspections on how they thought they solved the task. This revealed that they thought they made a whole-body mental transformation (i.e. mentally rotated their whole body in space) to match the orientation of the image presented. Once this was done, participants were then able to make 'obvious' judgments as to the sidedness of the outstretched arm. This obvious judgment appears to be enabled by BSD (Corradi-Dell'Acqua et al., 2009) (participants were able to use the visuospatial information that was provided to them (i.e. body parts in relation to one another), compare this to their general representation they hold for 'bodies' and then give their answer. There was no suggestion from Parsons (1987a) that the process required any use local IMI (i.e. imagining the arm moving to the position shown).

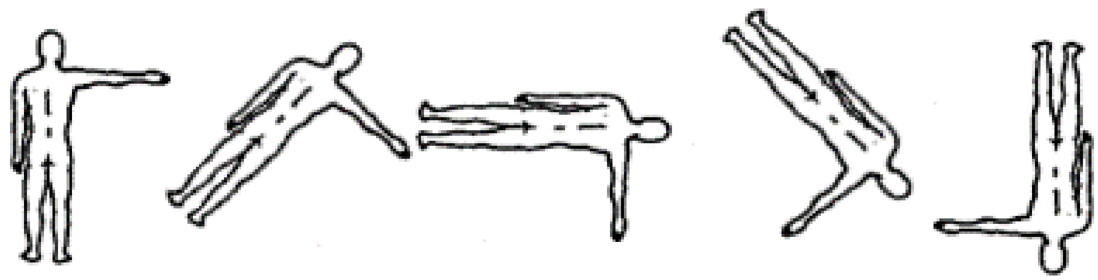


Fig 1.3 showing the line drawn whole body images presented in Parsons (1987a). Note the orientations presented here are examples and not exhaustive of the ones used in Parsons (1987a).

Given the recent development of other forms of LRJT (Bray and Moseley, 2011, Wallwork et al., 2013, Breckenridge et al., 2017) and the associated claims, recognising the dissociation described above will be shown to be particularly important and one that appears not to have been considered by those who have developed these new tasks.

1.5 The development of other body part based LRJTs.

In 2001, a hand-based LRJT was used as a tool to investigate whether BSc could be affected by peripheral factors such as pain. It was noted that in people with Chronic Regional Pain Syndrome (CRPS) judgment RTs were greater for images corresponding with the affected limb compared to the unaffected limb (Schwoebel et al., 2001). In a case study, Moseley (2004) noted that performing a hand-based LRJT caused feelings of pain and physical swelling in a patient suffering from CRPS.Further, Moseley (2004b) showed that the longer a patient had been suffering with CRPS the worse their performance was in a hand-based LRJT (Moseley, 2004b). Thus, there was a recognistion that the hand-based LRJT could be used as a measure of the motor representation of the affected limb. Additionally, as undertaking a hand-based LRJT elicits IMI, asking patients with chronic pain to practice the task may have therapeutic value by (i) activating motor representations of a painful limb, and (ii) its implicit nature would be unthreatening to patients who may be reluctant to achieve this by other means. Building on these potential clinical benefits, other LRJTs were introduced. For example, Bray and Moseley (2011) asked healthy participants and participants with low back pain to undertake a trunk-based LRJT, asking people to indicate which way the trunk was deviated (i.e. to the left or right?) on a series of images. It was reported that participants with low back pain were significantly less accurate (though not slower) than healthy controls, the authors interpreting this finding as one that showed the ability of their task to capture distortions in the body schema of individuals with back pain.

This and further research (Moseley et al., 2005, Moseley et al., 2008, Moseley, 2004b, Moseley, 2004a) research led to the development of the Graded Motor Imagery Handbook (GMIH) (Moseley et al., 2012). This handbook states that the longer pain persists the greater cortical reorganization takes place. This cortical reorganization allows for two things to happen. It lowers the level of stimulation needed for an individual to feel pain and secondly it allows the area that feels pain to spread, both of which lead to overall increased levels of pain (Moseley et al., 2012). It also sets out guidelines for clinicans on how to use LRJTs as part of a graded process (see Fig.1.4.) that helps to combat this cortical reorganization and help chronic pain suferers move without pain. This process aims to exploit the fact that LRJTs elicit IMI to help patients dissociate movement and pain. The theory is that IMI can activate pre-motor areas of the brain, which then in turn can change the excitabilty of the motor areas of the brain, without directly activating the motor areas. It is this direct activation of the motor areas which causes the pain. The authors claim that using IMI does two things. The first claim is that it promotes the inhibition of pain, and secondly, allows patients to dissociate movement from pain. The authors of the GMIH go on to suggest that if practiced enough times, it will eventually allow the patient to use expliict motor imagery in a way that does not evoke any feelings of pain (Moseley et al., 2012).

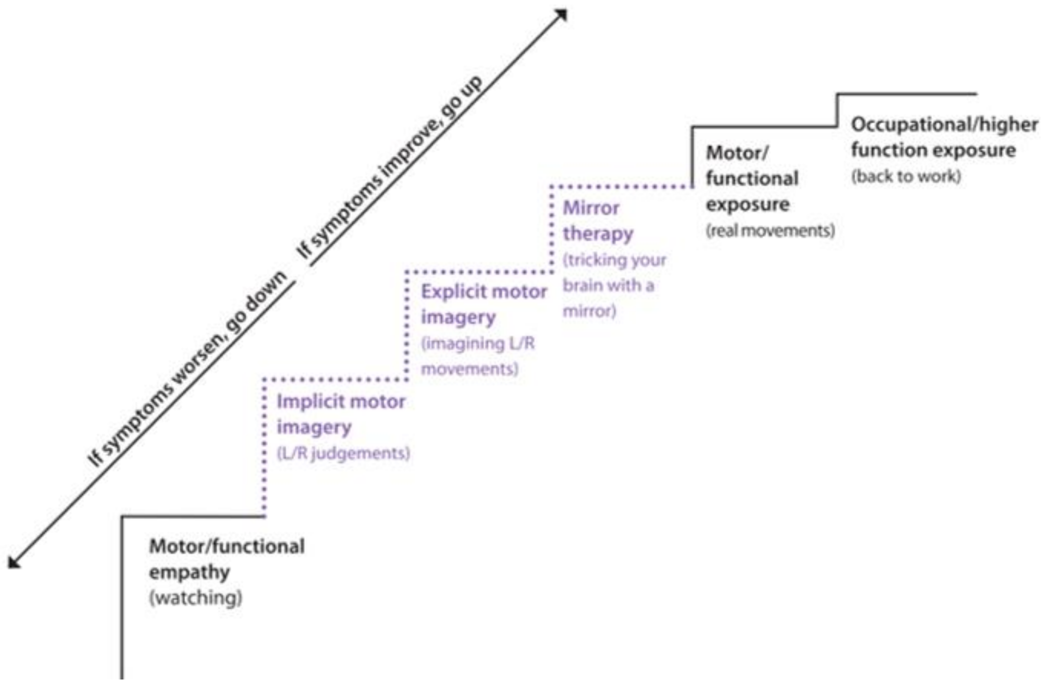


Fig. 1.4. This figure is taken from the Graded Motor Imagery Handbook (Moseley, Butler et al., 2012, p. 40). This shows the different steps of the graded motor imagery process.

Fig. 1.4 shows the proposed method by which the Graded Motor Imagery Handbook works acording to its authors. It illustrates the different steps of how graded motor imagery can be used as a wider rehabilitation plan. The plan doesn't have a definite starting point, but starts from what people can cope with. If performing a left/right judgment (LRJ) is too much for the participant, i.e. it causes pain, then the participant will start from the motor empathy stage. Each step to the left (on the above diagram) represents a step further away from directly stimulating the motor cortex. The motor empathy stage purely involves watching others move. Anecdotaly it has been shown to help improve the symptoms of a chronic pain sufferer who's pain worsened while they were completeing LRJTs . It is supposed that these improvements are somewhat down to mirror neurons (brain cells that fire the same way as when you complete an action yourself, or observe another completing the same action) (Moseley et al., 2012). The role of explicit motor imagery is that it replicates the cortical activation nearly as much as an actual movement, but does not cause the movement, and therefore does not have a chance to cause the sensory feedback of pain (Moseley et al., 2012). The authors speculate that the role of mirror therapy may be better replaced by further explicit motor imagery, but from a therapy standpoint, mirror therapy is a good tool to use as it is fun and novel and keeps motivation to stick to the overall rehabilitation program high (Moseley et al., 2012). If at any point a participant's symptoms worsen, the program drops back to the previous step, untill the participant can do this step pain free, and then works towards the end goal of functional, pain free movement. Each step is designed to more closely activate the pre-motor or motor cortex than the previous step; it is this gradual step process that the authors claim allow this program to work. It is important to rember this is the ideas expressed in the Graded Motor Imagery book and this process as a whole does not have supporting evidence.

The aim of the more recently developed LRJTs of the trunk (Bray and Moseley, 2011), knee (https://apps.apple.com/gb/app/recognise-knee/id1082943360), neck (Wallwork et al., 2013) and shoulder (Breckenridge et al., 2017) has been to exploit the same processes that have been demonstrated for the hand-based task (i.e. to elicit IMI of the given body parts) to help reduce pain in the resepective areas of the body. This is done under the assumption that the same methods are used to complete the hand-based task as theseother body part-based tasks.

1.6 Potential problems with the teraputic use of newer forms of LRJTs.

The more recent LRJTs have have been developed for theraputic use with the aim of reducing pain in various different body parts. The rationale behind this, as discussed earlier, is that these tasks elicit IMI. The authors of neck (Wallwork et al., 2013) and shoulder (Breckenridge et al., 2017) based LRJTs have drawn on siimilarities between their work and data from hand-based LRJTs for support that the same mechanisms are used. Although this may seem plausible, there are key differences between images of disembodied hands and the images used in the more recent tasks. Here, these differences will be discussed as a basis for recognising that individuals may use processes other than IMI in order to solve these tasks. Firtsly, there are very different amounts of visual information that are displayed in an other body part-based LRJT compared to an image of a disembodied hand (see Fig.1.5). An image of a disembodied hand forces comparison with one's own body to judge the sidedness. An image that contains any more information than just a disembodied hand or foot allows us to have access to BSD (see above), the visuospatially derived body representation which does not require the use of any IMI. This is explained by the findings of Ottoboni et al., (2005) and Tessari et al., (2012).

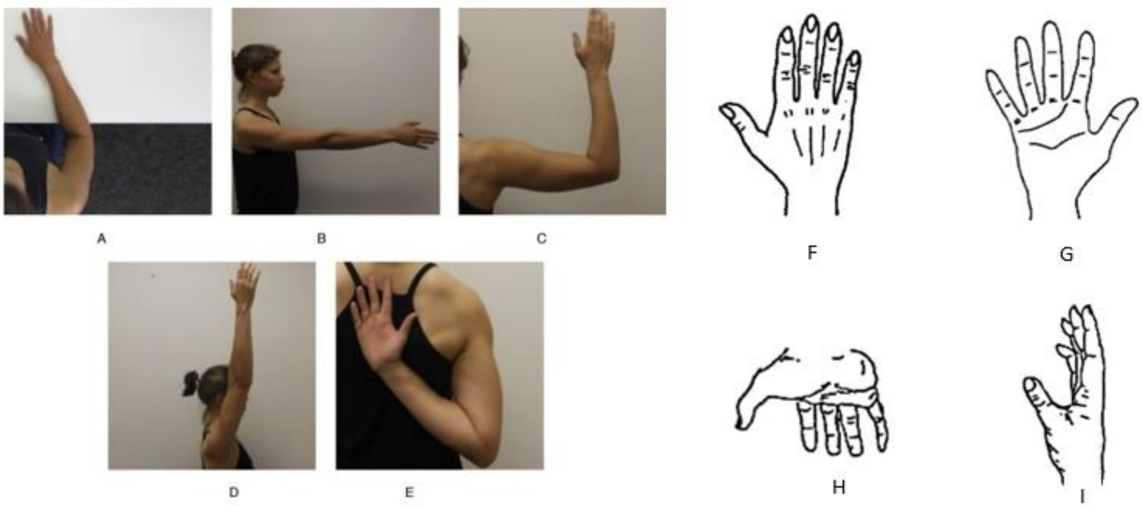


Fig. 1.5. Images A-E show shoulder-based images from Breckenridge *et al.,* (2017). Images F to I show the hand-based images presented in Parsons (1994). Images A-E show far greater amount of information than images F-I. Some contain the head where others do not. This fact forms a fundamental issue with the idea that LRJTs other than images of disembodied hands elicit IMI.

Ottoboni et al., (2005) completed a series of experiments to investigate the automaticity of handedness recognition. This was completed using a task adapted from the Simon paradigm (Simon, 1969) Ottoboni *et al.* presented photographs of hands from either the palm or back of the hand view and placed a coloured dot (red or blue) in the middle of the hand. Participants were then instructed to press a left sided button when the red circle appeared and a right sided button when the blue circle appeared. The results showed that when there was congruence between the hand required to indicate the response and the hand the coloured circle was presented in, there was a faster RT, but only for the back of the hand view. When the coloured circle was presented in the palm of the hand, this effect was reversed; there was a faster RT when the incongruent hand was shown. The authors termed this a *sidedness* effect. They inferred that what was automatically coded was not simply the laterality of the hand, but the side that hand belonged to on an imagined body map. If you are looking at the palm of a right hand, and this is connected to a body, that hand is on the left-hand side of the body, and therefore an automatic left sided code was generated. In the experiment, this led to faster RTs to a red circle when displayed in the palm of a right hand. This imagined body map is our body structural description representation. The key part of this study is that this finding only occurred once the images of the hand also included a forearm, there was no effect when the images of the hands were cut off at the wrist. Crucially the inclusion of the forearm allows the observer to “code the position of the hand in relation to an imaginary body, that faces away or towards the observer.” (Ottoboni *et al.*, 2005, p. 784).

This study was followed up by Tessari et al., (2012) partly replicating Ottoboni *et al.,* (2005) but this time using feet. The rationale for this study was that the hands are represented by larger proportions of the primary motor cortex and the primary somatosensory area, therefore it's not unreasonable to hypothesise that the more an area of the body is represented by these brain areas, the easier it is for that body part to be automatically coded within BSD. This study repeated the same procedure, with images of feet, and again found that it is *sidedness* which is coded for and not the laterality of the foot. Crucially, this was only the case when the image of the foot contained the ankle, when the ankle was removed, no effect was found. The role of the ankle, as with the forearm in the Ottoboni *et al.,* (2005) study, acts as a connector to the imaginary body. Although the hands and feet have different levels of representation in the somatosensory and motor cortex, this task has shown that they both show an automatic recognition of comparable magnitude *only* when the disembodied hand or foot is 'connected' to the imaginary body via an ankle or forearm. The authors state that these findings allow us to suggest that BSD is an entirely visuospatial representation, in agreement with (Acqua and Rumiati, 2009). Importantly for the current study, this is evidence for BSD allowing an automatic recognition of sidedness, derived from a purely visuospatial representation of a body, without the need for any proprioception or efference copy information (BSc). This means that when participants are viewing images of a deviated shoulder, that contains 'connectors' such as the back, neck and head, it is highly likely that participants are able to solve these tasks using BSD.

There are further issues with the use of LRJTs based on body parts other than disembodied hands (and feet) concerning the orientation of the presented images. The hand can be displayed in any orientation and still be physically possible for a participant to physically replicate the position.This is not the case for other body parts. For example take image C from Fig. 1.5 This shows a person in 90° shoulder abduction and is taken from Breckenridge and McAuley et al., (2017). If this image is orientated 180° it becomes impossible for a participant to physically replicate this position. Therefore, in order to solve the task, participants are required to make a whole-body mental transformation (like that of Parsons 1987a) to match their own orientation with that of the presented image. This presents a key difference between the hand-based and other body part-based LRJTs. Participants mentally orientate their hand to a position that is physically possible in a hand-based task, but when using shoulder-based images, a person must first mentally orientate their whole body to match that of the stimulus (Punt, 2017).

The data from hand-based LRJTs (Parsons, 1994), whole body-based LRJTs (Parsons, 1987a) and LRJTs of partial body parts, neck (Wallwork et al., 2013) and shoulder (Breckenridge et al., 2017) have all displayed data that shows the further orientated the stimulus is from 0°, the slower the judgment time. This, however, is a reflection of different processes that allow the participant to solve the tasks. In the hand-based task it is a reflection of the time taken to mentally represent the physical movement as discussed earlier and as is shown by various work (Parsons, 1994, Parsons, 1987b, de Lange et al., 2006). In comparison, in the *other* body part-based tasks, it appears that it is the tiime taken to make a whole body transformation to match the correspoinding orientaion of the presented stimulus that is critical and not the body part that is the focus (i.e. shoulder, knee, trunk, neck) of any particular LRJT (Parsons 1987a).

1.7 The present study

Considering the development of LRJTs of body parts other than disembodied hands, this study aims to test the claims of recent studies (Wallwork et al., 2013, Bray and Moseley, 2011, Bowering et al., 2013), that these elicit IMI, and therefore asses their use as a therapeutic tool. This study will compare the *movement* and *judgment* time of LRJT in *hands* and other parts of the body, with the aim of investigating whether local IMI is used to solve LRJTs. It is expected that the data from the LRJT of the *hands* will be in line with previous research and will be indicative of local IMI. For the first time this study will investigate LRJT of other parts of the body by comparing the *movement* time to the *judgment* time, using a similar procedure to Parsons (1994). If the results show similarities between the *judgment* and *movement* times, then this is a key piece of evidence of LRJT of other body parts eliciting IMI and could support their use in a clinical setting to have therapeutic value. If on the other hand, they do not demonstrate temporal regularity, this would be demonstrative of a lack of local IMI and therefore the therapeutic value of these tasks would be brought into question, along with the use of commercially available web-based tools.

Chapter Two: Examining Judgment times and movement times in response to images used in hand-based and trunk-based left/right judgment tasks (Experiment One)

2.1. Introduction

In Chapter One, evidence was presented from studies supporting the ability of hand-based LRJTs to elicit IMI. Much of this focused on the influential work of Parsons and in particular on a series of experiments he reported (Parsons, 1994). Importantly, this work showed the close relationship between the time taken to judge the sidedness of an image depicting a disembodied hand and the time taken to move one's corresponding hand from its current position to the one depicted. By doing so, it provided persuasive evidence that hand-based LRJTs elicit IMI. Perhaps most notably, this included providing the main basis for Parsons' related "exact match confirmation hypothesis" (Parsons, 1994, pg. 730) outlining the proposed process by which individuals make left/right judgments of images depicting disembodied hands. Accordingly, a critical component of this involves the mental simulation of one's own limb from its current position to the one depicted, so that these representations may be 'matched' before a judgment is made. In summary, Parsons (1994) provided compelling behavioural evidence that hand-based LRJTs elicit IMI. The subsequent introduction of hand-based LRJTs into clinical practice was therefore based on solid foundations.

With this in mind, the development and introduction of different types of LRJTs to clinical practice based on the assumption that they elicit IMI of a given part of the body (Moseley et al., 2012) may be considered problematic. Studies have emerged focusing on trunk-based (Bray and Moseley, 2011, Bowering et al., 2013) neck-based (Wallwork et al., 2013), shoulder-based (Breckenridge et al., 2017) and knee-based (Stanton et al., 2012) LRJTs, with each claiming that the tasks elicit IMI of the related body part and suggesting that the tasks be used both to assess body schema in individuals and as a therapy. However, to date none of these studies have examined resulting data for signs that the tasks actually elicit IMI in the manner claimed. The approach of examining judgment times and movement times for comparable patterns of data as described above (Parsons, 1994) provides a basis to generate such data, providing either empirical support for the claims of recent studies or suggesting such tasks have limited value.

Accordingly, this study had two main aims. Firstly, it aimed to replicate Experiment One from Parsons' (1994) influential study exactly, examining both judgment times and movement times to images depicting disembodied hands. By doing so, the study sought to replicate the similar patterns of data for each, providing further confidence in the robustness of the approach. Secondly, this study aimed to then apply the exact same approach to images of trunk-based LRJTs. Given the related concerns referred to above, together with the different makeup of these tasks compared with the hand-based task (outlined in Chapter 1), it was hypothesised *judgment times* and *movement times* to trunk-based LRJTs would not show similar patterns (contrary to those for hand-based LRJTs). If this proved to be the case, data would provide evidence against the ability of trunk-based LRJTs to elicit IMI of trunk movements.

2.2 Methods

2.2.1 Subjects:
Twenty-five right-handed participants (fourteen male) took part in this study. All participants were students from the University of Birmingham, mean age of 21.9 (range 18-35). Handedness was classified by the Edinburgh Handedness Inventory (Oldfield, 1971), no participants had any injuries or conditions affecting their limbs, and all had normal or corrected to normal vision. All participants provided written informed consent prior to their participation and the study was conducted in line with the Declaration of Helsinki as well as the university's policies for research and ethics.

2.2.2 Stimuli:
Hands: Line drawings of left and right hands were presented in four different views (back, palm, thumb and wrist) and in twelve different orientations (0°, 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300° and 330°). Stimuli of left and right hands were mirror images of each other. In total, there were ninety-eight different images of the hands. These are the same drawings that were used in Parsons' (1998), see Fig. 2.1

Trunks: Digitised images made using Poser software (https://www.posersoftware.com/) depicting a 3D model of a male human were presented in two different positions (rotation and side-flexion (see Fig. 2.2 and 2.3)), two different amplitudes (small and large see Fig. 2.2 and 2.3) and in two different views (allocentric and egocentric (see Fig. 2.2 and 2.3)). In total there were 196 different images of the trunk.

2.2.3 Procedure:
The experiment was a within-subject experimental design. The experiment took place in a quiet university laboratory with the experimenter present. All of the experiments were controlled by E-Prime 2 (Psychology Software Tool Inc. www.pstnet.com). The

experiment was split into two different tasks; a *Hand* task and a *Trunk* task, these both had a *judgment* and *movement* condition. Order of the tasks were counterbalanced. *Hand judgment task:* Participants were sat at a desk of a self-selected height at a comfortable distance from the computer monitor. Participants were asked to complete an LRJ using the stimuli shown in Fig. 1, i.e. select if you are looking at a right or left hand. Participants' responses were logged using a serial response box (see Fig. 2.4). Participants indicated a response of 'left' by pressing the leftmost button with their left index finger and indicated a response of 'right' by pressing the rightmost button with their right index finger. The trial started with a fixation cross appearing onscreen for a random period of time between 1000 milliseconds (ms) and 2500ms until one of the ninety-six images appeared at random. Participants were instructed to answer as quickly and as accurately as possible. Each image was shown only once. After a response was registered, a fixation cross was then displayed, followed by another stimulus. This continued until the end of the block. See Fig. 2.5 for an example of the onscreen progression. Participants were instructed to keep their head as still as possible whilst completing the task. If participants started to move their head during the experiment, the experimenter gave a verbal cue to keep still.

Hand movement task: Participants were again seated in front of a computer monitor at a self-selected height and a comfortable distance away from the screen. In this task, participants were asked to move their own hand to match the position shown. The order of the images was blocked, all of the left-sided images were shown to participants and then all of the right-sided images, or vice versa. The order of the blocks was randomised. Using the right side as an example, participants were instructed to press and hold down the rightmost button of the response box using their right index finger.

A fixation cross would be presented again lasting between 1000ms and 2500ms until an image was presented. When ready to move, the participant would take their index finger off the button and move to replicate the image shown on screen with their right hand. Once they had reached the target position, participants then pressed a footswitch to indicate they had done so. This also ended the trial and the fixation cross was presented again. The procedure was the same for the left hand images, except participants used their left hand index finger on the leftmost button to start the trial and moved their left hand to the target location.

Trunk judgment task: Participants in the trunk tasks were asked to stand, this is so the full range of motion required to reach the target position could be achieved unhindered. Studies have shown that posture can affect performance on LRJTs (Ionta and Blanke, 2009) and therefore the posture needed to be kept the same between the trunk *judgment* task and *movement* task. This task was designed to replicate the hand task as closely as possible, but with different stimuli. Participants were asked to make an LRJ of the 3D models presented in Fig. 2, i.e. is the model deviating towards their left or right side? In the trunk task there were 196 different images, compared to the ninety-eight of the hand-based task. This was due to the images being presented in two different views, twelve different orientations, two different sides and two different amplitudes. The procedure of this task was the same as the *hand judgment* task.

Trunk movement task: This task was designed to replicate the hand movement task as closely as possible. Again, participants were stood a comfortable distance in front of the computer monitor. Participants were presented with a 3D model deviated at the trunk. They were then asked to replicate the position shown as quickly and as accurately as possible. As with the hand movement task, the sidedness of the images were presented consecutively in left or right sided blocks. This enabled the participant to know which side they were going to move to before they saw the image. The way the response was measured in this task differed from the hand task; this was to ensure optimal measuring of the response time (RT) given the movements required from the participants. Using the right-sided block as an example, participants were instructed to hold a computer mouse in their right hand, down by their side and hold down the click. This triggered the fixation cross to be presented for between 1000ms and 2500ms. After the fixation cross the participant was presented with an image. Once the participant was ready to move, they were instructed to let go of the click, move to replicate the image presented and then press a footswitch to signify that they had reached their target position and end the trial.

2.2.4 Data analysis:

Accuracy and response time (RT) were analysed. Accuracy was only logged by E-prime in the *judgment* task. RT was the time between stimulus onset and either the participants pressing the response box button (for judgment tasks) or footswitch (for the movement tasks) and was measured in ms. For the *judgment* task correct responses only were analysed. Two participants scored below 75% accuracy on the *judgment* task, as a result they were not included in analysis. Only responses to the hand-based tasks that were between 500ms – 3500ms were included in analysis, this is in line with Ionta and Blanke (2009). For the trunk-based tasks, only responses that were between 500ms-5000ms were included. This was because a large portion of the data was longer than 3500ms. RT was analysed using four separate analyses of variance (ANOVA) with repeated measures: hand judgment, hand movement, trunk judgment and trunk movement. The ANOVAs for hand-based judgment and movement tasks included: *View* (back, palm, wrist, thumb), *Orientation* (30°, 60°, 90°, 120°, 150°), *Awkwardness* (medial, lateral) and *Side* (left, right). The ANOVAs for trunk-based judgment and movement tasks included *View* (allocentric, egocentric), *Position* (rotation, side-flexion), *Orientation* (30°, 60°, 90°, 120°, 150°), *Amplitude* (large, small) and *Side* (left, right).

Fig. 2.1. This shows the right-handed images used in the hand-based tasks. These images were mirror reversed to create the left-handed images. These images were taken from Parsons (1994).

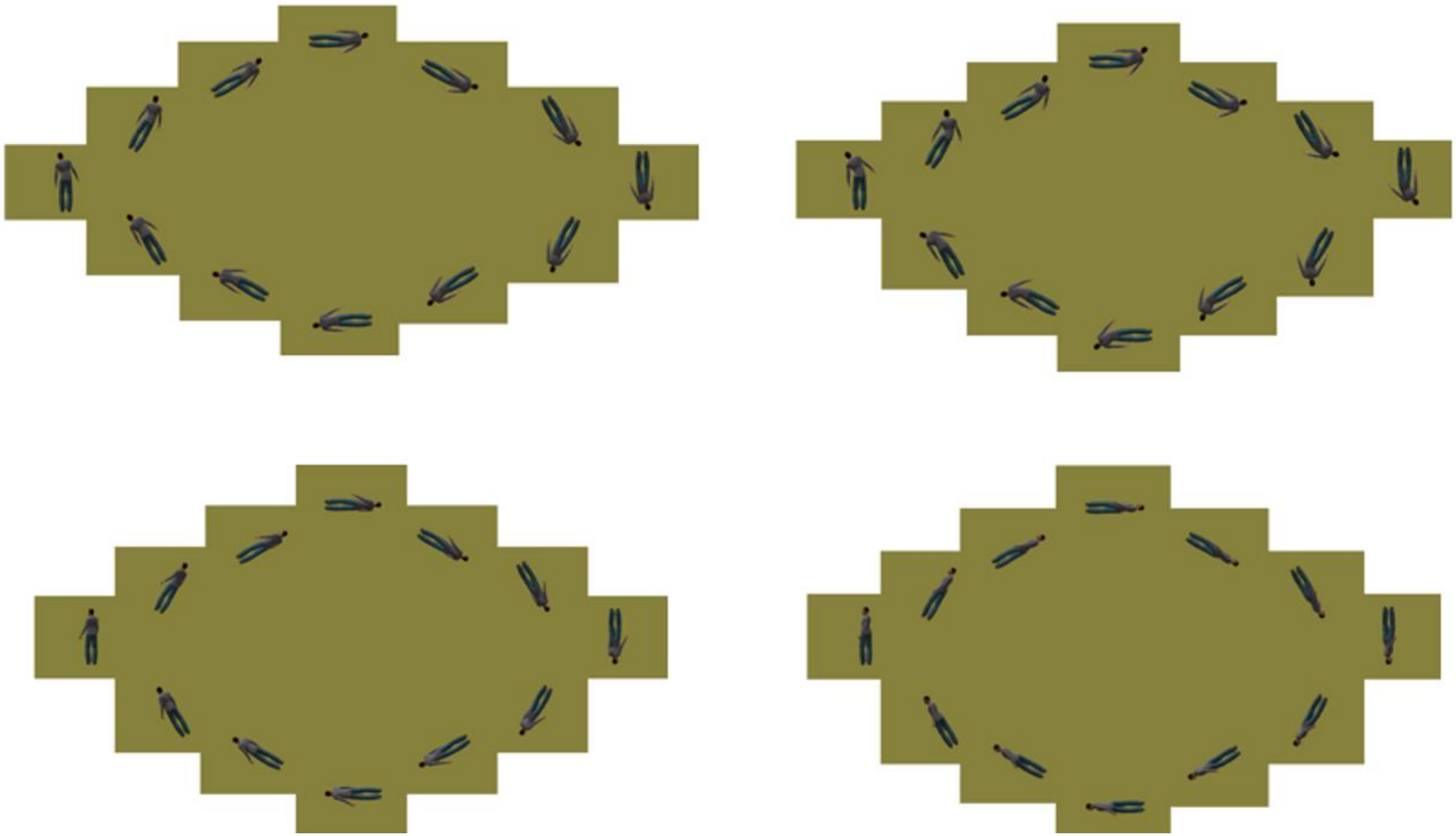


Fig. 2.2. Displaying the egocentric 3D models in all positions. From top left clockwise: egocentric left side-flexion small amplitude, egocentric left side-flexion large amplitude, egocentric left rotation large amplitude, egocentric left rotation small amplitude. These images were mirror reversed to create the right-sided images. Allocentric images were the same with the models facing towards the participants.

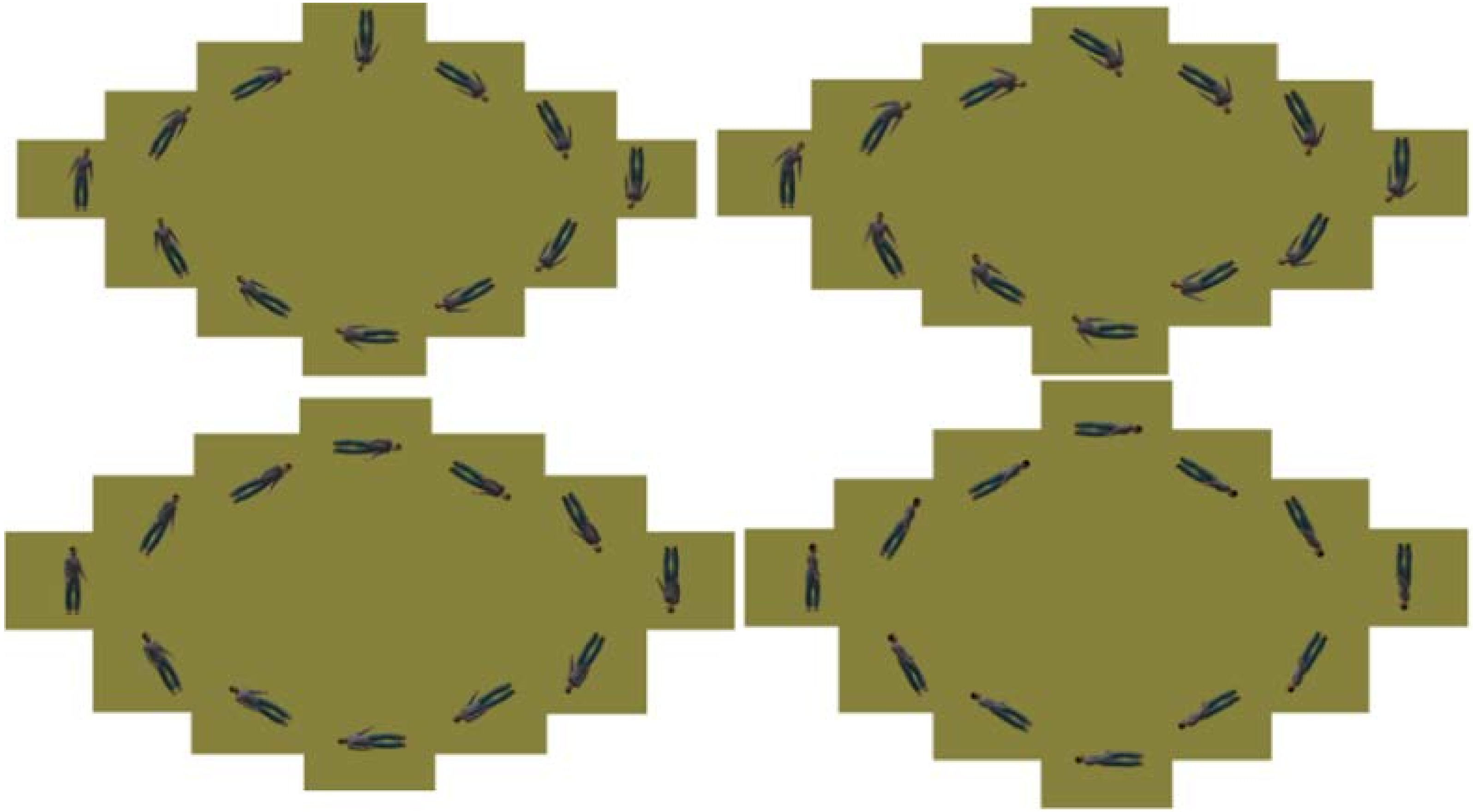


Fig. 2.3. Showing all allocentric images. Clockwise from top left: left side-flexion small amplitude, left side-flexion large amplitude, left-side rotation large amplitude, left-side rotation small amplitude. These images were mirror reversed to create the right-sided images.

Fig. 2.4. Shows the response box used in the experiment. Pressing the leftmost button with the left index finger indicated a left-sided response, pressing the rightmost button with the right index finger indicated a right-sided response, in the judgment tasks.

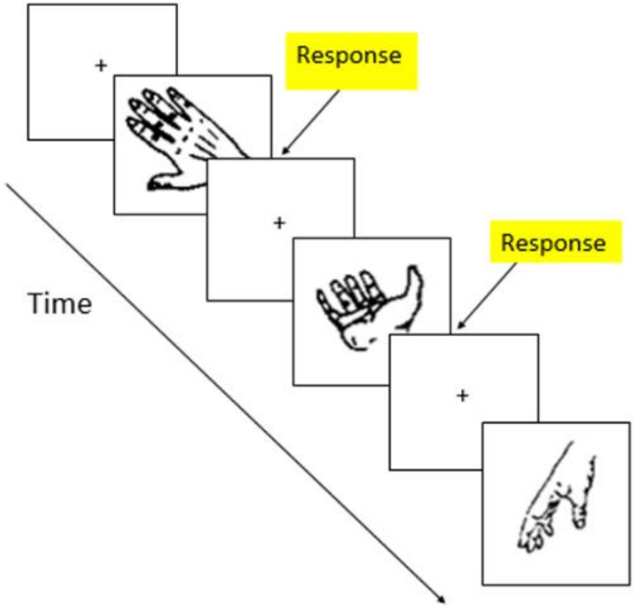


Fig. 2.5. Shows an example of the screen progression in a hand-based task.

2.3 Results

2.3.1 Hand judgment task

Across the group, overall mean accuracy was 96% (range 90%-100%), only correct judgments were included in further analysis. Filtering results for RT led to a loss of just 4% of trials. For the statistical analysis, any missing values were replaced by mean values; this accounted for just 4% of the total data set.

As expected, there was a significant main effect of View [$F(3,66)=11.08$, $p< .001$, $\eta^2_p= 0.34$]; wrist was fastest, followed by thumb, back and then palm. Orientation caused a main effect [$F(4,88)= 19.44$, $p< .001$, $\eta^2_p= 0.47$]; the further the image was orientated away from 0°, the greater RT. This is due to the biomechanical constraints of the arm and wrist. *Awkwardness* also caused a main effect [$F(1,22)=44.39$, $p< .001$, $\eta^2_p= 0.67$], again due to biomechanical constraints, lateral stimuli taking longer to be judged than medially orientated stimuli, see Fig. 2.6. There was a further main effect of *Side*, right hand images were faster to be judged than left [$F(1,22)=11.24$, $p< .05$, $\eta^2_p= 0.34$]. This was the expected result as only right-handed people were recruited for this study.

There were also numerous interactions. *View and Awkwardness* [$F(3,66)=13.94$, $p< .001$, $\eta^2_p= 0.39$] palm, and wrist view images demonstrated an effect of *awkwardness* but not back and thumb images. These effects can be seen in Fig. 2.6. A further interaction was found between *View* and *Orientation* [$F(12,264)=5.273$, $p< .001$, $\eta^2_p= 0.20$]. *Orientation* had a significant effect on all views, but its effect was much greater on images of back and thumb views, than on those of the palm and wrist views. The effects can again be seen in Fig. 2.6. An interaction was found between *Orientation* and *Awkwardness* [$F(4,88)=3.84$, $p< .01$, $\eta^2_p= 0.15$] with *Awkwardness* having a much greater effect when stimuli were presented in 90° of rotation compared with any other orientation, see Fig. 2.6. Finally, there was a three-way interaction between *View, Orientation* and *Awkwardness* [$F(12,264)=2.56$, $p< .01$, $\eta^2_p= 0.10$], see Fig. 2.6.

2.3.2 Hand movement task

Across the group overall mean RT was 1832ms, filtering for RT led to a loss of 8% of the results. For statistical analysis, any missing values were replaced by the mean values, this accounted for 7% of the total data set.

As with the judgment task, there was a significant effect of *Orientation* [$F(4,88)=26.12$, $p< .001$, $\eta^2_p= 0.63$] *Awkwardness* [$F(1,22)=73.01$, $p< .001$, $\eta^2_p= 0.84$] and S*ide* [$F(1,22)=16.64$, $p< .001$, $\eta^2_p= 0.47$]. These effects all followed the same pattern as in the *judgment* task, see Fig. 2.6.

There were also similar interactions found in the *movement* task. *View* and *awkwardness* [$F(3,66)=7.97$, $p< .001$, $\eta^2_p= 0.33$], *awkwardness,* this time having an effect on all views, but much greater on palm and thumb images (see Fig. 2.6). Another interaction that follows the same pattern of the *judgment* task was between *view* and *orientation* [$F(12,264)=11.25$, $p< .001$, $\eta^2_p= 0.31$]. *Orientation* had the largest effect on back and thumb view with a smaller effect on palm view, however, this time there was no effect on wrist view, see Fig. 2.6. A further interaction was between *orientation* and *awkwardness* [$F(4,88)=8.94$, $p< .001$, $\eta^2_p= 0.29$] the greatest effect of *awkwardness* was found at 90° (same as *judgment* task) and 120° conditions, see Fig. 2.6. An interaction that was not found in the *judgment* task was a*wkwardness* and s*ide* [$F(1,22)=4.46$, $p<.05$, $\eta^2_p= 0.07$]. There was a stronger effect of *awkwardness* for medially presented stimuli than for laterally presented stimuli.

The same three-way interaction from the *judgment* task *view, orientation* and a*wkwardness* [$F(12,264)=3.83$, $p< .001$, $\eta^2_p= 0.14$] was produced for the *movement* task. Back *view* did not produce a significant *orientation* by a*wkwardness* interaction, but the rest of the views did, see Fig. 2.6.

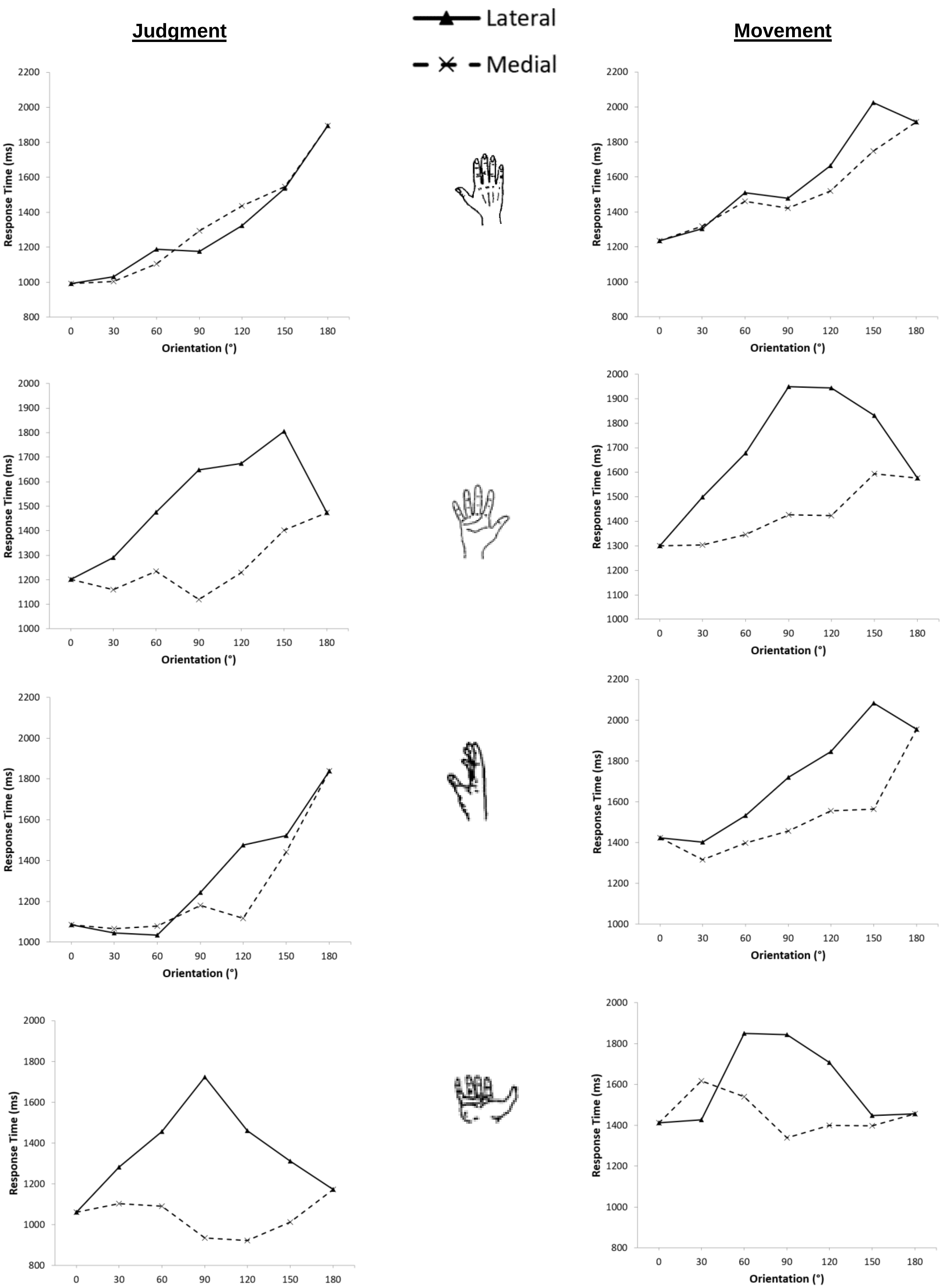


Fig. 2.6. Shows the *judgment* times (shown on the left) compared to the *movement* times (shown on the right). The images show similar patterns between the two, this is the crucial piece of supporting evidence for IMI being used to solve this task. Compare to Fig. 1.1 for data from Parsons (1994).

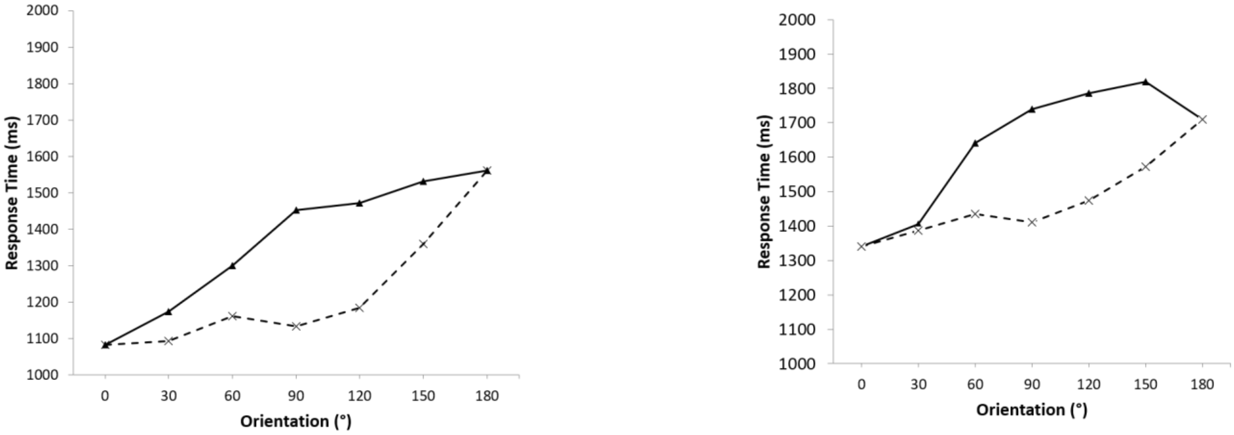


Fig. 2.6 continued. Presented on the left is the data from the judgment data collapsed across all views of the hand, presented on the right is the movement data collapsed across all views of the hand.

2.3.3 Trunk Judgment Task

Across the group, overall mean accuracy was 91% with a range of 77%-99%, only correct judgments were included in further analysis. Filtering results for RT led to a loss of just 6% of trials. For the statistical analysis, any missing values were replaced by the mean values; this accounted for less than 1% of the trials.

The crucial result is that there was a lack of main effect of *amplitude* in the judgment task, see Fig. 2.7A.

Main effects were found for *View* [$F(1,21)=58.09$, $p< .001$, $\eta^2_p= 0.73$] with allocentric view significantly slower than egocentric view, which was to be expected, this is shown in Fig. 2.8A. A second main effect of *Position* was discovered [$F(1,21)=50.96$, $p< .001$, $\eta^2_p= 0.71$] side-flexion was significantly faster than rotation, this is displayed in Fig. 2.9A. *Orientation* had a further main effect, this followed the same pattern as the hand-based task, the further rotated the stimulus was from 0°, the greater the amount of time taken to judge the sidedness of the image [$F(4,84)=59.10$, $p< .001$, $\eta^2_p= 0.74$] shown in Fig. 2.10A.

Again, there were numerous interactions; *position* and *orientation* [$F(4,84)=5.15$, $p=.001$, $\eta^2_p= 0.20$], *orientation* had a greater effect on rotation compared to side-flexion. A further interaction was *view* and *orientation* [$F(4,84)=11.43$, $p< .001$, $\eta^2_p= 0.35$]. *Orientation* had an effect on both but with a much greater effect on egocentric view compared to allocentric view, see Fig. 2.17. *Orientation* and *side* [$F(4,84)=2.86$, $p< .05$, $\eta^2_p= 0.12$] demonstrated an interaction, but there was no effect found when the simple effects were explored.

2.3.4 Trunk movement task

Across the group, the overall mean RT was 1853ms. After filtering for RT there was a 1% loss of trials. For further analysis, any missing results were replaced by the mean values and this was the case for less than 1% of all data.

All the main effects in the trunk *judgment* tasks, caused the same main effects and followed the same patterns as in the trunk *movement* tasks. Allocentric *view* caused slower movements than egocentric [$F(1,21)=10.74$, $p< .01$, $\eta^2_p= 0.27$], see Fig. 2.8B. *Position* [$F(1,21)=15.48$, $p= .001$, $\eta^2_p= 0.25$], side-flexion was faster to move to than rotation, see Fig. 2.9B. *Orientation* [$F(4,84)=11.00$, $p< .001$, $\eta^2_p= 0.08$] the further rotated away from 0° the greater the RT, see Fig. 2.10B. An additional main effect of *amplitude* was found in *movement* task, large amplitude stimuli took longer to move than small *amplitude* stimuli [$F(1,21)=14.90$, $p= .001$, $\eta^2_p= 0.55$], see Fig. 2.10B.

Again, numerous interactions were found; *position* and *orientation* [$F(4,84)=3.14$, $p< .05$, $\eta^2_p= 0.54$] following the same pattern as trunk *judgment*, *orientation* had a greater effect on rotation compared to side-flexion. A further interaction of *orientation* and *amplitude* was found [$F(4,84)=4.50$, $p< .01$, $\eta^2_p= 0.1$]. *Orientation* only had an effect on a*mplitude* in the 0°, 30° and 150° conditions.

Finally, a three-way interaction was found between *side, orientation* and *view* [$F(4,84)=3.10$, $p< .05$, $\eta^2_p= 0.12$]. Only right-handed images displayed an interaction between *rotation* and *view,* when explored further, the ANOVA revealed that only the 30° and 60° conditions demonstrated an effect of side.

Judgment **Movement**

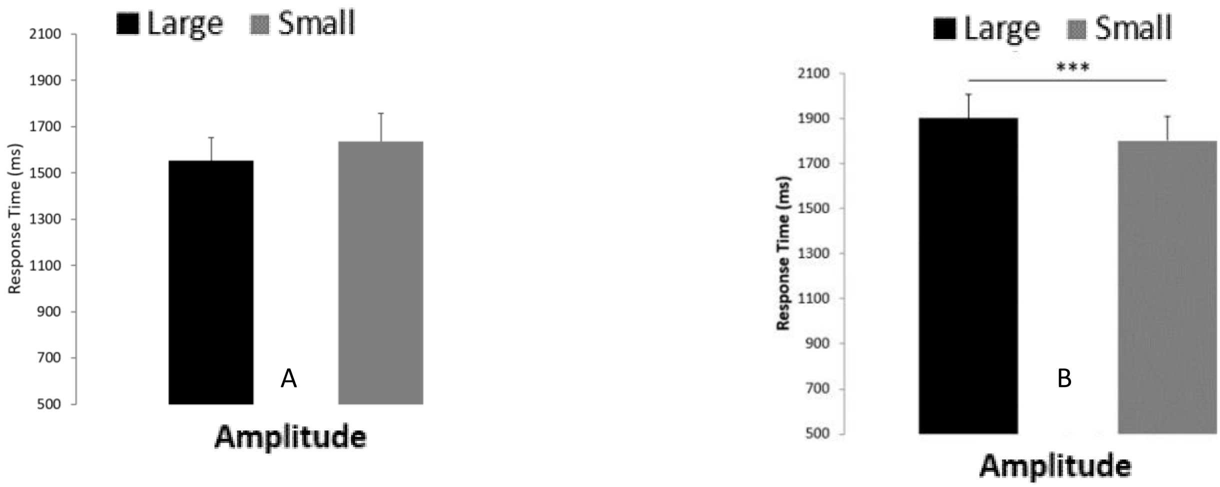


Fig. 2.7. Fig. 2.7A shows the lack of effect of *amplitude* on the judgment task. 2.7B shows the effect amplitude has on the movement task. This is a finding that is inconsistent with IMI. ***= p< .001

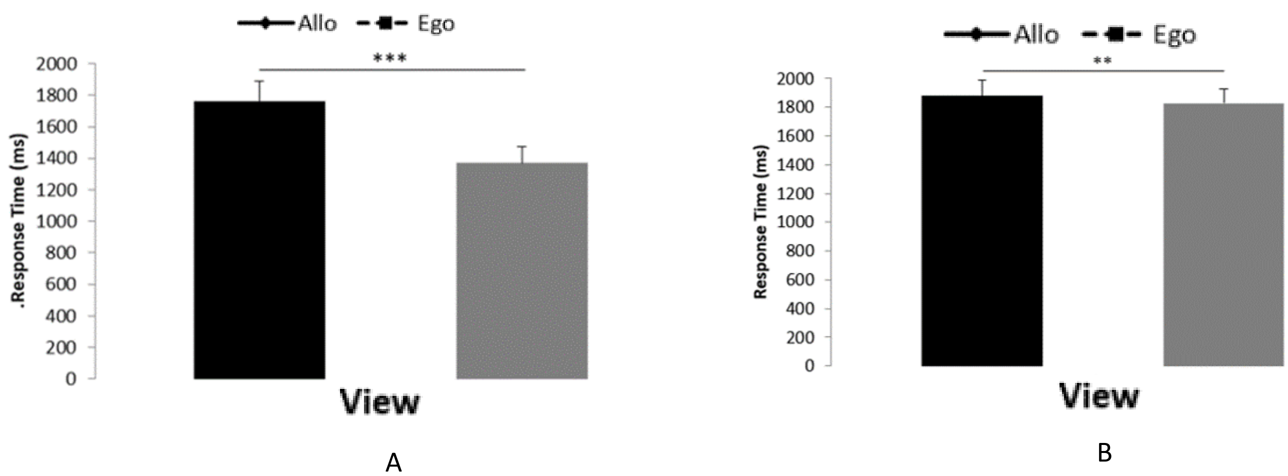
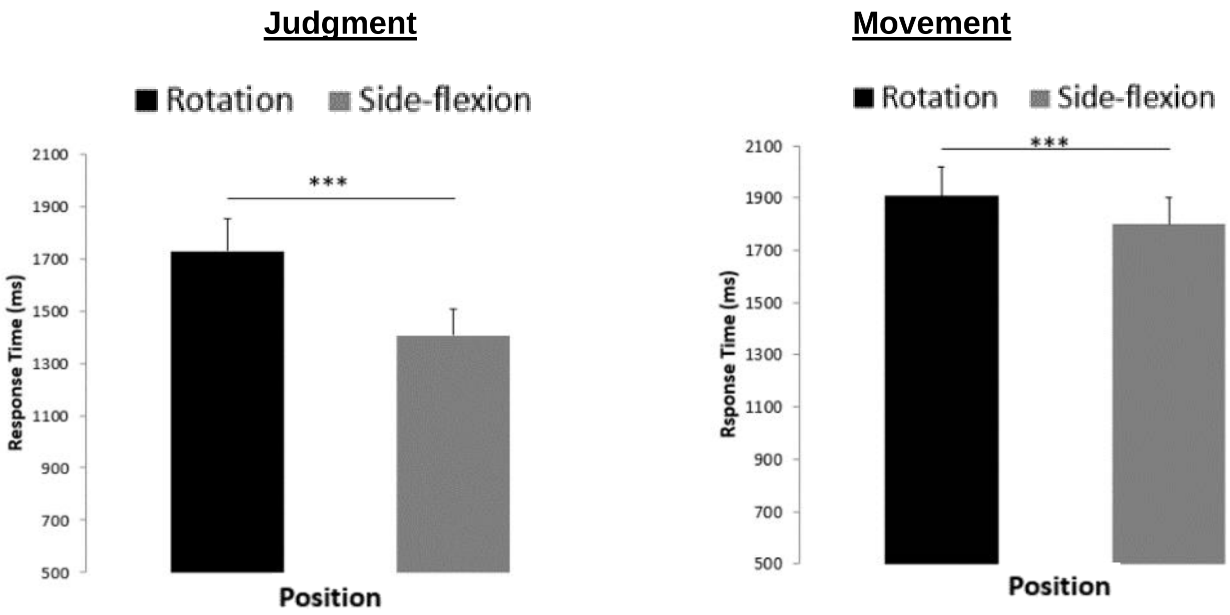
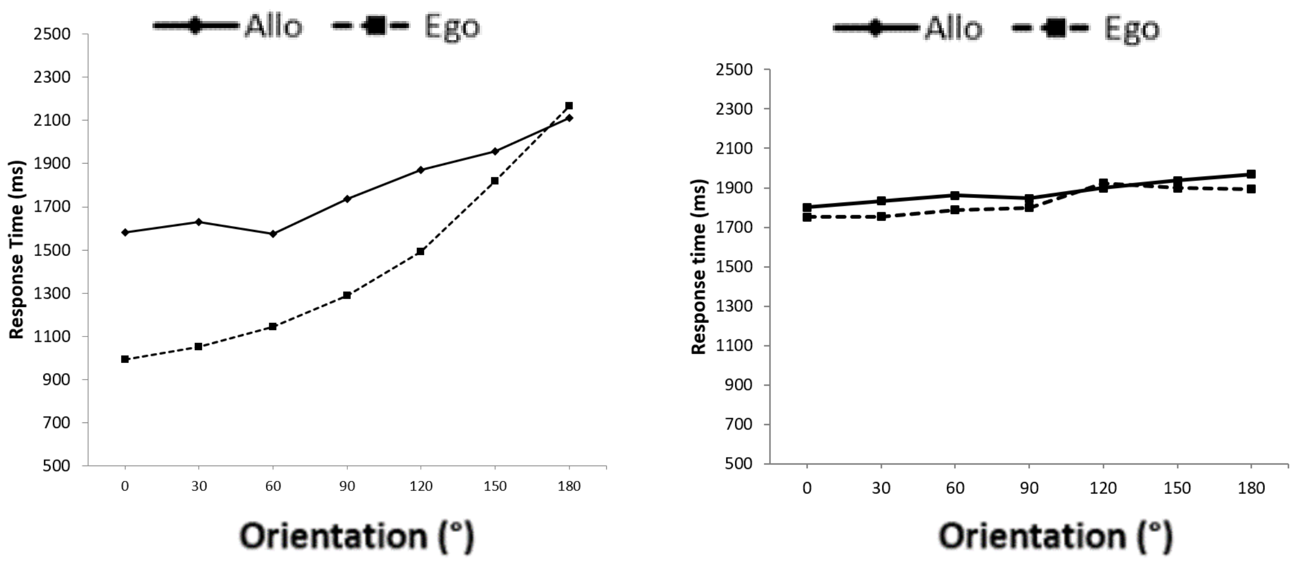


Fig. 2.8. Fig. 2.8A shows the effect of *view* on the judgment task. 2.8B shows the effect amplitude has on the movement task. ***= p< .001 **= p< .01



A B

Fig. 2.9. Fig. 2.9A shows the effect of *position* on the judgment task. 2.7B shows the effect *amplitude* has on the movement task. ***= p< .001



A B

Fig. 2.10. Fig. 2.10A shows the interaction between *view* and *orientation* in the judgment task. Fig. 2.10B shows the lack of interaction in the *movement* task.

2.4 Discussion

This initial study had two aims. Firstly, in a replication of *Experiment One* from Parsons' (1994) influential study, it aimed to examine the patterns of data when individuals made either (i) left/right judgments to stimuli presenting disembodied and disoriented hands, or (ii), made movements with their own hands to match the orientation of the same stimuli, without the requirement for a LRJ. Secondly, the study aimed to use comparable methodology to examine judgment times and movement times in response to stimuli used in trunk-based LRJTs. Accordingly, participants made either LRJs or made actual movements (without the requirement for a LRJ) to match the trunk-based stimuli presented.

Taking the hand-based task first, data from Experiment One in this study were consistent with those presented by Parsons (1994); judgment times appeared to parallel movement times supporting the view that the process of making such judgments involves the simulation of upper limb movements (or IMI). These parallels were evident in a number of different ways. Stimuli presenting hands in orientations more distant from the participant's resting/starting position resulted in slower judgment and movement times. Furthermore, stimuli presenting hands in more awkward (lateral) orientations resulted in slower judgment and movement times than stimuli presenting hands in more natural (medial) orientations, independent of their distance away from the resting/starting position of the participant's own hands. For judgment times, these findings are well established and typically referred to as reflecting the biomechanical or anatomical constraints of movement (Cooper and Shepard, 1975, Sekiyama, 1982, Parsons, 1987b). Parsons'(1994) subsequent work that is replicated here further cemented this relationship and drew explicit attention to how one could demonstrate the similarities between motor imagery and actual movement. By replicating this work, this study provides further confidence in the findings of Parsons' (Parsons, 1994) elegant and influential research.

Turning to the trunk-based task also examined in this initial study, data were illuminating. Rather than demonstrating the similarity between judgment times and movement times, as shown in the hand-based task, data pointed to the disparity between these. Movement times were dominated by two findings. Firstly, there was a clear difference in the time taken to make movements of different amplitudes; larger amplitudes taking longer than smaller amplitudes. Secondly, in the absence of a LRJ being required, the body's orientation had no effect on resulting movement times. In contrast, judgment times showed almost the opposite pattern of data. Here, the amplitude had no effect on the time taken to make a LRJ. However, there was a clear and progressively increasing time required to make LRJs as the body's orientation in stimuli deviated away from a neutral (upright) position. In itself, this pattern of data provides no support for the ability of trunk-based LRJTs to elicit IMI of trunk movements even though this assumed ability was the reason for their introduction into clinical practice (Bray and Moseley, 2011, Bowering et al., 2013).

If the process of making accurate judgments in the trunk-based task does not involve IMI of trunk movements (as previously claimed), then what is the process underpinning these? Judgment time data presented here are consistent with a series of studies that offer a coherent and logical explanation (Parsons, 1987a, Lenggenhager et al., 2008, van Elk and Blanke, 2014, Alazmi et al., 2018). Accordingly, data suggest that the key process involved in making LRJs to disoriented body images requires a mental realigning of one's own *whole body* with that of the image/stimuli. Once one has performed this *whole body matching*, the asymmetry is then considered obvious and automatic. Here we see a profound difference in the processes underpinning the hand-based and the trunk-based tasks. Whereas orientation of the stimulus in the hand-based task is central to its ability to elicit IMI of upper limb movements, IMI of trunk movements is not elicited by the trunk-based LRJT. As such, judgment time data here align with those reported recently questioning the therapeutic value of trunk-based LRJTs (Alazmi et al., 2018). The additional evidence reported here showing the disparity between judgment times and movement times in response to trunk-based LRJT stimuli, further strengthens the case against their use in clinical practice.

There are wider implications for the use of recently developed LRJTs (i.e. for neck-, shoulder- and knee- based tasks) stemming from data presented here. As discussed in Chapter One, the composition of stimuli presented in these tasks deviates substantially from hand-based (and foot-based) LRJTs, where a series of single disembodied hands (or feet) is presented. Rather, these new LRJTs present a body or a body segment with some element of asymmetry that is required to be detected. In all these cases, it seems likely that the critical component in determining a LRJ is the ability to align one's whole body with the one presented in the stimulus; IMI of an individual body part does not appear to be required. It is therefore interesting that a recent systematic review (and meta-analysis) of LRJT data in clinical populations suggested that only hand and foot-based LRJTs provoked impaired performance in individuals with chronic peripheral pain; other LRJTs (e.g. trunk-based, neck-based) failed to do so in those with chronic spinal pain (Breckenridge et al., 2019). One possible explanation for these findings (though not considered by the authors) is that these newly developed LRJTs simply do not elicit or require IMI of the related movements as claimed.

In order to address these wider implications further, Chapter Three reports findings from an experiment examining judgment times and movement times in response to shoulder-based LRJT stimuli. In addition to investigating whether findings presented in this chapter (i.e. using trunk-based LRJT stimuli) extend to another variant of the task, it will also aim to examine the processes underpinning related judgments in further detail.

Chapter Three: Examining Judgment Times and Movement Times in Response to Images Used in Shoulder-Based Left/Right Judgment Tasks (Experiment Two)

3.1 Introduction

Experiment one (Chapter two) highlighted two important issues in relation to the use of LRJTs. Firstly, by demonstrating that judgment times and movement times showed comparable patterns of data for hand-based LRJT images, it replicated influential work conducted by Parsons (1994) and further confirmed the ability of hand-based LRJTs to elicit IMI of upper limb movements. Secondly, applying the same methodology (i.e. analysing judgment and movement times) to trunk-based LRJT images revealed markedly different patterns of data. These data were not consistent with trunk-based LRJTs eliciting IMI of back movements, the assumed basis for their development and implementation in clinical practice (Bray and Moseley, 2011, Bowering et al., 2014).

While data from Experiment one were consistent with some previous findings concerning trunk-based LRJTs (Alazmi et al., 2018), they may also have wider relevance and implications for other recently developed LRJTs. As discussed in Chapter one, the composition of LRJT images nominally focused on the neck (Wallwork et al., 2013), the knee (noigroup, 2016b) and the shoulder (Breckenridge et al., 2017) takes a similar approach to that used for trunk-based LRJTs. As the ability of any given LRJT appears to be dependent on its composition, it therefore seems likely that these other newer forms of LRJT also fail to elicit IMI of the body part for which they purport to do.

In Experiment two, this likelihood was tested by applying the same methods as Experiment one to images based on those used in shoulder-based LRJTs. By doing so, the experiment aimed to examine whether movement time and judgment time data from such images were consistent with related judgments eliciting IMI of shoulder movements. If, as predicted, data again failed to support such an interpretation, this would help to generalise the concerns raised in Chapter two and elsewhere (Alazmi et al., 2018, Punt, 2017) relating to new forms of LRJTs currently used in clinical practice.

In addition, this experiment offered an opportunity to gather further data from the movement task to provide more insight about the processes involved in the judgment of shoulder-based LRJT images. Accordingly, in addition to measuring movement time as defined in Experiment one and by Parsons (1994) , this measure was separated for Experiment two in the following way. Rather than simply having a movement time measure from stimulus onset to movement completion, movement onset was also captured by having participants depress a button prior to stimulus onset with the button being released at *movement onset*. The time between *stimulus onset* and *movement onset* was subsequently captured and defined as *planning time*. The period between *movement onset* and *movement end* was also captured and defined as *execution time*. Alongside this modification to the dependent variables, blocks of trials were conducted where participants either were or were not instructed as to which limb they should move. That is, unlike in Experiment one, there was a block of trials during the movement task where participants had to determine which limb to move.

The hypothesis driving this approach was as follows. If the critical component of the judgment task is to mentally align one's whole body with that of the stimulus, then planning time in the *unknown* movement task should be the same as the judgment time in the judgment task. It was predicted that execution time in the *known* and *unknown* conditions would be the same, the difference in the overall movement time being accounted for by the increased requirements of planning in the *unknown* condition.

Finally, as in Experiment one, amplitude of shoulder movement (i.e. small vs large) was manipulated. It was similarly predicted that large movements would result in longer execution (and movement) times. As in Experiment one, if the same pattern was found for judgment times, this would signify support for the tasks eliciting MI of shoulder movements. However, given the findings from Experiment one, it was hypothesised that images depicting small and large amplitudes of movement would result in comparable judgment times.

3.2 Methods

3.2.1 Subjects

Thirty-seven right-handed participants (nineteen male) took part in this study. All participants were students from the University of Birmingham and aged between eighteen and twenty-two (mean age = 21.3). Handedness was classified by the Edinburgh Handedness inventory (Oldfield, 1971), no participants had any injuries or conditions effecting their limbs, all had normal or corrected to normal vision. All participants provided written informed consent prior to their participation and the study was conducted in line with the declaration of Helsinki as well as the university's policies for research and ethics.

3.2.2 Stimuli

Digitised images of a 3D model of a male human were made using Poser software. The images were designed to be similar to that of Parsons, (1987) with the 3D model standing upright with an outstretched arm, in this study the arm was stretched at either 45° (small amplitude) or 90° (large amplitude). The images were displayed in the same way as Experiment one; in two different amplitudes (small and large), two views (allocentric and egocentric) and twelve orientations (0°, 30°, 60°, 90°, 120°, 150°, 180°, 210°, 240°, 270°, 300° and 330)°. Stimuli of left and right sidedness were mirror images of each other, see Fig. 3.1

3.2.3 Procedure

The order of the trials was counterbalanced. At the start of each condition participants were given practice trials to familiarise themselves with the task and were given opportunity to ask any questions. The experiment was a within-subject experimental design. The experiment took place in a quiet university laboratory with the experimenter present. All the experiments were controlled using E-Prime 2 software (Psychology Software Tool Inc. www.pstnet.com). This experiment was split into three tasks, a *judgment* task, a *known sidedness* movement task and an *unknown sidedness movement* task.

Judgment task: This task had the same procedure as Experiment one trunk judgment task, apart from the change in stimuli. This time participants were making a *judgment* on which arm of the model was raised.

Known sidedness task: again, this was similar to the trunk movement task in Experiment one. The images were presented in blocks so participants would see all forty-eight images belonging to one side, and then all forty-eight belonging to the other. This negates the need to make an LRJ. The participants were stood in front of the computer monitor, first they would see the fixation cross, followed by an image and were instructed to replicate the posture of image as quickly and as accurately as possible. To measure the response participants were instructed to hold the mouse down by their side, as in Experiment one, with the mouse click held in to prompt the display of the fixation cross. They would then be presented with the image. Once the participant was ready to move, they let go of the click, move into position and then click the mouse once more to end that trial.

Unknown sidedness task: in this task participants were instructed to replicate the position of the model shown as quickly and accurately as possible. This time the images were not presented in blocks of sidedness. Participants were presented with all ninety-six images in random order requiring an LRJ before being able to make a movement. To measure the response in this task participants stood in front of the computer screen, with a mouse in both hands, and both hands down by their side. When the click on both mouses was held down the fixation cross screen was initiated, followed by an image. Once they were ready to move the participant then relieved the click of the arm they were going to move, moved to the correct position and then clicked the mouse to end that trial. During this task, the experimenter would press the 'J' key on the keyboard if the participant moved the incorrect arm, this would allow the trial to be discounted from further analysis.

3.2.4 Data Analysis

As with Experiment one, accuracy and RT were initially analysed. Again, no accuracy was measured for the *move one* task and only correct judgments were included in analysis for the *judgment* and *move both* task. One participant scored less than 75% in the judgment task and was therefore excluded from further analysis. For both j*udgment* and *movement* tasks, only RT that were between 500-5000ms were included for further analysis. Any missing values due to the exclusion criteria were replaced by the mean values before the data set was entered the ANOVA. RT was measured using a series of repeated measures ANOVAs: arm judgment task, arm overall movement, arm planning and arm movement only. Arm overall movement is a combination of movement and planning combined. The ANOVAs included: *View* (allocentric, egocentric), *Orientation* (30°, 60°, 90°, 120°, 150°), *Amplitude* (small, large) and *Side* (left, right).

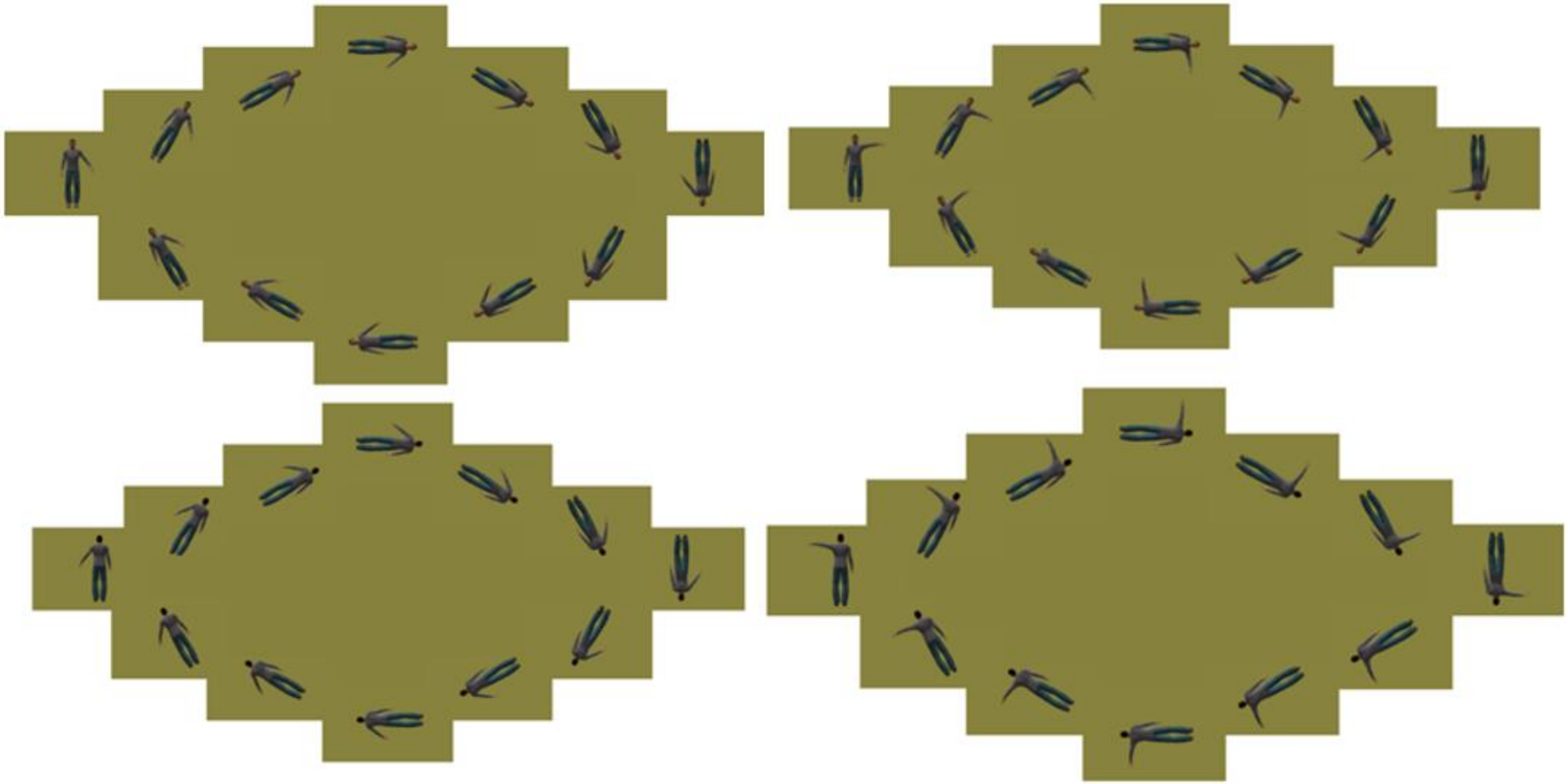


Fig. 3.1 shows the images presented to the participants in Experiment 2. Top-left allocentric small amplitude. Top-right is allocentric large amplitude, bottom-left is egocentric small amplitude, bottom-right is egocentric large amplitude.

3.3 Results

3.3.1 Judgment

One participant scored below 75% and was removed from any further analysis. Across the rest of the group mean accuracy was 95% (range 86-99%). Only correct responses were included in RT analysis. Filtering for RT led to a loss of 2% of trials. For the statistical analysis, any missing values were replaced by the mean values; this accounted for 5% of the total data set.

There was a significant main effect for *View* [$F(1,31)=67.84$, $p< .001$, $\eta^2_p= 0.69$], with images showing allocentric perspectives resulting in slower judgment times than images showing egocentric perspectives [$p< .001$], see Fig. 3.2. A further significant main effect was found for *Orientation* [$F(6,186)=76.91$, $p< .001$, $\eta^2_p= 0.71$], this largely follows the same pattern as Experiment One the further rotated from 0° the greater the time to judge, 30° and 0° were not different [$p= .712$] and 180° was significantly slower than all other orientations [$p< .001$], see Fig. 3.2. The ANOVA revealed one interaction *View x Orientation* [$F(6,186)=8.95$, $p< .01$, $\eta^2_p= 0.22$]. There was no difference between allocentric and egocentric in the 180° but there was at every other *orientation*, see Fig. 3.2. Note there was no *amplitude* effect in this task. This is a key finding and one that is inconsistent with the idea of motor imagery of shoulder movements being used to solve this task see Fig. 3.8.

3.3.2 Known Sidedness Task

Overall movement

Only 1% of trials were lost due to the RT filtering process. Across the group, the overall mean RT was 1248ms. For the statistical analysis any missing values were replaced by the mean RT for that image; this was the case for less than 1% of results.

Amplitude was the only significant main effect found for the *known sidedness movement* condition [$F(1,34)=108.23$, $p< .001$, $\eta^2_p= 0.76$]; as anticipated large amplitude images resulted in longer movement times than small amplitude images: see Fig. 3.4.

3.3.3 Unknown Sidedness Task

Overall Movement

The movement time filtering process removed 4% of trials. Across the group the mean movement time was 1775ms. For statistical analysis, any missing values were replaced by the group mean values for the relevant condition. This accounted for 2% of the total data set.

Significant main effects were found for all variables and all were as expected. Movement times for images with an Allocentric *View* were slower than to those with an egocentric view [$F(1,32)=172.63$, $p< .001$, $\eta^2_p= 0.84$] (see Fig. 3.3). There was also a significant main effect of *Orientation* [$F(6,192)=72.74$, $p< .001$, $\eta^2_p= 0.69$]; the further the image was rotated from 0° the slower the movement time. Again 180° *orientation* was significantly slower than all other orientations [$p< .001$] (see Fig. 3.3). Larger *amplitude* images led to a slower movement time than smaller amplitude images [$F(1,32)=82.53$, $p< .001$, $\eta^2_p= 0.72$] see Fig. 3.5.

There was a *view x orientation* interaction [$F(6,192)=13.1$, $p= .001$, $\eta^2_p= 0.29$]; while the above differences between allocentric and egocentric images held for most orientations, these were diminished at larger orientations and movement times were comparable at 180° (see Fig. 3.3).

3.3.4 Planning

As can be seen in Fig. 3.3, the pattern of data for planning times was very similar to that for overall movement times in the *unknown sidedness* task. Accordingly, there were significant main effects of *View* [$F(1,34)=163.85$, $p < .001$, $\eta^2_p = 0.87$], *Orientation* [$F(6,204)=90.76$, $p < .001$, $\eta^2_p = 0.6$] and a *View* x *Orientation* interaction [$F(6,204)=16.52$, $p < .001$, $\eta^2_p = 0.18$].

3.3.5 Unknown Sidedness Execution

As anticipated, there was a significant main effect for *Amplitude* [$F(1,34)=121.88$, $p < .001$, $\eta^2_p = 0.78$], execution times for images depicting large amplitudes were slower than execution times for images depicting small amplitudes (see Fig. 3.5) Importantly, there was no effect of *View* or *Orientation* for execution times.

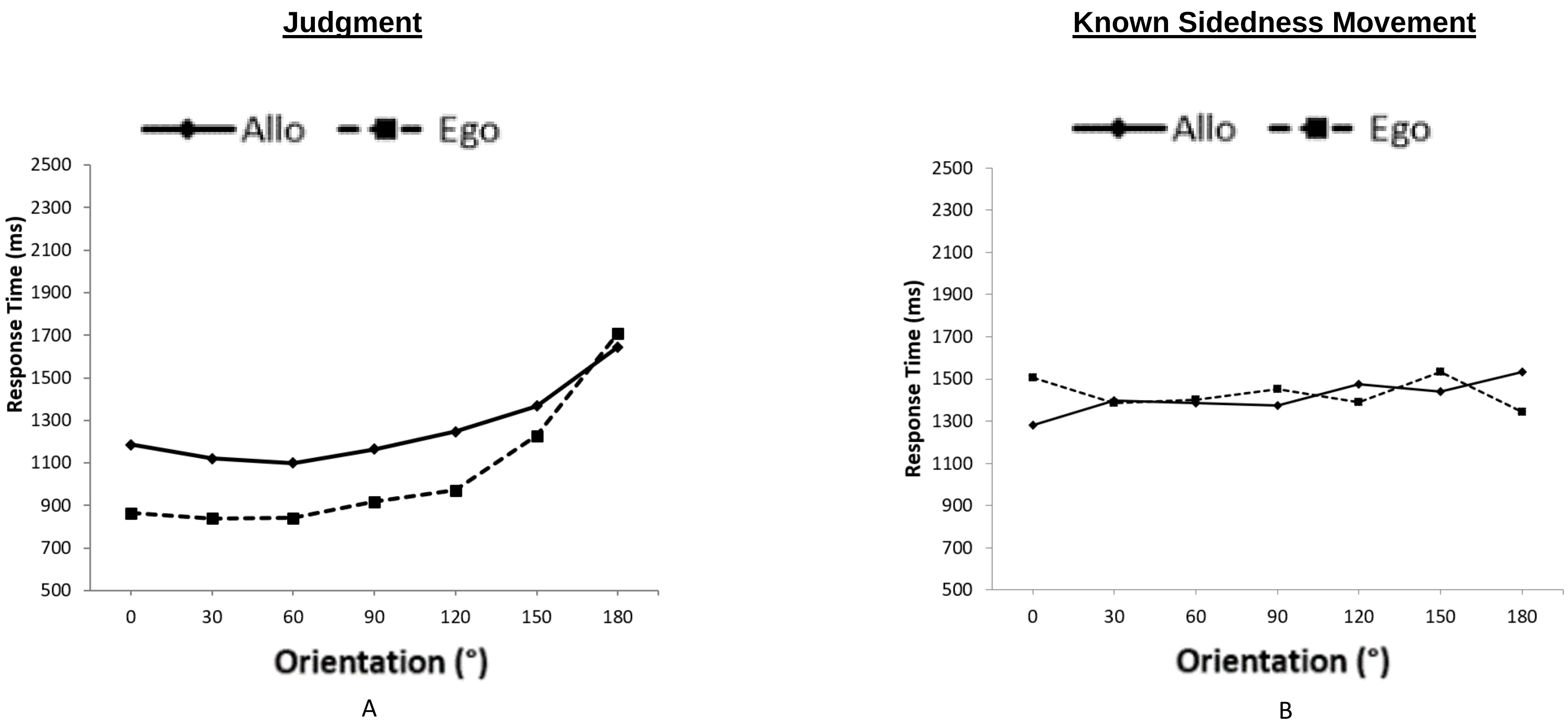


Fig. 3.2. A shows the interaction between *view* and *orientation* in the judgment task. B shows the lack of interaction in the movement task. The two graphs also show the inconsistency of local MI being used to solve the task. Fig. 3.2A and 3.2B should show a similar pattern of data for it to be deemed that this task is eliciting IMI.

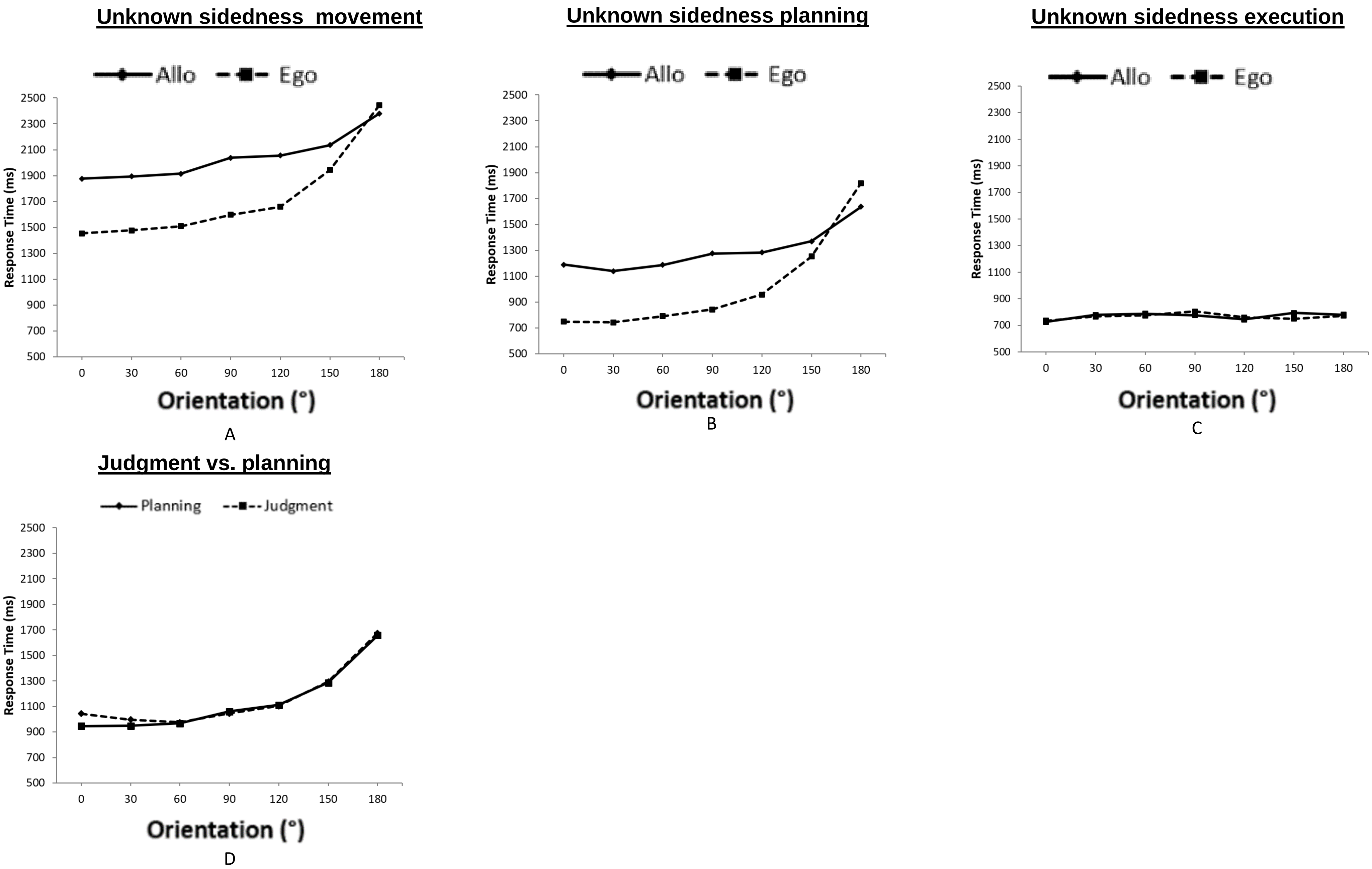
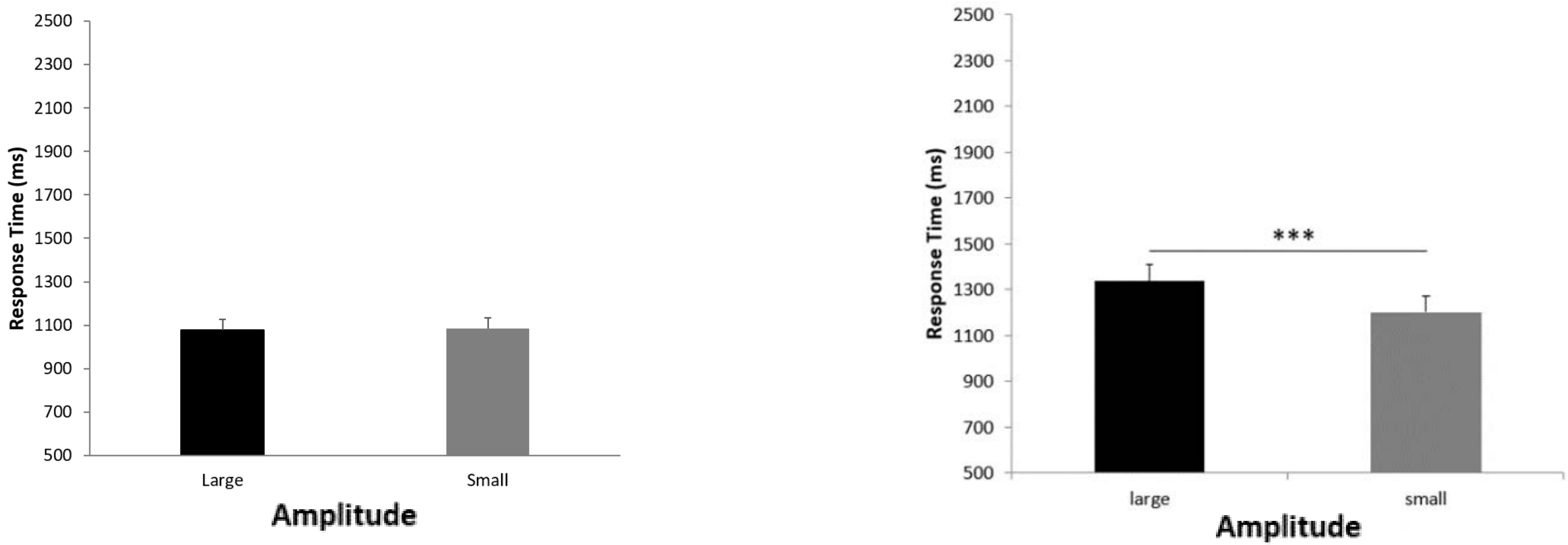


Fig. 3.3. showing the *view* by *orientation* interaction. Fig. 3.3A shows the *unknown sidedness* task. Fig. 3.3B shows the *planning* time only of the *unknown sidedness task.* Fig. 3.3C shows the *execution* time only. Here the crucial element of the *unknown sidedness* task is the *planning* time can be seen, and as is shown in Fig. 3.3D the planning and the judgment time are almost identical.

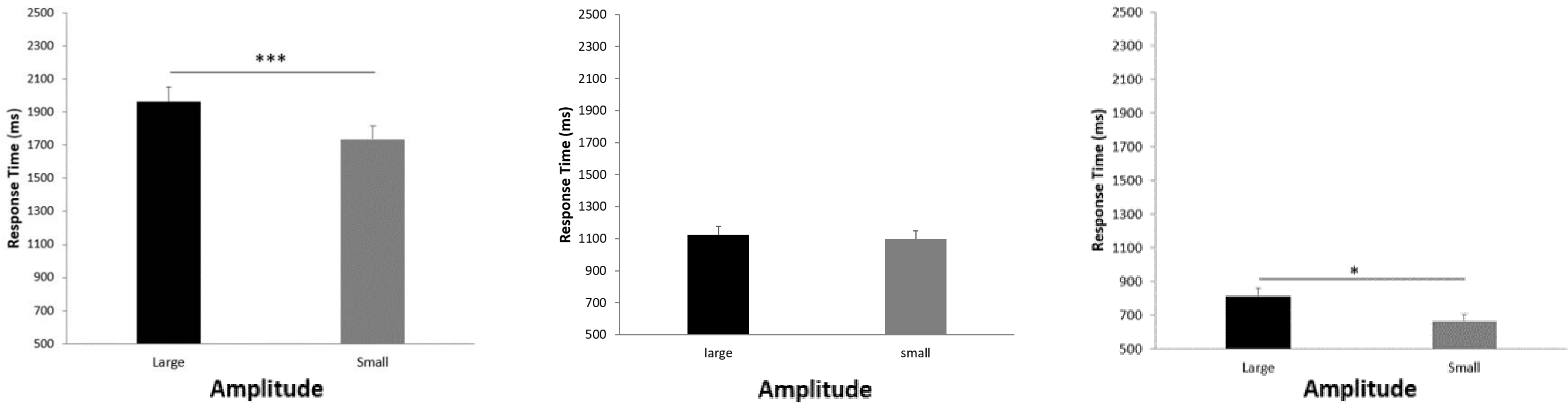
Judgment **Known Sidedness Movement**



A B

Fig. 3.4. A shows the lack of interaction in the judgment task. 3.4B shows that larger amplitude images were slower to physically move to. This is a finding that is inconsistent with IMI being used to solve the task. ***= p< .001

Unknown Sidedness Movement **Unknown Sidedness Planning** **Unknown Sidedness Execute**



A B C

Fig. 3.5. Fig. 3.5A shows the interaction of *amplitude* in the *unknown sidedness movement* task. 3.5B shows the planning stage and 4.5C shows the execution. Due to the lack of interaction showing in Fig. 3.5B the main effect of *amplitude* can be attributed to the *execution* stage and not the *planning.* A finding that is inconsistent with IMI being used. ***= p< .001, *= p< .05

3.4 Discussion

The aim of this experiment was to further investigate the mechanisms which underpin our ability to solve LRJTs of body parts other than disembodied hands. As in Experiment one (Chapter two), this experiment included both a judgment task and a movement task so it was possible to examine the patterns of data produced by both, in line with Parsons' (1994) approach. In addition, this experiment also included a further task. Unlike Experiment one and the approach taken by Parsons (1994), participants were asked to complete a further version of the movement task where they were not informed of which limb they should move in advance. The logic of this approach was to test the mechanism underpinning left/right judgments proposed earlier; i.e. that participants match the orientation of their whole body with that of the stimulus and once they have performed this transformation, the sidedness judgment is automatic. Accordingly, it was predicted that *planning* time for this *unknown side movement task* would display a similar pattern of data to judgment times.

The key finding in this experiment was once again the lack of temporal regularity displayed between the *movement* and *judgment* tasks. Images depicting a larger *amplitude* of shoulder deviation from neutral (i.e. 90° abduction) incurred a slower movement time than images displaying a smaller amplitude of shoulder deviation from neutral (i.e. 45° abduction), while related *judgment* times were comparable. As with the trunk-based LRJT data presented in the previous chapter, data here for a shoulder-based LRJT are inconsistent with participants performing IMI of shoulder movements in order to make their judgments.

The *unknown sidedness* task also produced useful information. The *planning times* for this task showed very similar patterns of data to those for the judgment task and therefore appeared to support the mechanism for solving the task proposed by this this thesis. Accordingly, if once one has *matched* the orientation of one's whole body with that of the stimulus, the LRJ is automatic, then one would expect planning times and judgment times to be comparable. Neither judgment times or planning times appeared to include any additional cost associated with imagining a movement of one limb or the other. Of course, the *unknown side movement* task also included an *execution* component and the time to perform the movement reflected the amplitude of movement required. However, this time was not reflected in judgment times and appears to be redundant in terms of the judgment process.

Together, shoulder-based data reported in Experiment two were in line with trunk-based data reported in the previous chapter (Experiment one) and further highlight the mechanisms underpinning these new LRJTs. They demonstrate that such tasks do not require or elicit MI of the local body part (i.e. the back or the shoulder) as part of the judgment process. As such, they expose the incorrect assumptions that have been made previously about these tasks (Bray and Moseley, 2011, Bowering et al., 2013, Breckenridge et al., 2017) which has driven their introduction into clinical practice and their commercial availability (Recognise Knee: https://apps.apple.com/gn/app/recognise-knee/id1082943360, Recognise Shoulder: https://apps.apple.com/gn/app/recognise-shoulder/id108247661). Data presented in this chapter are entirely inconsistent with these assumptions that have polluted recent literature in the field and masqueraded as informing evidence-based practice.

In conclusion, this task shows no findings which are consistent with the idea of IMI being used to solve this task. From the evidence provided it seems much more likely that the participants use a whole-body mental transformation to match the orientation of the presented image. Once this has been completed the participants then have the necessary visual information to have access to BSD which allows them to automatically code for the *sidedness* of the deviation. This task does not require a mental transformation of the arm to complete a confirmatory process as is seen in hand-based LRJTs. The increase in RT that is seen in this task as a result of image orientation and that Breckenridge *et al.*, (2017) and Wallwork *et al.*, (2013) claim allows us to infer that IMI is being used, is a result of the whole-body mental transformation taking place, and not a reflection of IMI of an individual body part.

Chapter Four: Examining Judgment Times and Movement Times in Response to Commercially – Available Images for Shoulder-Based Left/Right Judgment Tasks (Experiment Three)

4.1 Introduction

Chapter Three illustrated that data from a shoulder-based LRJT are not consistent with participants’ performing local IMI of shoulder movements to solve the task. This was demonstrated by a lack of temporal regularity between *movement* and *judgment* times, that one would expect from a task that does elicit IMI (Parsons, 1994). Experiment Three again investigates a shoulder-based LRJT but this time uses images from (Breckenridge et al., 2017) that are available commercially. As earlier noted, these images have been developed with the explicit intention of eliciting IMI of shoulder movement, and claim to accomplish this as part of the Graded Motor Imagery process (Moseley et al., 2012) (see Fig. 1.4). Demonstrating that this does not appear to be the case for some LRJTs (e.g. the trunk-based and shoulder-based tasks examined in Chapters Two and Three) the findings of this thesis so far threaten the claims that therapeutic value is conveyed by such tasks as such value would be contingent on the tasks eliciting local IMI of the body part the task is targeting.

Investigating performance on a shoulder-based LRJT, Breckenridge *et al.,* (2017) state:

> *"Performance on the shoulder LRJT was consistent with the prevailing theory underpinning this motor imagery task - that judgements take longer for more awkward images (Parsons, 1987a, Parsons, 1987b, Decety et al., 1989) This strongly implies that the shoulder LRJT is performed using the same strategy as that used for other LRJTs, which provides compelling support for the shoulder LRJT as a measure of implicit motor imagery of the shoulder."*
>
> \- (Breckenridge *et al.*, 2017, p. 44)

In addition to confirming the authors' acceptance of the unsubstantiated assumption that the task elicits IMI of shoulder movements, the statement provides an indication of the basis for this assumption. In referring to 'awkwardness' for their shoulder-based LRJT, Breckenridge *et al.,* (2017) invoke comparisons with hand-based LRJT data (Parsons, 1987b, Parsons, 1994). However, their approach to establishing awkwardness effects are confounded by the lack of consistence in 'perspective' or 'view' when presenting images. As Punt (2017) explained, "if one wishes to make a comparison between response times for images showing different levels of awkwardness/complexity this must be done on the basis of controlling the perspective from which the images is seen and the amount of visual information provided. Breckenridge *et al.* (2017) present images of the shoulder in a neutral position from above and compare related response times with those for other positions (e.g. flexion and abduction) from the side and behind; perspective is not controllled for." (Punt, 2017, p.87).

Nevertheless, although critisisms may be levelled at the images used by Breckenridge *et al.,* (2017), these are the images used commercially and given the aims of this thesis it seemed important to test these images using the same methods used in the previous two experimental Chapters. However, whereas Chapters Two and Three used systematic manipulation of the presented images to investigate the pattern of *movement* and *judgment* time data, in conducting the following experiment, it was accepted that such control would not be possible.

The aim of this experiemnt was to explicitly test the images used in Breckenridge *et al.,* (2017) using the same methodology as used in Chapters Two and Three. It was hypothesisied that as no other exmperimental studies involving either the Back (Chapter Two) or Shoulder (Chapter Three) has produced any data that are consitent with IMI, the images used in this experiment would also not show such effects. The key indicator of IMI is temporal regularity between the *movement* and *judgment* times (Decety et al., 1989).

4.2 Method

4.2.1 Subjects

Seventeen right-handed participants (twelve male) took part in this study. All participants were students at the University of Birmingham aged between eighteen and twenty-six (mean age = 21.6). Handedness was classified by the Edinburgh Handedness Inventory (Oldfield, 1971), no participants had any injuries or conditions affecting their limbs, all had normal or corrected to normal vision. All participants provided written informal consent prior to their participation and the study was conducted in line with the Declaration of Helsinki as well as the university's policies for research and ethics.

4.2.2 Stimuli

The images that were used in this study were taken from Breckenridge *et al*., (2017). The images used focus on the shoulder joint and were photographs and were chosen to represent varying difficulty and complexity. The five images we *neutral, 90° flexion, 90° abduction, 180° flexion and hand behind back (HBB)* see Fig. 4.1. Each of these images was presented in four different orientations (0°, 90°, 180° and 270°), and were mirrored to give a left and right side. In total there were forty images, see Fig. 4.2.

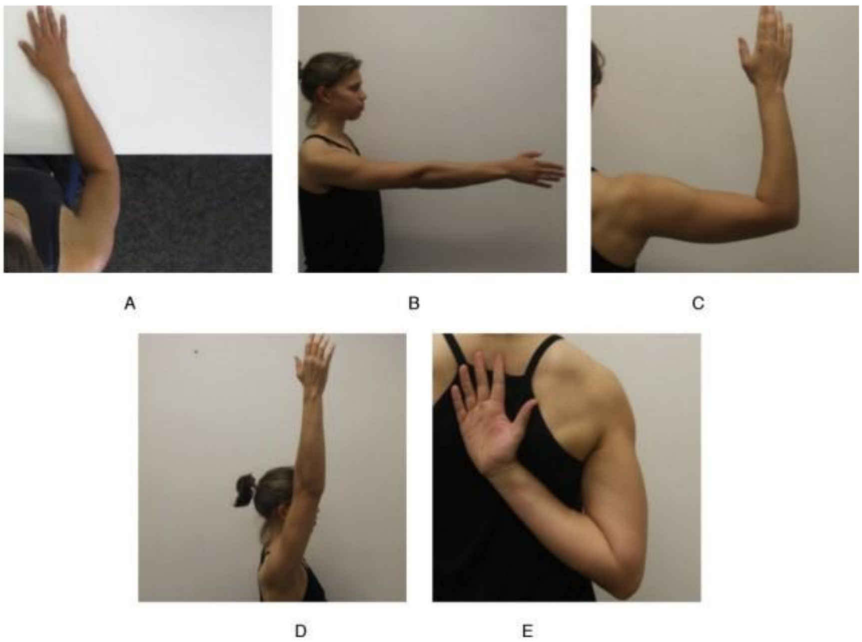


Fig. 4.1 shows the images used in experiment 3 and taken from *Breckenridge et al*., (2017). Image A shows Neutral, B, 90° flexion, C, 90° abduction, D, 180° flexion and E, HBB. Breckenridge *et al.,* (2017) claim these images increase in complexity and difficulty as you move from A to E.

4.2.3 Procedure

Before each task participants performed practice trials to familiarise themselves with the task and were given the opportunity to ask any questions. The order of the task was counterbalanced.

The experiment took place in a quiet university laboratory with the experimenter present. The experiment was controlled by E-prime 2 software (Psychology Software Tool Inc. www.pstnet.com). This experiment was structured the same way as Experiment Two; a *judgmen*t task, a *known sidedness* task and an *unknown sidedness* task.

Judgment task: this task was the same as Experiment One *judge trunk* task and Experiment Two *judgment* task, apart from the change in stimuli. Participants were instructed to make a LRJ as to which shoulder was manipulated, the response mode was the same as Experiment One *judge trunk*.

Known sidedness task: the images were blocked so the participant knew they were only going to be presented with all left or all right images, therefore this does not require a LRJ. Responses were collected in the same way as Experiment One move hands task. Using the right sided block as an example, participants pressed down the rightmost button on the SRT box with their right index finger, this caused the fixation cross to appear. After the fixation cross an image was presented and participants were instructed to replicate the position shown as quickly and accurately as possible. Once they were ready to move the participant let go of the button and moved into the target position. Once they were there, they pressed the footswitch to end that trial.

Unknown sidedness task: this is the same adaptation to the *known sidedness task* as Experiment Two. The images were no longer blocked so participants could be presented with any of the images at random requiring them to make a LRJ before moving. Participants started with their left index finger on the leftmost button on the SRT and their right index finger on the rightmost button on the SRT box. This prompted the fixation cross followed by an image. Participants were again instructed to replicate the position presented to them as quickly and as accurately as possible. Once ready to move participants took their finger corresponding to shoulder that was manipulated in the image, off the button and moved it into the correct position. Once in the correct position participants then pressed a footswitch to end that trial.

4.2.4 Data Analysis

As with other experiments, accuracy and RT were initially analysed. Again, no accuracy was measured for the *movement* task and only correct judgments were included in analysis for the *judgment* and *unknown sidedness* task. All participants scored above 90% so all were included. For all tasks only RT that were between 500-5000ms were included for further analysis. Any missing values due to the exclusion criteria were replaced by the mean values before the data set was entered the ANOVA. RT was measured using a series of repeated measures ANOVAs: *judgment, move known sidedness* and *move unknown sidedness*. All ANOVAs included: *Orientation* (0°, 90°, 180°, 270°) and *Position* (*neutral, 90° flexion, 90° abduction, 180° flexion, HBB*).

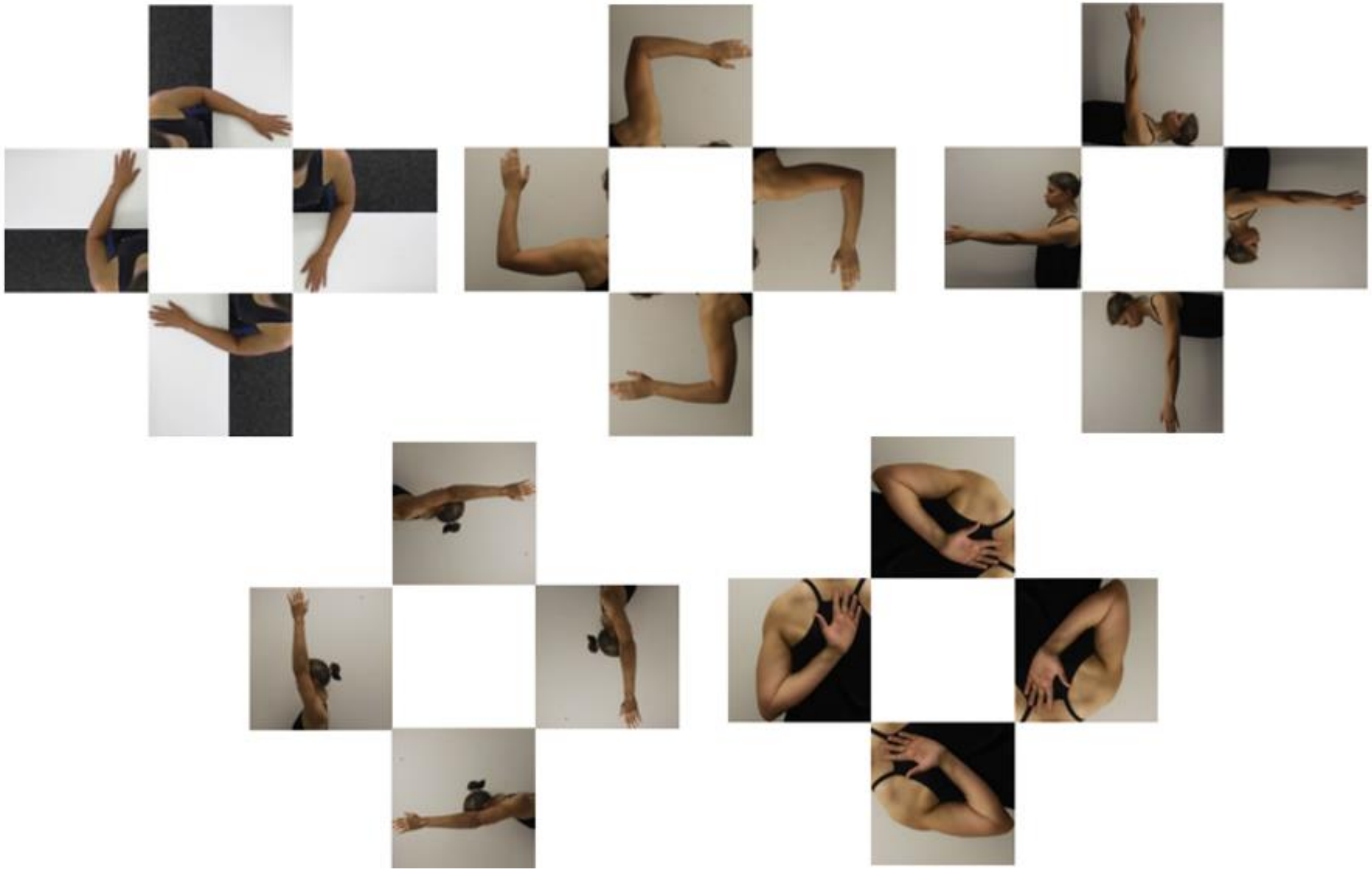


Fig. 4.2. Showing all the left sided images used in the experiment in all of their orientations. These images were mirror reversed to create the right sided images.

4.3 Results

4.3.1 Judgment Times

Across the group overall the mean accuracy was 98% (range 96-100%). Only correct *judgments* were included in the analysis. Filtering for accuracy and RT led to a loss of 1% of trials. For statistical analysis, any missing values as a result of this process were replaced by the group mean value for the relevant condition; this was the case for just three cells (less than 1% of the total).

There was a significant main effect of *orientation* [$F(3,45)=73.49$, $p < .001$, $\eta^2_p = 0.83$]. These data were broadly comparable with the previous chapter; images presented at 0° were faster to be judged than other orientations [$p < .001$] and images presented in 180° were slower [$p < .001$]. It is worth noting the difference between 0° and 180° was approximately 550ms. The data for images presented at 90° and 270° orientations were comparable [$p = .54$]; see Fig. 4.3a.

A significant main effect of *position* was also found [$F(4,60)=18.591$, $p < .001$, $\eta^2_p = 0.56$]. Images showing *90° abduction* were the fastest to be judged although comparable with images defined as *neutral* [$p = .795$] but were significantly faster than all other positions [$p < .001$]. Images depicting *180° flexion* were the slowest to be *judged* and were significantly slower than all but the *HBB* position [$p = .490$]; see Fig. 4.5a.

There was also a *position* x *orientation* interaction [$F(12,192)=2.97$, $p < .001$, $\eta^2_p = 0.16$]; *orientation* had the smallest effect on images showing*90° Abduction* and had the greatest effect on the images showing *180° Flexion*; see Fig. 4.6a.

4.3.2 Known Sidedness Movement

There was no measure of accuracy as participants were told prior to the trial which arm they would need to move. Filtering of movement times led to a loss of less than 0.5% of trials (two trials). There were no missing trials, so no data needed to be replaced by the relevant group mean when entering data for statistical analysis.

There was a significant main effect of *position* [$F(4,64)=23.53$, $p< .001$, $\eta^2_p= 0.54$]; images showing a *neutral* position and *90° flexion* were comparable [$p= .667$] but were significantly faster than all other positions [$p< .001$]. Images depicting *90° abduction* and *180° flexion* were comparable [$p= .31$]. Movement times for images depicting *HBB* were significantly slower than all other positions [$p< .001$];see Fig. 4.3c.

There was also a main effect of *orientation* [$F(3,48)=9.13$, $p< .001$, $\eta^2_p= 0.17$] Pairwise comparisons revealed a difference between images oriented at 0° (fastest to be moved to) and the 180° (slowest to be moved to);[$p< .001$]. Note the movement time difference between the images oriented at *180°* and *0°* orientations was around just 60ms. Movement time data for images oriented at 90°and 270° were comparable [$p= .245$]; see Fig. 4.4c.

In contrast to the judgment task (above), there was no interaction between *orientation* and *position; see* Fig. 4.7b.

4.3.3 Unknown Sidedness Task

Planning

Once more, there was a large main effect of *orientation* [$F(3,48)=84.99$, $p< .001$, $\eta^2_p= 0.85$]. Planning times for images oriented at 0° were significantly faster than all other *orientations* [$p< .001$]. Those oriented at 180° were significantly slower than all other *orientations* [$p < .001$]. Images oriented at and 90° and 270° were comparable [$p = .536$]; see Fig. 4.3b.

There was also a significant main effect of *Position* [$F(4,64)=21.89$, $p < .001$, $\eta^2_p = 0.57$]. Planning times for images depicting *90° abduction were fastest,* followed by those depicting a *neutral* position*.* The *180° flexion* and the *90° flexion* positions were comparable [$p = .84$] and were the slowest two positions, see Fig. 4.6b.

Execution

There was only one significant main effect found here and this was for *position* [$F(2,64)=27.48$, $p < .001$, $\eta^2_p = 0.63$]. Images depicting a *Neutral* position resulted in the fastest execution times but these were not significantly faster than for images depicting *90° flexion* [$p = .267$]. Images depicting *90° flexion* resulted in significantly faster execution times than all other positions [$p < .001$]. There was no difference between execution times for images depicting *90° abduction* and *180° flexion* [$p = .917$]; those for *HBB* were significantly slower than all other positions [$p < .001$] see Fig. 4.6a.

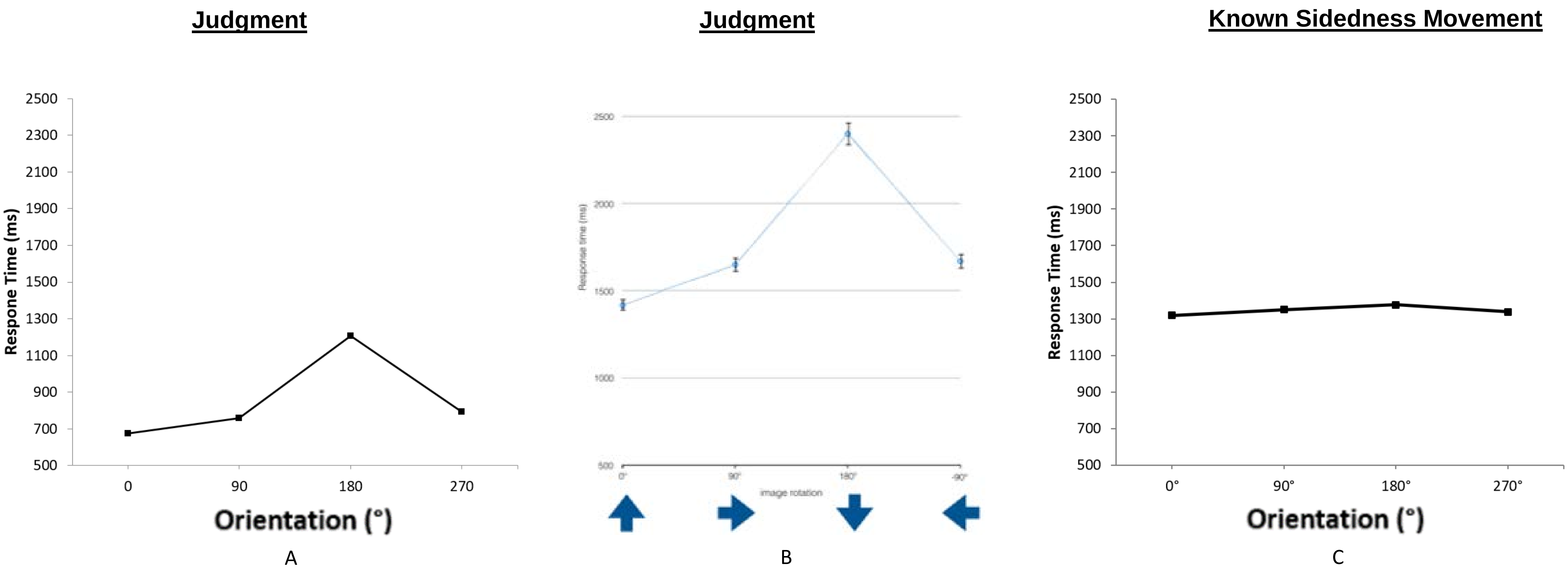
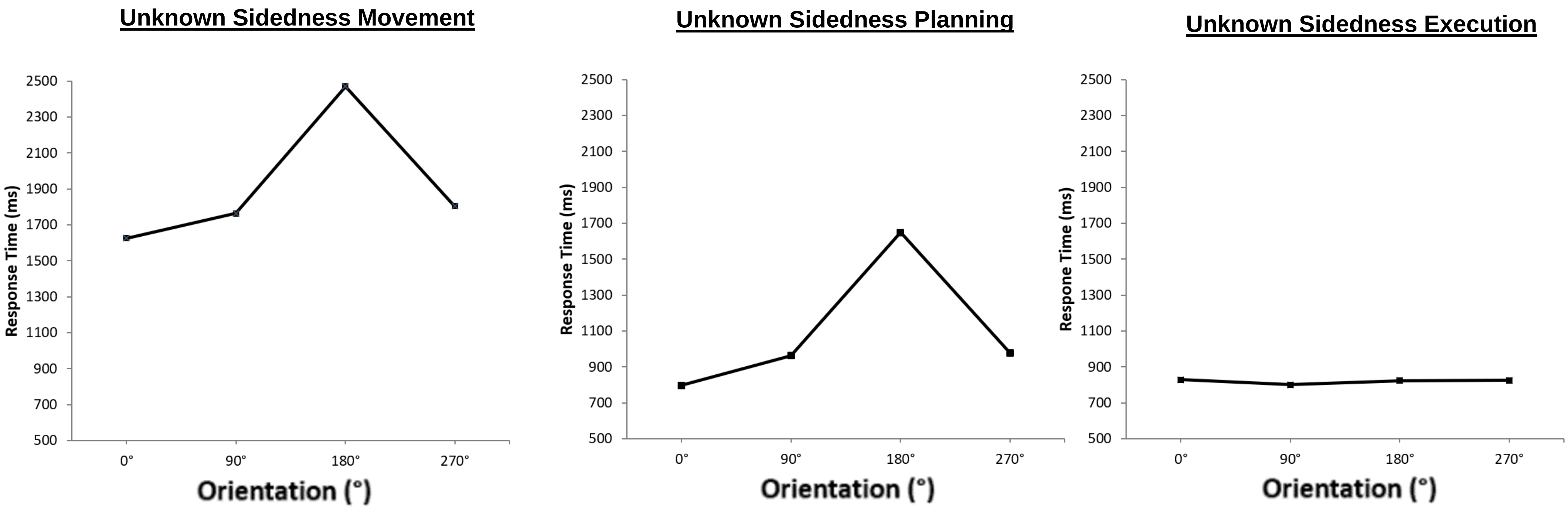


Fig. 4.3. These Figs. compare the *judgment* and *movement* time. Fig. 4.3a shows the *judgment* RT data from the current study, Fig. 4.3b is taken directly from Breckenridge *et al.,* (2017) and Fig. 4.3c is the *unknown sidedness movement* RT data. These Figs. display the clear difference in RT patterns from the *judgment* task and the *movement* task. Note the difference in RT between the Breckenridge *et al.,* (2017) *judgment* data fig. 4.3b and the data from the current experiment, fig. 4.3a.



A B C

Fig. 4.4. These Figs. show *unknown sidedness movement* RT. Fig. 4.4a shows the *overall movement* RT, Fig. 4.4b shows the *planning RT,* Fig. 4.4c shows the *execution* RT. There is no effect of *orientation* in the *execution* data.

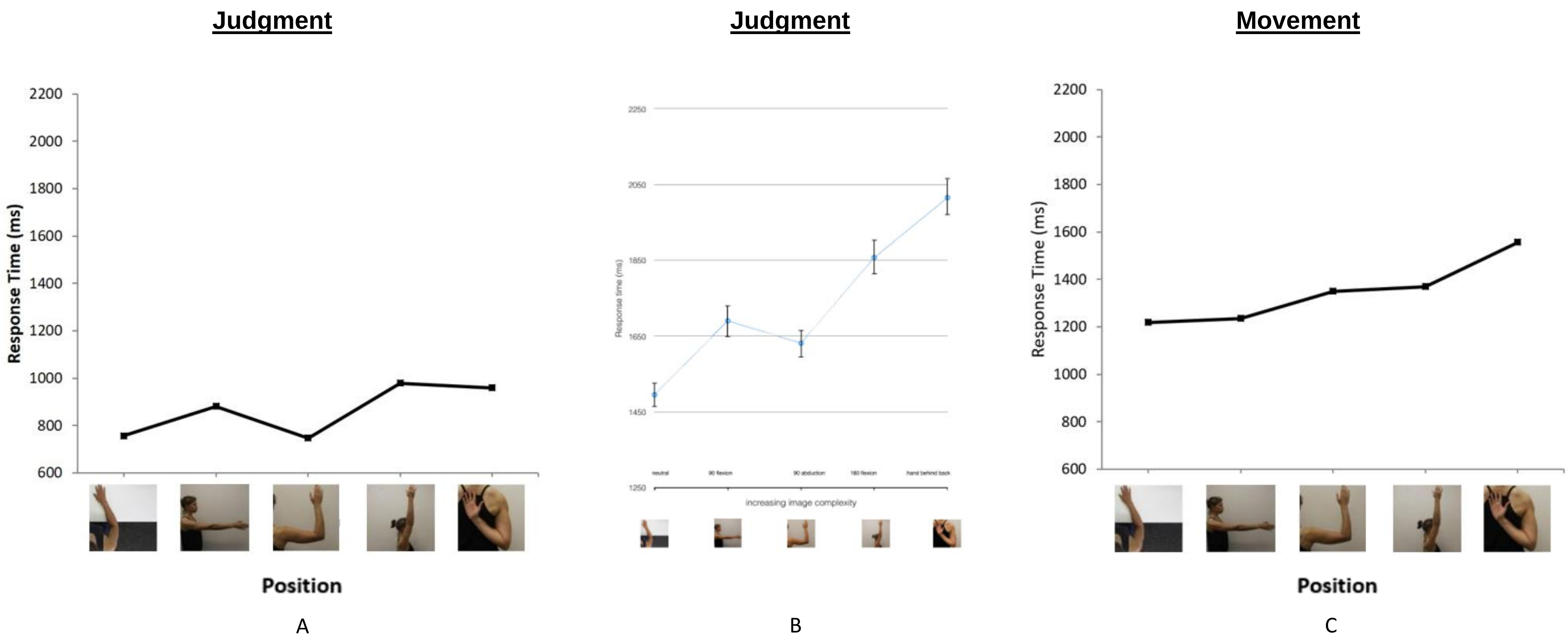


Fig. 4.5 These Figs. display the clear difference in RT patterns from the *judgment* task and the *movement* task. The data from the current experiment fig.4.5a is comparable to that of 4.5b, but the movement time shows a different pattern to both. A finding that is inconsistent with the idea that these tasks elicit MI of the shoulder.

A B C

Fig. 4.6. These Figs. show *unknown sidedness movement* RT and the effect of position. Fig. 4.6a shows the *overall movement* RT, Fig. 4.6b shows the *planning RT,* Fig. 4.6c shows the *execution* RT.

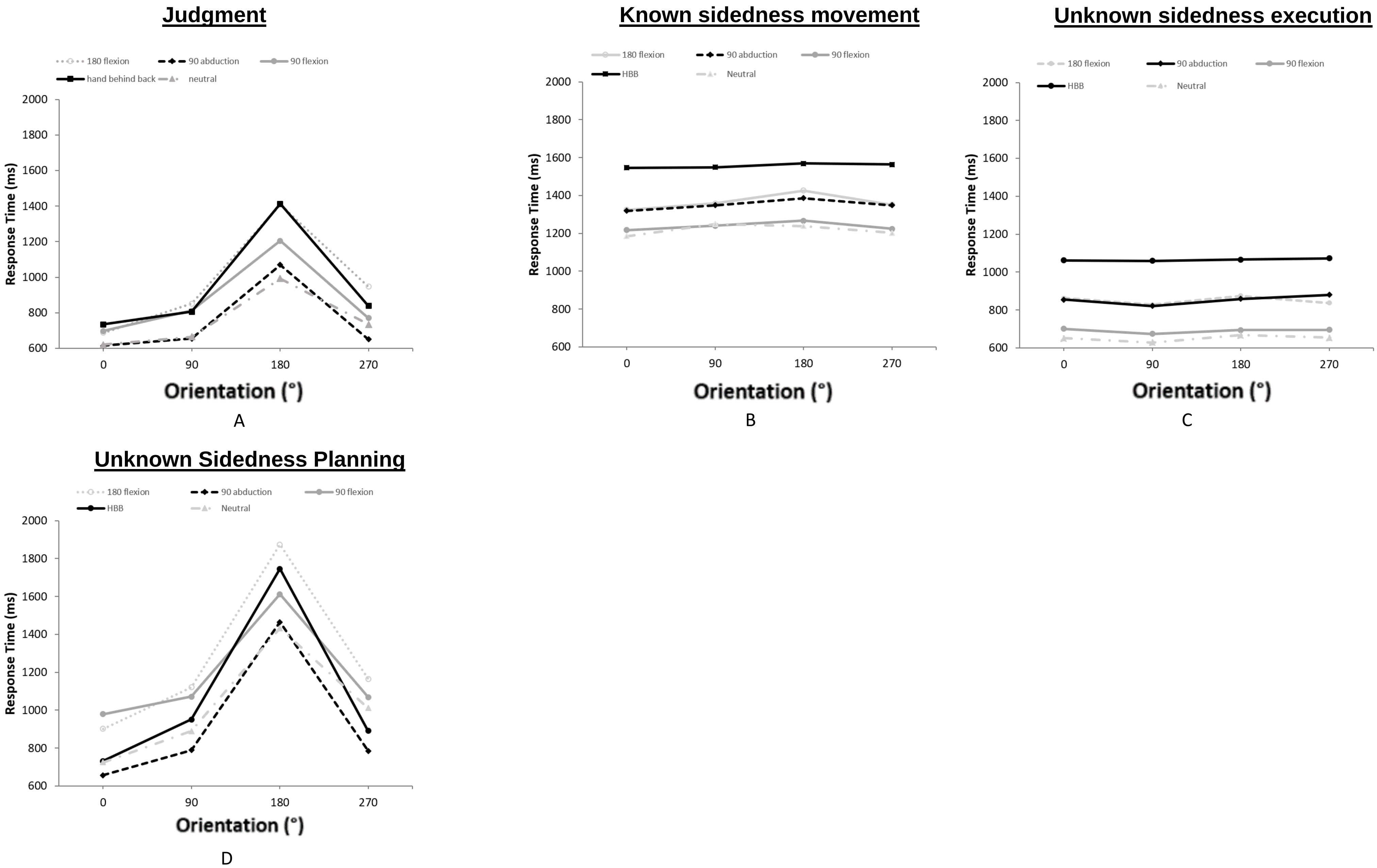


Fig. 4.7. These Figs. show the RT to the *position* by *orientation* interactions. Fig. 4.7a presents the interaction from the *judgment task.* Fig. 4.7b shows the data from the *known sidedness task,* Fig. 4.7c shows the lack of interaction from the *unknown sidedness execution* task and finally Fig. 4.7 shows interaction from the *unknown sidedness* planning.

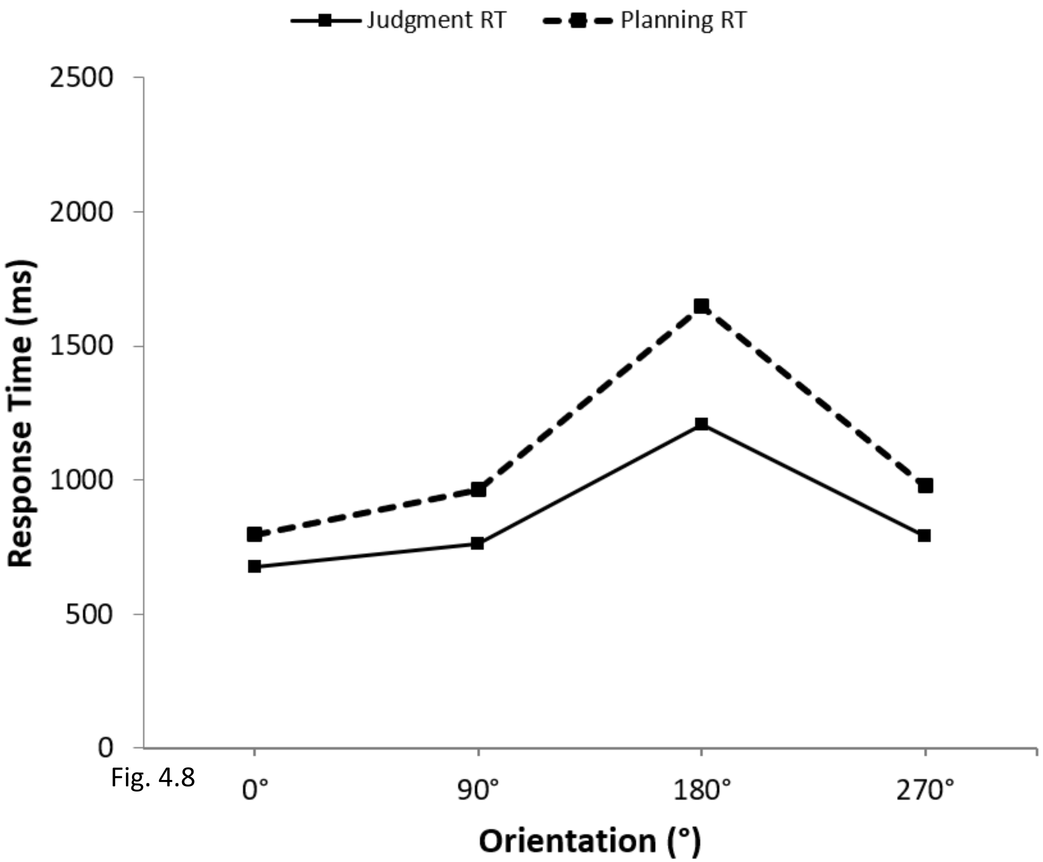


Fig. 4.8

Fig. 4.8 shown the *planning* RT in the *unknown sidedness task* and the *judgment* RT. Both of these data sets have already been reported but are here shown on the same graph to highlight the difference. In experiment two the *judgment* and *unknown sidedness planning RT* were almost identical. This Fig. presents two data sets which present a very similar pattern.

4.4 Discussion

The findings from Chapters two and three strongly suggest that trunk-based and shoulder-based LRJTs do not elicit IMI as claimed by previous studies (Bray and Moseley, 2011, Bowering et al., 2014, Breckenridge et al., 2017). However, images used in Chapters two and three were designed to manipulate key factors such as view, amplitude and orientation providing a means of examining any contribution that IMI might be making to related judgments. This would not have been possible using images used in previous studies or by using images that are available commercially. Nevertheless, given that this thesis has strongly challenged the theoretical basis of these tasks and their related application, a criticism of this thesis may be that it has not used the exact images used in previous studies or those available commercially, despite this being done with good reason (see above). In an attempt to address this issue, this final experiment aimed to investigate whether the images presented in Breckenridge et al. (2017) do elicit IMI of the shoulder as claimed, when presented as part of a shoulder-based LRJT.

Judgment data reported here show an identical pattern to those reported by Breckenridge et al. (2017). It is straightforward to recognise the relative speed with which participants responded to stimuli based on both the *position* presented and the *orientation* of the stimuli. However, as demonstrated in earlier chapters of this thesis, the fact that stimuli presenting different positions (and views) at different orientations result in different judgment times provides no indication that IMI of shoulder movements is part of the judgment process. For one to infer that IMI of shoulder movements is part of the judgment process, one would wish to see that movement time data show a similar pattern of data to judgment times (Parsons, 1994).

Movement time data reported here for stimuli used by Breckenridge et al., (2017) are therefore very interesting with regards to the issue. The methodological approach followed here during the *known sidedness* task was consistent with the approach taken by Parsons (1994) and in Chapters two and three of this thesis. Accordingly, in this task, participants were informed of which limb they were required to move prior to blocks of trials presenting stimuli requiring movement of either the left or the right upper limb (not both). The resulting movement times show a similar pattern to the judgment times for the different *positions* presented and one may therefore conclude from this that these data support the involvement of IMI in the judgment process. However, to do so would fail to recognise some important differences between judgment and movement data that were also evident and the contribution of other factors affecting the judgment process that do not appear to have been considered by Breckenridge et al. (2017).

Contrasting judgment times and movement times in this *known sidedness* task reported here in more detail reveals some important differences. While *orientation* effects were evident in both tasks, these were far more pronounced in the judgment task. As argued earlier, this supports the idea of the requirement to mentally align the orientation of one's whole body with that of the stimulus as a critical factor in determining sidedness in shoulder-based LRJTs. Furthermore, the interaction that occurred for judgment time data demonstrates that the process of mentally aligning one's whole body with that of the stimulus was not consistent for all positions. In contrast, there was no interaction for movement time data.

It seems likely that various aspects of the images used by Breckenridge et al. (2017) but not acknowledged by the authors are responsible for their data and those presented here. As Punt (2017) has explained, "if one wishes to make a comparison between response times for images showing different levels of awkwardness/complexity, this must be done on the basis of controlling the perspective from which the image is seen and the amount of visual information provided" (p.87). For the images used here, both of these critical aspects are uncontrolled and subsequently confound the resulting data. To take a relatively straightforward example, consider the images used for 90° flexion and 180° flexion. Broadly comparable positions from the previous chapter (i.e. small amplitude and large amplitude of shoulder abduction) resulted in different movement times (the larger amplitude taking longer) but comparable judgment times. Stimuli in this experiment not only result in different movement times (again, the larger amplitude of movement taking longer) but different judgment times as well, in the same direction. However, although perspective was consistent for the two positions (i.e. images were taken from the side), 180° flexion includes far less of the body and the fully abducted shoulder obscures the head. It is known that the amount of body information available affects the visual coding of body parts and that the inclusion of an appropriately aligned head is particularly important for this process (Corradi-Dell'Acqua and Rumiati, 2007, Ramm et al., 2010). For other *positions*, *perspective* (or *view*) is also inconsistent (e.g. neutral is from above, 90° abduction is from behind) adding inconsistency in other factors not acknowledged by Breckenridge et al. (2017), but that are known to significantly affect related data (Parsons, 1987a, Alazmi et al., 2018).

As with the previous chapter, this experiment aimed to include a further task where resulting data might be illuminating with regards to the underpinning processes governing LRJT performance for the presented images. Accordingly, a block of images were presented to participants where they were required to move their corresponding limb into the position shown, but were not informed about which limb this would be (i.e. *unknown sidedness*). It was expected that the *planning time* (i.e. the period between stimulus onset and movement onset) in this task would be very similar to judgment times, providing further evidence that aligning one's whole body with the stimulus presented is the critical aspect of the task. While this was largely the case (i.e. patterns of data were very similar for planning and judgment times), planning and judgment times were not as closely matched as in the previous chapter. One may speculate that the reason why planning times were slower than judgment times in this experiment was because of more varied and complex movements of the upper limbs that were required in this experiment. Importantly, this in no way suggests that the judgment task in this experiment elicited IMI of upper limb movements; these longer planning times were only a feature when an actual movement was required.

In conclusion, data reported in the chapter demonstrate the shortcomings of images used by Breckenridge et al. (2017) and highlight their inability to provide judgment time data that are persuasive of the task eliciting MI of upper limb movements. On the contrary, data are largely consistent with the view presented earlier in this thesis about the mechanism underpinning left/right judgments in these tasks; that once participants align/match their body's orientation with that of the stimulus, the sidedness judgment is automatic.

Chapter 5: General Discussion

This thesis aimed to investigate whether shoulder and trunk-based LRJTs elicit IMI in the way recent studies have claimed (e.g. Bray and Moseley 2011, Bowering et al., 2013, Breckenridge et al., 2017). These contributions have cited the findings of influential hand-based LRJT investigations (Parsons, 1987b, Parsons, 1994) and made related assumptions that these new versions of LRJTs elicit local IMI (i.e. of shoulder or back movements). Further, they have also claimed that, as it takes longer to judge stimuli that are presented further away from 0° this is evidence of IMI, and that images which are more "awkward" (Breckenridge et al 2017 p.44) also incur a greater judgment RT, supporting the involvement of local IMI being used. However, there are clear differences in the composition of images that involve disembodied hands compared and those focusing on other body parts, and to date, these did not appear to have been considered with the introduction of new tasks. Whereas there had been substantial research into how hand-based LRJTs are solved, to date there has been minimal research into the nature of LRJTs involving other body parts and their ability to elicit local IMI.

5.1. Summary of findings:

This thesis has reported a series of experiments investigating LRJTs, including hand-based, trunk-based and shoulder-based variants of the task. Chapter Two (Experiment One) aimed to replicate Parsons' (1994) study on the hand-based task and then to replicate the approach taken in this experiment as closely as possible using a trunk-based LRJT. By demonstrating a similar pattern of data for judgment times and movement times, Parsons' (1994) study was pivotal in confirming the use of IMI in making hand-based left/right judgments. Had the trunk-based task also shown similar patterns of data between judgment and movement times, this would have been supportive of the use of IMI as claimed by Bray and Moseley (2011) and Bowering (2013). For the hand-based task, results from Experiment One largely replicated those of Parsons (1994), showing very similar patterns of data for judgment times and movement times, indicative of IMI being used. However, data from the trunk-based task contrasted markedly with these and were entirely inconsistent with IMI of back movements being used in making related judgments. Movement times showed a very different pattern of data to judgment times. For example, where images depicted back postures that were either more deviated (large amplitude) or less deviated (small amplitude) from neutral, movement times reflected this (i.e. they were longer for the large amplitude). However, this factor had no effect on judgment times. The finding for judgment times in the trunk-based task replicate recent research questioning the ability of trunk-based LRJTs to elicit local IMI (Alazmi et al., 2018). In addition, Experiment One also explicitly showed how related movement times do reflect the different amplitudes presented. In short, data from the trunk-based LRJT in Experiment One are consistent with Alazmi et al. (2018). Further data suggest that trunk-based LRJTs are solved by individuals matching the whole body position of the image with their own body; once they have completed this, the sidedness judgment is automatic/obvious (Alazmi et al., 2017, Parsons 1987).

Chapter Three (Experiment Two) investigated a shoulder-based LRJT. Claims made in Chapter Two (and by Alazmi et al., 2018) relating to trunk-based LRJTs may also be relevant to other new forms of LRJTs (Breckenridge et al., 2017, Wallwork et al., 2013, Bray and Moseley, 2011) and this chapter aimed to generalise findings by selecting a different body part. This chapter (Experiment Two) took the same approach as in the previous chapter (i.e. examined the patterns of judgment times and movement times in response to the same images), but this time added a further condition; an *unknown sidedness* movement task, where participants were not informed of the sidedness of the trials beforehand (as in the standard movement task). In addition, responses for this condition were separated into *planning time* and *execution time*. This was done to further investigate the processes that are used by participants in solving the task. If the critical component of the judgment task is to mentally align one's whole body with that of the stimulus, then planning time in the *unknown movement task* should display a pattern of data that are similar to judgment times. As with Chapter Two, the results again displayed findings that were entirely inconsistent with local MI (i.e. IMI of shoulder movements) being used to solve the task. Images depicting larger amplitudes od movement resulted in slower movement times but comparable judgment times. Furthermore (see Fig. 3.3) the planning time and the judgment time were almost identical, supporting the mechanism suggested above.

Chapter Four (Experiment Three) again investigated a shoulder-based LRJT. The rationale behind completing another shoulder-based task was that this time the images were taken from Breckenridge et al., (2017) and are those that are available commercially and used clinically. These images have been criticised by Punt (2017) for not controlling important factors that may affect performance. Firstly, they display images from different viewpoints but don't acknowledge the known impact of this on performance (Parsons, 1987a) or include as a factor in analysis. The subsequent conclusions drawn by Breckenridge et al (2017) are therefore problematic. Furthermore, each image offers varying amount of information i.e. some images clearly show the head, where others do not (see Chapter Four discussion) and Punt et al.,

2017) for more detail. Despite this criticism, it was considered important to investigate these images with the same approach as was taken in the previous chapters, as these are the images that are available for clinicians/patients to use. Again, results were inconsistent with IMI being used to solve the task; the pattern of data for movement times were not consistent with the pattern of data for judgment times.

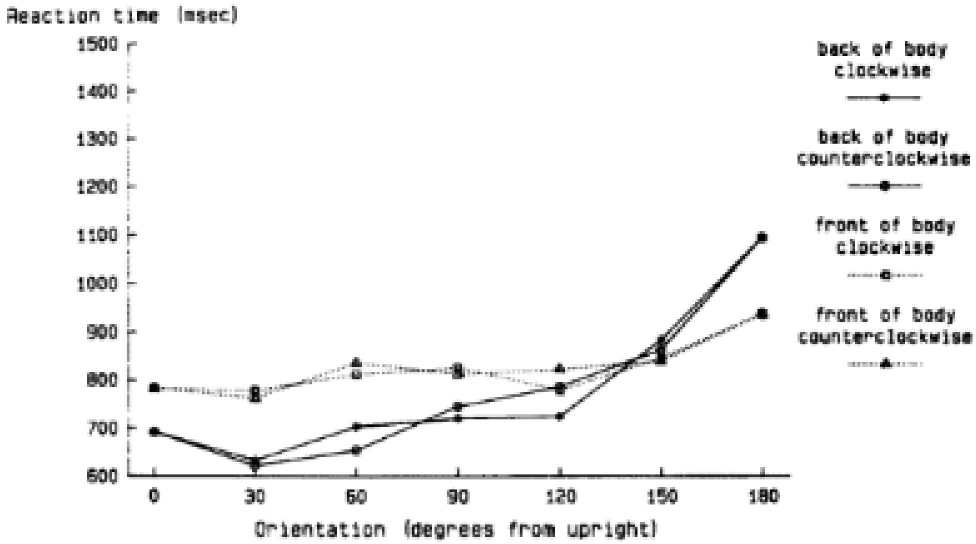
Overall this thesis strongly supports the ability of the hand-based LRJT to elicit IMI of upper limb movements as suggested by (Parsons, 1987b, Parsons, 1994) and their subsequent adoption for use in clinical practice (Ionta and Blanke, 2009, Shenton et al., 2004, de Lange et al., 2006, Nico et al., 2004). This is supported by the close matching of the data patterns for movement and judgment times in this task. This thesis challenges the more recent development of LRJTs into other parts of the body. The findings from the trunk-based LRJT (Chapter Two) highlighted major inconsistencies between movement times and related judgment times, as did the systematically manipulated images of the shoulder-based task (Chapter Three) and the commercially and clinically used images (Chapter Four). Together, the data reported in this thesis build a compelling argument that for body parts other than those of disembodied hands (and feet) LRJTs do not require the use of local IMI. Instead it is more likely that these tasks use a whole-body mental transformation and an automatic judgment of the sidedness.

5.2 Theoretical implications:

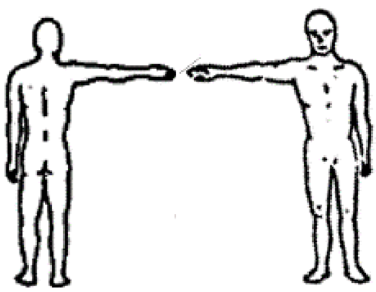
The data from the hand-based LRJT of chapter two (Experiment One) is consistent with the previous literature and is consistent with IMI being used to solve the task.

There is a strong relationship between the judgment time and the movement time. This relationship is crucial to provide support for motor imagery (Decety et al., 1989) , and therefore without it, it becomes very difficult to provide support for the idea that IMI is being used. Each of the remaining experiments in this thesis present results which are entirely inconsistent with IMI being used to solve LRJTs based on body parts other than disembodied Instead hands or feet. Instead of requiring the use of IMI, the data presented in this thesis are consistent with these tasks requiring a whole-body mental transformation to match the presented stimulus, followed by an automatic recognition of the sidedness.

For a task where the process one undertakes in order to solve it is critical to its clinical value, the introduction of new LRJTs into clinical practice (Bray and Moseley, 2011, Bowering, 2011, Wallwork et al., 2013, Breckenridge et al., 2017, noigroup, 2016b, noigroup, 2016a, noigroup, 2016c) on the basis of an assumption rather than any empirical evidence of great concern. As noted above, the trunk-based and shoulder-based LRJTs examined in this thesis provide support for the view that individuals perform a whole-body mental transformation before making an automatic (or obvious) sidedness judgment. Data in Fig. 2.10A, 3.2A and 3.3A show the interaction of *view* and *orientation* and appear comparable with those reported over thirty years ago (Parsons, 1987a) (see Fig 5.1). Interestingly, none of the rehabilitation-based studies supporting the use of these newer LRJTs have cited this theoretically influential work on whole-body mental transformations (Parsons, 1987a). This study investigated whole-body mental transformations, using a line drawing of a body with an outstretched arm. Participants reported making a whole-body mental transformation to the same orientation as the stimulus and then making an obvious judgment to the sidedness of the arm. The similarity between the data reported in Chapters two and three, compared to that of Parsons (1987a)(Fig. 5.1) supports the idea that it was the same process being used in both studies. For a detailed description of the possible methods by which these whole body mental transformation are complete see Parsons (1987a) (pg. 190-191). These methods explain why the allocentric and egocentric images cause different RT mappings in the *judgment* tasks.



A



B C

Fig. 5.1. A shows the data presented in Parsons (1987a). This data is comparable to Fig. 2.10A, 3.2A and 3.3A, therefore supporting the idea of a whole-body mental transformation followed by an automatic judgment. B shows a egocentric model or "back of body" to use the term of Parsons, C shows an allocentric or "front of body" model.

Subsequent support for whole-body mental transformations in making left/right judgments of the whole body has been provided (Zacks and Tversky, 2005, Lenggenhager et al., 2008, van Elk and Blanke, 2014). This investigation used line drawings of an outstretched arm similar to Parsons (1987a) and asked individuals which arm was outstretched. In this experiment the participants were given three conditions, two trial blocks with no instructions, one trial block with one set of instructions and a further trial block with a second, different set of instructions to manipulate the kind of transformation used by the participants. One instruction was "answer the question by forming a mental image of the figure shown on screen and imagine the figure rotating until it is upright." (Zacks and Tversky, 2005). The other was a perspective based transformation "answer the questions by imagining yourself in the position of the figure onscreen."(Zacks and Tversky, 2005). The RT data was then compared between the two manipulated instruction conditions and the non-instruction trials. The data showed that when given the object-based instructions RT increased compared to the non-instruction group, but when given the perspective-based instructions it made no difference. As there was no change in RT between the perspective-based instructions and no instruction group, it can be assumed that the same processes were being used in both conditions, therefore, assumed that naturally participants were using a perspective-based manipulation.

Once this mental transformation has been made, to match the orientation of the presented stimulus we then have easier access to the visual information presented to us (Ramm et al.,), and therefore access to BSD. BSD is the representation that relies on visuospatial information and not efference copy and proprioceptive information (i.e. the body schema), the potential use of it is important as it negates the use of BSc and IMI. Access to BSD is what enables us to be able to complete the LRJTs of other body parts, and not have to use our own body as a reference frame. Again, it is notable that the development of newer LRJTs has progressed with reference only to BSc and not other forms of body representations (i.e. BSD). We can gain access to BSD with very little information. Ottoboni et al. (2005) and Tessari et al. (2012) have shown that we can gain access to BSD with very little visual information. These studies presented data that showed as soon as a wrist or ankle was added to an image of a disembodied hand or foot a judgment of the sidedness of that hand or foot became automatic.

The reason the sidedness recognition becomes automatic is due to participants being able to connect the hand or foot to an imaginary body. Once the body part has been connected to the imaginary body, participants again have access to BSD, and negates the use of BSc. When using body parts other than a hand or foot, it is impossible to visually isolate that body part, e.g. it is impossible to show an image of the shoulder without showing some other body part such as the back, the arm, the head or neck (not necessarily all these parts in the same picture) Therefore, the other body parts surrounding it will be able to act as this 'connector' and allow participants access to BSD, negating the use of BSc and IMI.

To summaries the theoretical implications of this thesis, the data from the hand-based LRJT is consistent with previous work. The data in this thesis is consistent with hand-based LRJTs being solved using exact match confirmation theory to solve the task. This is a method that requires the use of our BSc body representation. Other body part-based LRJTs are likely to be solved using a full body mental transformation to match one's orientation to that of the presented stimulus. Once this has happened it allows the participant to be able to make an automatic judgment on the sidedness of the body part based on visual information. This require the BSD body representation. The difference in the methods used to solve these tasks is due to the different amount of visual information that is offered to participants when solving these tasks.

5.3 Clinical implications:

As previously stated, the clinical use of LRJTs in body parts other than the hands and feet has been strongly questioned in this thesis. The therapeutic role of a LRJ comes from the elicitation of IMI of movements of the body part in question. The Graded Motor Imagery Handbook (Moseley et al., 2012) states that IMI allows patients to dissociate movement and pain and may therefore logically have therapeutic value in patients with chronic pain. As is shown in this thesis, these tasks do not appear to elicit IMI even though it is this IMI which is fundamental to the clinical use of these tasks. In recent years these tasks have been developed and sold commercially (noigroup, 2016c, noigroup, 2016a). Although this was done undoubtedly with the best of intentions in an attempt to help chronic pain sufferers, in light of this research and the findings which show that IMI is *not* elicited when completing these tasks, these applications should be withdrawn. The evidence in this thesis is the first to directly compare *movement* and *judgment* RTs of other body part LRJTs. The methods used in this study are far more stringent than those used in (Wallwork et al., 2013, Breckenridge et al., 2017) and are therefore better able to comment on the ability of these tasks to elicit IMI.

This does not, however, necessarily mean the end of the use of LRJTs as a therapeutic tool. This thesis along with multiple other studies (Parsons, 1987b, Parsons, 1994, Ionta and Blanke, 2009, Cocksworth and Punt, 2013) supports the use of hand-based

LRJTs as a tool that elicits IMI. Although not studied in this thesis, it seems likely that images of disembodied feet will also elicit IMI. The critical factor in tasks eliciting (or not eliciting IMI) seems to be the amount of visual information that is offered. LRJTs of disembodied hands and feet force one to compare their own limbs with that of the presented image in order to solve the task. If the elicitation of IMI is as important as is claimed in the graded motor imagery process (Moseley et al., 2012) why do we need to develop a new task for the shoulder and knee? LRJT using disembodied hands and feet have been shown to elicit IMI, and in order for one to imagine movement of the hand or foot into the correct position it also requires imagined movement of the shoulder or knee (Rosser et al., 2019, Stanton et al., 2013). Due to the amount of visual information available when using other body part-based LRJTs IMI is not required to solve the task. This is an idea that is supported by a 2019 systematic review (Breckenridge et al., 2019). The data presented showed that when presented with lower or upper limb based LRJT, participants with chronic pain in those areas produced slower LRJ times compared to healthy controls. Whereas people with neck and back pain produced judgment RT data that was no different from healthy control. This thesis suggests that this is because the back and neck based LRJTs require different mechanisms from that of disembodied hand and foot LRJTs.

5.4 Future Research

Firstly, future research needs to recognise the difference in disembodied hand and foot LRJTs and LRJTs based on any other body part. Disembodied hands and feet offer a unique challenge that must be solved by manipulating a mental representation of one's own hands or feet, due to the relative lack of information. Other body parts cannot be isolated to the same extent, and the relatively high amount of visual information about the body that is offered allows participants access to BSD. This finding requires that a greater level of care needs to be used when comparing the findings from a hand-based LRJT to another body part based LRJT.

This thesis does not question the graded motor imagery process, just the fact that IMI is elicited by LRJTs of body parts other than disembodied hands (or feet). This process might be an effective therapeutic tool. In order to advance it, future research should be directed at finding other ways in which we can elicit IMI.

The images presented in these studies needs to be a key consideration for future research in this area. The amount of visual information that is offered needs to be carefully controlled. Breckenridge et al. (2017) for example, uses images that display i) different amounts of the body i.e. some images contain the head, and some do not; ii) images are presented from different perspectives i.e. the images are presented from the side, some from the back and one from above. These two factors make fair comparison between the images impossible. When the authors attribute an increased RT to the position of the stimulus could in fact be due to the perspective that the image was taken from, because the images are not consistently shown from the same perspective this acts as a confounding variable. It therefore requires a greater amount of care and thought to be used when producing images for LRJTs.

5.5 Strengths and Weaknesses

This is the first study that investigates the *movement* and *judgment* time associated with LRJTs of trunks and shoulders. Building on the influential work of Parsons (1994) that was pivotal in providing conclusive evidence that hand-based LRJTs are solved using LRJT, this thesis compared the *movement* and *judgment* times for images used in trunk-based and shoulder-based LRJTs in the same way. Resulting data from these newer forms of LRJTs were all inconsistent with their ability to elicit IMI of the given body part.

The tasks in these experiments were all conducted under laboratory conditions, with participants observed and using programs that result in millisecond level timing accuracy. This is contrast to much of the more recent work that has been completed in the field (Wallwork et al., 2013, Breckenridge et al., 2017), that have used web-based tools, such as the Recognise ™ App (noigroup, 2016b, 1985, noigroup, 2016a, noigroup, 2016c). These web-based tools have been shown to be a valid and reliable tool for collect LRJT data (Williams et al., 2019). However, it can never be certain how much attention to the task the participant is paying, when using a web-based task. The situation the participant is in, such as being in a loud room, or having a conversation at the same task is a factor that cannot be controlled for using these home-based tasks. When comparing the judgment data from Experiment Two with that of Breckenridge *et al.,* (2017) (see Fig. 4.3A and 4.3B) there is a large disparity between the two. The only difference in methodology between the tasks is that Breckenridge *et al.,* (2017) uses a web-based task and this thesis uses a lab-based study. The advantage a web-based task has over a lab-controlled study is the fact that the study has a much larger reach. It would be logistically unrealistic to test as many people in a lab-based setting as it is via the web. The benefits of a larger reach and sample, but potentially less accurate data should be considered before using a web-based approach.

A further strength to the current thesis is that the images used in Experiments One and Two are well designed. They aimed to very systematically manipulate the intended variables. Images of whole bodies were used, for example, to ensure that different postures presented to participants did not offer different amount of visual information that may have helped when solving the task. Experiment Three used images from (Breckenridge et al., 2017) although these images were not so well controlled, i.e. they were taken from different perspectives, it was necessary to test these images in order to expose the downfalls of using partial bodies in this way.

Finally, the thesis has helped to develop a more general understanding of how LRJTs of body parts other than disembodied hands and feet are solved. The data from both the trunk-based task and shoulder-based task offer very similar data. It is hard to imagine why, when it looks very likely that the methods used to solve these tasks are a whole-body mental transformation to match the orientation of the presented stimulus followed by an automatic judgment, different body parts (other than disembodied hands and feet) would allow the use of a different system.

5.6 Conclusion

The data from this extensive study of LRJTs highlights the different mechanisms that are used when solving disembodied hand-based LRJTs compared to LRJTs of other body parts. The data from this thesis is consistent with literature that hand-based LRJTs use *exact match confirmation strategy* and therefore elicit IMI of the hands. The *leap* made in developing newer forms of LRJTs based on findings from hand-based LRJTs was based on the assumption that participants will use the same mechanisms for the rest of the body (i.e. IMI of movement of the given body part). The evidence presented in this thesis shows that this is not the case. All the findings from this thesis argue that local IMI is not used to solve these tasks when they are based in other body parts. It is likely that one first completes a whole-body mental transformation to match the orientation of the presented image. After this mental transformation one can use the larger amount of visual information that are presented during other body part based LRJTs to access their BSD representation. This is a representation of bodies in general that relies on visuo-spatial information. The relative lack of visual information we are presented with during a hand-based LRJT forces the use of BSc. This is a proprioception and efference copy based representation, which allows one to compare the presented image of a hand with their own body.

6. References

ALAZMI, L., GADSBY, G. E., HENEGHAN, N. R. & PUNT, T. D. 2018. Do trunk-based left/right judgment tasks elicit motor imagery? *Musculoskeletal Science and Practice,* 35**,** 55-60.

BOWERING, J. 2011. *Implicit motor imagery in people with a history of back pain, current back pain, both or neither. An investigation into the effects of low back pain on left/right trunk rotation judgements.* BPhty Research Dissertation, University of South Australia.

BOWERING, K. J., BUTLER, D. S., FULTON, I. J. & MOSELEY, G. L. 2014. Motor imagery in people with a history of back pain, current back pain, both, or neither. *Clinical Journal of Pain,* 30**,** 1070-5.

BOWERING, K. J., O'CONNELL, N. E., TABOR, A., CATLEY, M. J., LEAKE, H. B., MOSELEY, G. L. & STANTON, T. R. 2013. The effects of graded motor imagery and its components on chronic pain: a systematic review and meta-analysis. *Journal of Pain,* 14**,** 3-13.

BRAY, H. & MOSELEY, G. L. 2011. Disrupted working body schema of the trunk in people with back pain. *British Journal of Sports Medicine,* 45**,** 168-173.

BRECKENRIDGE, J. D., GINN, K. A., WALLWORK, S. B. & MCAULEY, J. H. 2019. Do People With Chronic Musculoskeletal Pain Have Impaired Motor Imagery? A Meta-analytical Systematic Review of the Left/Right Judgment Task. *Journal of Pain,* 20**,** 119-132.

BRECKENRIDGE, J. D., MCAULEY, J. H., BUTLER, D. S., STEWART, H., MOSELEY, G. L. & GINN, K. A. 2017. The development of a shoulder specific left/right judgement task: Validity & reliability. *Musculoskeletal Science and Practice,* 28**,** 39-45.

BUXBAUM, L. J. & COSLETT, H. B. 2001. Specialised structural descriptions for human body parts: Evidence from autotopagnosia. *Cognitive Neuropsychology,* 18**,** 289-306.

COCKSWORTH, R. L. & PUNT, T. D. 2013. When the left hand does not know what the left hand is doing: response mode affects mental rotation of hands. *Experimental Brain Research,* 228**,** 87-95.

COOPER, L. A. & SHEPARD, R. N. 1975. Mental transformations in the identification of left and right hands. *Journal of Experimental Psychology: Human Perception and Performance,* 104**,** 48-56.

CORRADI-DELL'ACQUA, C. & RUMIATI, R. I. 2007. What the brain knows about the body: evidence for dissociable representations. *In:* SANTOIANNI, F. & SABATANO, C. (eds.) *Brain development in learning environments: embodied and perceptual advancements.* Newcastle: Cambridge Scholars Publishing.

CORRADI-DELL'ACQUA, C., TOMASINO, B. & FINK, G. R. 2009. What is the position of an arm relative to the body? Neural correlates of body schema and body structural description. *J Neurosci,* 29**,** 4162-71.

DE LANGE, F. P., HELMICH, R. C. & TONI, I. 2006. Posture influences motor imagery: an fMRI study. *Neuroimage.,* 33**,** 609-617.

DECETY, J., JEANNEROD, M. & PRABLANC, C. 1989. The timing of mentally represented actions. *Behavioural Brain Research,* 34**,** 35-42.

GENTILUCCI, M., DAPRATI, E. & GANGITANO, M. 1998. Right-handers and left-handers have different representations of their own hand. *Cognitive Brain Research,* 6**,** 185-192.

IONTA, S. & BLANKE, O. 2009. Differential influence of hands posture on mental rotation of hands and feet in left and right handers. *Experimental Brain Research,* 195**,** 207-217.

IONTA, S., PERRUCHOUD, D., DRAGANSKI, B. & BLANKE, O. 2012. Body context and posture affect mental imagery of hands. *PLoS ONE,* 7.

KOSSLYN, S. M., DIGIROLAMO, G. J., THOMPSON, W. L. & ALPERT, N. M. 1998. Mental rotation of objects versus hands: Neural mechanisms revealed by positron emission tomography. *Psychophysiology,* 35**,** 151-161.

LENGGENHAGER, B., LOPEZ, C. & BLANKE, O. 2008. Influence of galvanic vestibular stimulation on egocentric and object-based mental transformations. *Experimental Brain Research,* 184**,** 211-21.

MOSELEY, G. L. 2004a. Graded motor imagery is effective for long-standing complex regional pain syndrome: a randomised controlled trial. *Pain,* 108**,** 192-198.

MOSELEY, G. L. 2004b. Why do people with complex regional pain syndrome take longer to recognize their affected hand? *Neurology,* 62**,** 2182-2186.

MOSELEY, G. L., BUTLER, D. S., BEAMES, T. B. & GILES, T. J. 2012. *The Graded Motor Imagery Handbook,* Adelaide, Noigroup Publications.

MOSELEY, G. L., GALLACE, A. & SPENCE, C. 2008. Is mirror therapy all it is cracked up to be? Current evidence and future directions. *Pain,* 138**,** 7-10.

MOSELEY, G. L., SIM, D. F., HENRY, M. L. & SOUVLIS, T. 2005. Experimental hand pain delays recognition of the contralateral hand--evidence that acute and chronic pain have opposite effects on information processing? *Cognitive Brain Research,* 25**,** 188-194.

NICO, D., DAPRATI, E., RIGAL, F., PARSONS, L. & SIRIGU, A. 2004. Left and right hand recognition in upper limb amputees. *Brain,* 127**,** 120-132.

NOIGROUP. 2016a. *Recognise Back* [Online]. Australia: Neuro Orthopaedic Institute. Available: https://apps.apple.com/au/app/recognise-back/id1082941708 [Accessed 17/09/19 2019].

NOIGROUP. 2016b. *Recognise Knee* [Online]. Australia: Neuro Othopaedic Institute. Available: https://apps.apple.com/au/app/recognise-knee/id1082943360 [Accessed 09/09/19 2019].

NOIGROUP. 2016c. *Recognise Shoulder* [Online]. Australia: Neuro Orthopaedic Institute. Available: https://apps.apple.com/au/app/recognise-shoulder/id1082947661 [Accessed 17/09/19 2019].

OLDFIELD, R., 1971. The Assessment and Analysis of Handedness: The Edinburgh Inventory. *Neuropsychologia,* 9, 91-113.

OTTOBONI, G., TESSARI, A., CUBELLI, R. & UMILTÀ, C. 2005. Is Handedness Recognition Automatic? A Study Using a Simon-Like Paradigm. *Journal of Experimental Psychology: Human Perception and Performance,* 31**,** 778-789.

PARSONS, L. M. 1987a. Imagined spatial transformation of one's body. *Journal of Experimental Psychology: General,* 116**,** 172-191.

PARSONS, L. M. 1987b. Imagined spatial transformations of one's hands and feet. *Cognitive Psychology,* 19**,** 178-241.

PARSONS, L. M. 1994. Temporal and kinematic properties of motor behavior reflected in mentally simulated action. *Journal of Experimental Psychology: Human Perception and Performance,* 20**,** 709-730.

PUNT, T. D. 2017. Re: The development of a shoulder specific left/right judgement task: Validity & reliability. *Musculoskeletal Science and Practice,* 30**,** e87.

RAMM, B. J., CUMMINS, T. D. R. & SLAUGHTER, V. 2010. Specifying the human body configuration. *Visual Cognition,* 18**,** 898-919.

ROSSER, C. A., PUNT, T. D. & RYAN, C. G. 2019. Left/right limb judgement task performance following total knee replacement. *Journal of Back and Musculoskeletal Rehabilitation,* 32**,** 77-84.

SCHWOEBEL, J. & COSLETT, H. B. 2005. Evidence for multiple, distinct representations of the human body. *Journal of Cognitive Neuroscience,* 17**,** 543-553.

SCHWOEBEL, J., FRIEDMAN, R., DUDA, N. & COSLETT, H. B. 2001. Pain and the body schema - Evidence for peripheral effects on mental representations of movement. *Brain,* 124**,** 2098-2104.

SEKIYAMA, K. 1982. Kinesthetic aspects of mental representations in the identification of left and right hands. *Perception and Psychophysics,* 32**,** 89-95.

SHENTON, J. T., SCHWOEBEL, J. & COSLETT, H. B. 2004. Mental motor imagery and the body schema: evidence for proprioceptive dominance. *Neuroscience Letters,* 370**,** 19-24.

SIMON, J. R. 1969. Reactions toward the source of stimulation. *Journal of Experimental Psychology,* 81**,** 174-176.

SIRIGU, A. & DUHAMEL, J. R. 2001. Motor and visual imagery as two complementary but neurally dissociable mental processes. *J Cogn Neurosci.,* 13**,** 910-919.

SIRIGU, A., DUHAMEL, J. R., COHEN, L., PILLON, B., DUBOIS, B. & AGID, Y. 1996. The mental representation of hand movements after parietal cortex damage. *Science,* 273**,** 1564-1568.

STANTON, T. R., LIN, C. C., SMEETS, R. J. E. M., TAYLOR, D., LAW, R. & MOSELEY, G. L. 2012. Spatially defined disruption of motor imagery performance in people with osteoarthritis. *Rheumatology,* 51**,** 1455-1464.

STANTON, T. R., LIN, C. W., BRAY, H., SMEETS, R. J., TAYLOR, D., LAW, R. Y. & MOSELEY, G. L. 2013. Tactile acuity is disrupted in osteoarthritis but is unrelated to disruptions in motor imagery performance. *Rheumatology (Oxford),* 52**,** 1509-19.

TESSARI, A., OTTOBONI, G., BARONI, G., SYMES, E. & NICOLETTI, R. 2012. Is access to the body structural description sensitive to a body part's significance for action and cognition? A study of the sidedness effect using feet. *Experimental Brain Research,* 218**,** 515-525.

VAN ELK, M. & BLANKE, O. 2014. Imagined own-body transformations during passive self-motion. *Psychological Research,* 78**,** 18-27.

WALLWORK, S. B., BUTLER, D. S., FULTON, I., STEWART, H., DARMAWAN, I. & MOSELEY, G. L. 2013. Left/right neck rotation judgments are affected by age, gender, handedness and image rotation. *Manual Therapy,* 18**,** 225-30.

WILLIAMS, L. J., BRAITHWAITE, F. A., LEAKE, H. B., MCDONNELL, M. N., PETO, D. K., MOSELEY, G. L. & HILLIER, S. L. 2019. Reliability and validity of a mobile tablet for assessing left/right judgements. *Musculoskeletal Science and Practice,* 40**,** 45-52.

ZACKS, J. M. & TVERSKY, B. 2005. Multiple Systems for Spatial Imagery: Transformations of Objects and Bodies. *Spatial Cognition & Computation,* 5**,** 271-306.