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An Investigation of the Effects of Age and Stroke on Implicit Motor Imagery as Demonstrated by a Hand Laterality Judgment Test

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Abstract

Background Explicit motor imagery is recommended for stroke rehabilitation but can be difficult to practice. Hand Laterality Judgement (HLJ) stimulates implicit motor imagery which may be easier for stroke patients, but its benefits are unknown. Previous studies are inconclusive and have not considered the effects of older age.

Objectives. This thesis investigated the effects of older age and stroke on HLJ and the effects of practising HLJ after a stroke.

Methods Three experiments were undertaken. The first compared HLJ in twenty young, healthy participants (mean=22(2) years) with twenty aged 60 -70 years (mean=67(3) years) and twenty-two aged ≥ 70 years (mean=77(5) years). The second compared HLJ of eleven stroke survivors aged ≥ 60 years (mean =69 (6)) with age-matched controls. The third examined the effects of practising HLJ in four stroke survivors.

Main findings There were no significant differences in HLJ response times between the young and older groups (p=.06) or between the stroke and control group (p=.13). Both older groups were significantly less accurate than the younger group (young group =92%; older groups= 81%-86% p≤ .00). There were no significant differences in accuracy between the two older groups (P=.10) or between the stroke and control groups (p=.59). All groups engaged in implicit motor imagery, but this was impaired by early old age. Visuospatial imagery was impaired in later old age and by stroke. There were no significant relationships between HLJ performance and upper limb impairment post-stroke. There were no significant effects of practising HLJ, but trends towards increased accuracy (d=.24) and slower response times (d=.46).

Conclusion Stroke survivors can perform HLJ as well as similarly aged healthy individuals. Stroke may impair visuospatial imagery, but accuracy improves with practice. Further research is needed to determine if there are any benefits to post-stroke upper limb rehabilitation.

Key Words: Stroke, Hand Laterality judgement, implicit motor imagery.

Declaration

I, Frances Jane Sapsford declare that this thesis is my own work and has not been submitted in substantially the same form for the award of a higher degree elsewhere.

The word count of 36,683 excluding bibliography does not exceed the maximum allowed.

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List of Abbreviations

ARAT	Action Research Arm Test
CIMT	Constraint induced Movement Therapy
CVA	Cerebral Vascular Accident
EEG	Electroencephalogram
EMG	Electromyogram
ERD	Event Related Desynchronization
ERP	Event Related Potential
ERS	Event Related Synchronisation
FMA-UE	Fugl Meyer Assessment Upper Extremity
fMRI;	Functional magnetic resonance imaging
HLJ	Hand Laterality Judgement.
LHS	Left Hemisphere Stroke
ME	Motor Execution
MEP	Motor Evoked Potential
MI	Motor Imagery
PET	Positron Emission Tomography
PMA	Premotor area
rMT	Resting Motor threshold
RHS	Right Hemisphere Stroke
RTT	Repetitive Task Training.
SMA	Supplementary motor area
SULCS	Stroke Upper Limb Capacity Scale
TMS	Transcranial Magnetic Stimulation

Introduction

Stroke affects around 100,000 people in the UK per annum, mainly in older populations (Public Health England 2018). Many stroke survivors do not regain useful upper limb function, despite undergoing rehabilitation (Krakuer, 2005; Nijland et al., 2010; Houwinck et al., 2013). Although it is known that stroke survivors benefit from intensive rehabilitation, resources are limited so there is a need for therapies that the stroke survivor can practice independently.

Motor imagery is recommended by stroke guidelines as a method of enhancing upper limb therapy (Intercollegiate Working Party, 2016). This refers to explicit motor imagery, in which the individual follows instructions and purposely imagines movements (Sharma, Pomoroy and Baron, 2006). Many stroke survivors have language and cognitive impairments, making it difficult to engage in explicit motor imagery. Implicit motor imagery may have a wider application to stroke populations as it occurs spontaneously in response to a stimulus (Lotz and Zentgraf, 2010).

Hand laterality judgement (HLJ) is a type of implicit motor imagery, in which the laterality of rotated hand images is determined. The behavioural and neurophysiological characteristics of HLJ have been widely studied, and it is agreed that subconsciously matching the hand to the image stimulates implicit motor imagery (Cooper and

Shepard, 1975; Sekiyama, 1982; Parsons, 1987; Sekiyama 2006). The only documented use of HLJ in clinical practice is as part of the Graded Motor Imagery approach for chronic pain syndromes (Moseley et al., 2012) and it is unknown if practicing it after stroke has any benefits.

This thesis investigated the effects stroke on HLJ, in order to explore its use for this population. Three experiments were conducted. As previous research mostly concerns young, healthy populations, the first determined normal age-related effects, by examining HLJ in healthy older people. The results of this experiment were compared to the second which examined HLJ in a group of stroke survivors. The final experiment explored the effects of practicing HLJ, in a small group of stroke survivors.

Thesis Structure

Chapter one reviews the literature providing the background and context of this thesis. Current knowledge related to stroke, upper limb recovery and rehabilitation is examined. Theories of explicit and implicit motor imagery are discussed, followed by review or HLJ studies in healthy young, old and stroke populations. This chapter concludes with the rationale for this thesis. Chapter two defines the research questions and sets out the aims and objectives for the three experiments. In chapter three the research methodology and the design of the HLJ test are presented and procedures common to all three experiments detailed. The ethical considerations and ethical procedures that were undertaken for each experiment are discussed in chapter four. Chapters five, six and seven include the procedures, results and pertinent discussions for each experiment.

A general discussion in chapter eight brings together the findings of the three experiments and presents the original contributions of this thesis. The limitations, clinical implications and recommendation for further research are explored. This thesis concludes with a review of the aims and a summary of the findings.

1.0 Literature Review

1.1 Introduction

This chapter provides the context and rationale for this thesis. It begins with an overview of the pathology of stroke evidence for upper limb recovery. The use and effectiveness of upper limb therapies are discussed, followed by a review of the theory and practice of motor imagery. An in-depth examination of hand laterality judgement in healthy and stroke populations follows. This chapter concludes with the rationale for this thesis

1.2 Literature Searches

Literature searches were carried out initially and were updated throughout the production of this thesis. The following databases were accessed: Academic search complete; CINAHL; Cochrane Database of Systematic Reviews; MEDLINE; PUBMED and PsycARTICALS.

The keywords initially used were: Stroke; CVA; cerebral infarction; upper limb; arm; hand; Motor imagery; mental imagery; kinesthetic imagery; implicit motor imagery; explicit motor imagery; hand laterality recognition and hand laterality judgement. The following keywords were used to expand the initial searches: Mental rotation; Hand mental rotation; ageing; aging and old.

The Boolean operators AND/OR and NOT were used to widen and narrow the searches as required.

The literature was limited to that published peer-reviewed journals in English. Relevant literature was also retrieved from previously read articles and texts.

1.3 The Pathology of Stroke

Around 57,000 people annually have a stroke in England, with 59% aged over seventy (Public Health, 2018; Stroke Association, 2017). Although the incidence is high, mortality rates have halved in the last twenty years (Royal College of Physicians, 2017a; Public Health England, 2018). Despite this, stroke remains a cause of significant disability, with an estimated cost to society of £26 billion a year (Patel et al., 2017).

Strokes are either the result of vascular ischaemia or haemorrhage within the brain circulation (Muir, 2012; Hankey, 2017). Ischaemic strokes are most common, causing around 80% of all strokes. An ischaemic stroke is usually caused when an artery is occluded, either through an embolus or as a result of atherosclerosis (Hankey, 2017).

A stroke can result in a variety of physical and cognitive impairments, depending on its location within the cerebral circulation (Muir, 2012). 75% of strokes occur within the anterior circulation that supplies the frontal and parietal lobes of the brain (Fitzgerald et al., 2007). These typically cause contralateral hemiplegia, with motor weakness and sensory impairments of the arm, face and leg (Muir, 2012; Markus, 2012).

Most of the recovery in the first three months after a stroke occurs spontaneously, due to restoration of blood flow, resolution of oedema, and the reversal of diaschisis (Doonan, 2008; Heiss, 2012; Nudo, 2011; Gonzalez- Castellon and Kitago, 2015). Diaschisis, first termed by Von Monakow (1914), is reduced cortical activity in areas distant from stroke lesion. Its reversal is thought to lead to rapid improvements in function in the first few weeks after stroke (Nudo, 2011). Transcranial magnetic stimulation (TMS) and functional magnetic resonance imaging (fMRI) studies have linked recovery of motor function to the rebalancing of intra-hemispheric inhibition and cortico-motor activity (Magniotti et al., 2008; Swayne et al., 2008; Huynh et al., 2016; McDonnell and Stinear, 2017).

The rapid recovery of motor function in the acute stage of stroke is followed by slower improvement in the subacute and chronic stages. This improvement is thought to be due to Hebbedian or learning dependant neuroplasticity, causing demand-responsive remapping or remodelling of the cortical representation of the body (Murphy and Corbett, 2009). Rehabilitation therapies aim to promote neuroplasticity by engaging patients in intensive, activity-based interventions (Buma, Kwakkel and Ramsey, 2013).

1.4 Upper Limb Recovery after Stroke

Around half of stroke survivors do not recover any useful function of their affected upper limb (Krakauer, 2005). Evidence from longitudinal studies suggests that the early return of movement is the best predictor of recovery (Kwakkel et al., 2003; Nijland et al., 2010; Houwinck et al., 2013; Winters et al., 2016).

In a sample of 102 stroke patients, Kwakkel et al. (2003) found a Fugl Meyer Upper Limb Score of ≥ 19, at four weeks post-stroke, predicted a 94% chance of regaining hand dexterity. However, by six months, only 11% achieved full upper limb function; 38% recovered some dexterity, and the remaining 51% had no functional recovery.

In a later study Nijland et al. (2010), reported better outcomes at six months with 36% of the 156 stroke patients in their study recovering full hand dexterity, and a further 34% some hand function (defined as an Action Research Arm test (ARAT) score ≥ 10). The return of finger extension and shoulder abduction within three days of a stroke, gave a 98% probability of the return of some hand function by six months (ARAT score ≥10). In a later study, Winters et al. (2016), found that the return of finger extension by four weeks predicted future upper limb recovery. 45% of stroke patients in their sample (n=100), with no finger extension by eight days, recovered some hand function (ARAT score ≥10) by six months.

The above studies suggest that those with persistent paralysis in the acute stages of stroke are unlikely to regain function in the longer term. However, clinical decisions based on these findings should be made with caution. Stinnear, Byblow and Ward (2014), argued that upper limb performance measures, such as the ARAT, were poor predictors of future recovery. Combining physical performance scores with neurophysiological measures of cortico-motor tract integrity produced superior predictions. In a study of forty stroke patients that used this method, 30% of those with low scores on physical measures had recovery potential, and only those with negative results in all three tests were unlikely to recover (Stinear et al., 2012).

The above studies suggest that most recovery occurs in the first six months post-stroke, but positive effects of intensive upper limb therapy have been documented in chronic stroke populations (Corbetta et al., 2015). Furthermore, other factors in addition to corticospinal tract integrity may impact recovery (Furlan et al., 2016). Evidence from TMS and fMRI studies suggest that recovery of motor function is related to the rebalancing of intra-hemispheric inhibition and reactivation of cortico-motor activity (Magniotti et al., 2008; Swayne et al., 2008; Huynh et al., 2016; Furlan et al., 2016; McDonnell and Stinear, 2017). Furthermore, physical improvements in chronic stroke patients, following intensive upper limb therapy, have been associated with neuroplastic changes in cortical connectivity (Carey et al., 2002; Koski et al., 2004; Wu et al., 2015). Neuroplastic adaptations may also lead to negative changes, such as the development of disordered muscle tone and abnormal movement patterns (Takeuchi and Izumi, 2012; Jang, 2013; Kolb and Gibb, 2014). Compensatory movement strategies, helpful for achieving function early after stroke, may result in pain, reduced range of movement, and increased energy expenditure (Levin et al., 2009). Additionally, preferential use of the non-paretic arm may result in "learned non-use" of the affected one, even when recovery has occurred (Takeuchi and Izumi, 2012; Buma, Kwakkel and Ramsey, 2013). These changes may affect the ability of stroke patients to achieve earlier predicted levels of function and are often the target of therapy interventions.

In conclusion, the severity of stroke is the main determinate of future upper limb recovery. Aside from natural processes, recovery is dependent on positive neuroplastic changes. Therapy is aimed at maximising this potential in the acute and chronic stages of stroke.

1.5 Upper Limb Therapy after Stroke

There are numerous interventions aimed at improving upper limb function following stroke. Surveys of UK physiotherapists indicate that the most frequently provided are repetitive task practice, passive range of movement exercises, and strengthening exercises (Connell et al., 2014; Serrada, Mcdonnell and Hilier, 2016; Richards et al., 2018).

An overview of forty systematic reviews reported that high-quality evidence for any upper limb therapy was lacking (Pollock et al., 2014a). There was moderate evidence for the effectiveness of repetitive task training; constraint-induced movement therapy (CIMT); motor imagery; mirror therapy, and virtual reality training (Pollock et al., 2014a). Later systematic reviews reported that evidence to support the use of repetitive task training, CIMT, or virtual reality training was of low quality. (Corbetta et al., 2015; French et al., 2016; Laver et al., 2017).

Regardless of the intervention, stroke guidelines recommend daily treatment durations of between thirty to forty-five minutes (Veerbeck et al. 2014; Intercollegiate Stroke Working Party, 2016), but little of that time is spent on upper limb rehabilitation (Hayward and Bruer 2015; Serrada, Mcdonnell and Hilier., 2016; de Jong et al., 2018). A review of ten observational studies of acute and subacute stroke patients suggested that insufficient doses of therapy limited the potential for upper limb recovery. Around six minutes of physiotherapy and twelve minutes of occupational therapy, a day was spent on upper limb rehabilitation, with exercise repetitions too low to effect lasting change (Hayward and Bruer, 2015). Serrada, Mcdonnell and Hilier (2016), reported similar findings in a review of seven observational studies of acute stroke patients. Pooled results showed that less than eight minutes of upper limb therapy was provided daily. Furthermore, a recent cross-sectional survey of UK physiotherapists, reported that an average of twenty-nine minutes of upper limb therapy was undertaken three times a week, equating to a daily dose of twelve minutes (Stockley et al., 2019). These modest amounts of therapy are unlikely to promote neuroplastic changes, highlighting the need for independent practice to compensate for the lack of resources. Whilst those with higher levels of upper limb function can supplement therapy sessions with home exercises, this is less feasible for those with moderate or lower levels of function.

Motor imagery is one method that could provide an alternative means of self-practice for those with limited upper limb movement (Furlan et al., 2016). It has been described as a "back door" to the motor system after stroke, allowing access to corticomotor systems in the absence of active movement (Sharma, Pomoroy and Baron, 2006).

Although motor imagery is recommended in stroke guidelines (Veerbeek et al., 2014; Intercollegiate Stroke Network 2016; Winstein et al., 2016), it is not widely used for upper limb rehabilitation in the UK (Stockley et al., 2019).

1.6 Motor Imagery

Motor imagery is a cognitive process during which neurological networks generate internal representations of previously experienced movement (Mulder, 2007). Within the literature, motor imagery has also been referred to as movement imagery; kinaesthetic Imagery or kinaesthetic motor imagery (Moran et al., 2012). The term motor imagery is used throughout this thesis,

Several disciplines have examined motor imagery and its use is well established in the field of sports psychology, where it is known to enhance the effects of physical practice (Schuster et al., 2011). Whilst acknowledging the research from sports psychology, and its influence on other disciplines; this section focuses on research from the disciplines of neuropsychology and neurophysiology.

Explicit motor imagery is the most widely studied and occurs when movement is purposely imagined but not executed (Munzert, Lorey and Zentgraph 2009). In contrast, implicit motor imagery occurs subconsciously in response to a stimulus or task (Lotz and Zentgraf 2010). Motor imagery can occur from a first-person (egocentric) perspective, or a third person (allocentric) perspective (Moran et al., 2012).

1.6.1. Theories of Motor Imagery

Jennerod's (2001) Motor Simulation Theory is widely accepted as a model for motor imagery (Muldor, 2007). Jennerod argued that a cognitive plan termed a simulation, preceded all motor actions. These simulations shared the same processes as motor actions except that movement was inhibited (Jennerod, 2001; Jennerod, 2006). Therefore, real and imagined movements share overlapping neural networks, last similar durations, and follow Fitts's law (Fitts 1954).

Neurophysiological studies agree that motor imagery activates similar cortical sensorimotor areas as found during active movement. These include the premotor cortex; basal ganglia; cerebellum, and the parietal lobe (Kosslyn, Gannis and Thompson, 2001; Munzert, Lorey and Zentgraph, 2009; Berman, 2012; Hètu et al., 2013). Within the frontal lobe, the supplementary motor area and the dorsal premotor cortex are considered important in the planning and preparation of movement, with the cerebellum and basal ganglia engaged in movement control and modulation (Munzert, Lorey and Zentgraph, 2009; Hètu et al., 2013). Visuomotor transformations and the internal selection of movement representations are thought to occur in the inferior and superior parietal lobules of the posterior parietal cortex (Hètu et al 2013; Oshea and Maran 2017).

It is debatable whether engaging in motor imagery activates the primary motor cortex and corticospinal tracts. An activation likelihood estimation (ALE) analysis of seventy-five fMRI and positron emission tomography (PET) studies, failed to find any evidence of consistent primary motor cortex activation during motor imagery (Hètu et al 2013). Furthermore, a TMS study of thirty-two healthy participants, imagining a finger tapping task, showed that small amounts of subliminal motor activity occurred in those that did not consciously inhibit it (Bruno, Fossataro and Garbarini, 2018).

Whilst Jennerod's (2001) Motor Simulation Theory is an established model, it may be too simplistic to suggest that motor imagery is simply unexecuted movement. The roles of proprioceptive and kinaesthetic representations are not addressed (Grush, 2004, O'Shea and Moran, 2017). As it is possible to mentally imagine different types of movement, motor imagery must involve sensory processes, incorporating external feedback (Kosslyn, Gannis and Thompson., 2001).

In an extension to Jennerod's work, Grush's (2004) Emulation Theory of Representation considered the role of sensorimotor feedback in both real and imagined movement. A neural model of previously experienced movement, termed a sensorimotor emulator, was proposed. During overt movement, the emulator predicts motor outcomes and enhances sensory feedback, increasing accuracy and speed. During motor imagery, the emulator relies on stored sensory information from previously executed movement (Grush, 2004). This raises the possibility that stroke patients, with upper limb paralysis, can engage in motor imagery by recalling previously learned movement.

Latterly, the importance of executive function has been raised. The Motor-Cognitive Model of motor imagery (Glover and Baran, 2017), asserts that motor imagery includes both planning and execution phases. As in the previous models, the planning phase is based on motor representations stored in memory, but the execution phase requires conscious executive control to substitute for proprioceptive feedback. This suggests that motor imagery places greater demands on cognitive function than active movement, posing a challenge for stroke patients with cognitive impairments.

1.6.2 Motor Imagery in Stroke Rehabilitation

Stroke guidelines support the use of explicit motor imagery to supplement upper limb therapy, but this is based on a small number of studies (Intercollegiate Stroke Network 2016). Zimmermann-Schlatter et al. (2008), reviewed four randomised controlled trials (RCT) but two found clinically meaningful differences in support of motor imagery. Whereas, a meta-analysis of five RCTs, (Barclay-Goddard et al., 2011), found significant effects on motor function scores in favour of motor imagery (SMD= 1.37, 95% CI =0.60 - 2.15, $p \leq .00$).

In more recent systematic reviews, evidence in favour of motor imagery varies (Braun et al., 2013; Guerra, Luchetti and Luchetti, 2017). Braun et al.'s (2013) systematic review and meta-analysis of sixteen RCT's found positive effects of motor imagery on ARAT scores in seven studies (SMD=.62, 95% CI=.05-1.19, $p \leq .00$). Guerra, Luchetti and Luchetti (2017), reported significant improvements in ARAT (SMD=4.80, 95% CI=2.47-7.13, $p \leq .00$) and Fugl-Meyer Upper Limb subscale scores (SMD=3.94, 95% CI=.76-7.12, $p \leq .00$) in eleven studies, but further analysis, restricted to high- quality studies (n=4), showed no significant effects of motor imagery. The studies were limited by small heterogeneous samples, poor methodological quality, and a lack of standardised motor imagery protocols. Clarity regarding content, duration and optimal delivery of interventions was lacking (Guerra, Luchetti and Luchetti 2017). This contrasts with motor imagery research in sport, where interventions use standardised frameworks (Holmes and Collins, 2001).

1.6.3 Neurophysiological Studies of Motor Imagery in Stroke

Neurophysiological studies provide further insight into motor imagery after stroke. Table 1.1 details six fMRI investigations and one EEG study that were reviewed (Kimberley et al., 2006; Sharma et al., 2009; Sharma, Baron and Rowe 2009; Confalonieri et al., 2012; Kaiser et al., 2012; Szameitat et al., 2012; Kraft et al., 2015).

All fMRI studies found that similar patterns of activation occurred during motor imagery and motor execution, suggesting that stroke patients imagined movements of the impaired upper limb. These included increased bilateral activation of cortical areas, and the contra-lesional hemisphere (Kimberley et al., 2006; Sharma, Baron and Rowe, 2009; Confalonieri et al., 2012; Szameitat et al., 2012; Kaiser et al., 2012). In contrast to studies of healthy individuals, increased primary motor cortex activity occurred during motor imagery, which may reflect difficulties inhibiting movement of the stroke-affected upper limb (Kimberley et al., 2006, Sharma et al., 2009, Sharma Baron and Rowe (2009), Szameitat et al., 2012, Kraft et al., 2015). It was concluded that neuroplastic changes, linked to upper limb recovery, might be enhanced by practising motor imagery (Sharma et al. 2009; Kraft et al. 2015).

1.6.4 Motor Imagery in Clinical Practice

There are few examples of the use of motor imagery in clinical practice. Two studies found no effects of embedding motor imagery into therapy in nursing home settings (Bovend'Eerdt et al., 2010; Braun et al., 2012). Bovend'Eerdt et al. (2010), incorporated five weeks of thirty-minute video-guided motor imagery to the therapy sessions of thirty stroke patients. 85% of therapists and 72% of patients did not complete the protocol as directed. Barriers to implementation included poor staffing levels and the participant's inability to follow the instructions. Braun et al. (2012), also found that therapists had difficulty implementing motor imagery protocols in their study of thirty-six stroke patients. Six weeks of motor imagery practice was added to usual therapy but there was no standardisation of dose. The complexity of the intervention; lack of standardisation and frailty of participants were all cited as limitations of the study.

Table 1.1.

Neurophysiological studies of the effects of stroke on explicit motor imagery.

Author/ Year	Study	Participants (n)	Methods	Findings
Kimberley et al (2006)	fMRI	s=10 severe c=10	Wrist tracking movements	MI of affected hand increased primary motor and premotor activity in contra-lesional hemisphere.
Sharma et al (2009)	fMRI	s =8 c =13	Finger opposition task.	Similar areas of activation as controls during ME and MI: Abnormal patterns of connectivity between motor and premotor cortices.
Sharma,Baron and Rowe. (2009)	fMRI	s=20 acute/sub-acute c=17	Finger opposition task	Stroke: similar activation to controls during ME and MI. Increased bilateral activation during MI including primary motor cortex. Stroke= disorganised patterns of activation.
Confalonieri et al (2012)	fMRI	s=11 chronic stroke	Real and imagined visuomotor finger tracking task.	MI and ME similar areas of activation; Bilateral activation: ventral and dorsal lateral premotor cortex; SMA; inferior parietal lobe and pons. No primary motor activation.
Keiser et al (2012)	EEG	S= 29 Mild stroke	Real and imagined hand movements.	No change in MI of unaffected hand. MI affected hand. ERD increased in contra-lesional hemisphere with increased impairment.
Szameitat et al (2012)	fMRI	S=5 chronic stroke c= 21	Compared MI; Passive movement and observation of wrist movements.	Pattern of motor imagery similar to that of execution. Stronger in affected hemisphere. Bilateral primary motor activation.
Kraft et al (2015)	fMRI	S=29 C=12	Real and imagined grip force	Stroke participants: no shift to contra-lesional hemisphere. hemispheric balance was preserved more during MI than in ME. Primary motor cortex activation in contra-lesional hemisphere.

Key: ERD = event related desynchronization; fMRI =functional magnetic resonance imagery ; n= number ;MI =motor imagery, ME= motor execution, SMA =supplementary motor area. S=stroke group

The evidence presented so far suggests that motor imagery may enhance the effects of physical therapy by promoting neuroplasticity. It is also an efficient means of practice, with durations of around twenty minutes thought to be effective (Malouin, Jackson and Richards, 2013). However, there is a lack of standardised protocols and those with language and cognitive deficits may be unable to follow complex instructions. Evidence of its use in clinical settings is also lacking, and it is not known if those with limited upper limb recovery can benefit. A further limitation is its covert nature. Unless patients are directly questioned, it is difficult to ascertain how they are practising and to avoid reinforcing abnormal movements.

Implicit motor imagery, in the form of HLJ, may have wider application in stroke populations. It does not rely on the conscious generation of a motor image, so should be easier for stroke patients. HLJ exercises are usually computer-generated and response times and error rates can be objectively measured (Moseley, 2012). Response times follow specific patterns, allowing engagement with motor imagery to be determined (Parsons, 2001). HLJ is used as part of the Graded Motor Imagery approach for chronic pain patients where it is delivered via an online application (Moseley 2012), but its use in stroke rehabilitation has not been widely reported.

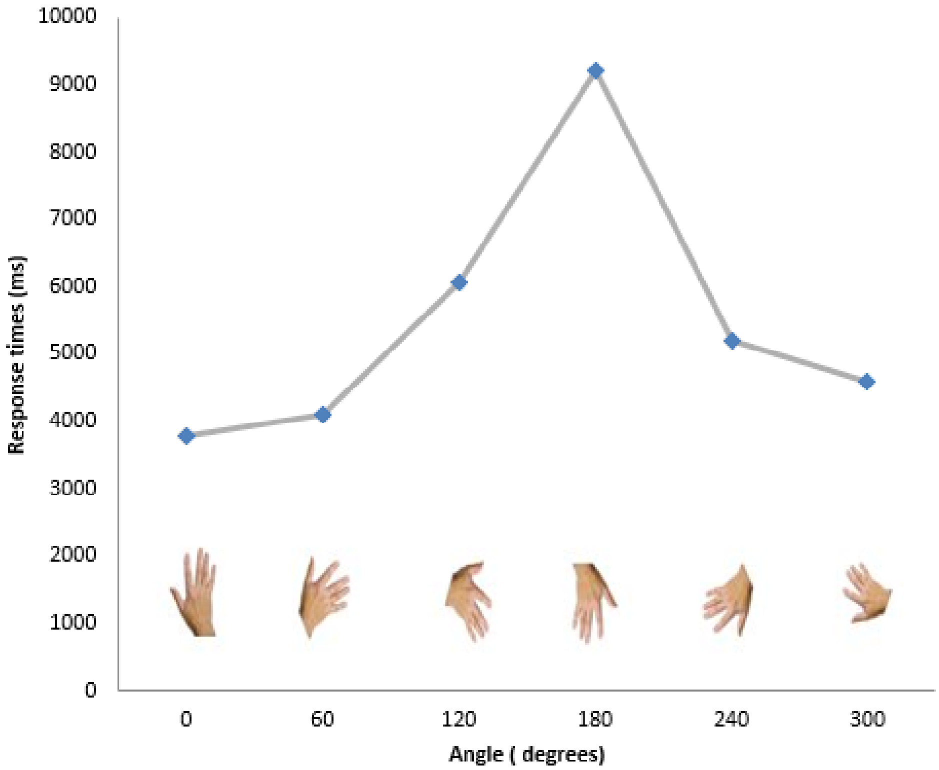
1.7 Hand Laterally Judgement

Most knowledge about HLJ has been produced from neuropsychological studies of young, healthy populations. It is an example of the cognitive process of mental rotation. Mental rotation was first described in Shepard and Metzler's (1971) seminal study, in which eight participants decided if pictures of rotated three-dimensional shapes matched. Response times increased linearly and correlated with the angular disparity between the two shapes. It was concluded that subjects mentally rotated the images to determine the match.

A further study involved judging the laterality of rotated hand images. Response times increased linearly for images rotated to 180° but decreased for those at larger angles (Cooper and Shepard, 1975). It was suggested that the eight subjects mentally rotated their own hands to match the image, and the increased response times at 180° reflected the difficulty in moving the hand into that position. Figure 1.1 shows the typical response time pattern.

Figure 1.1.

Graph showing the pattern of response times as described by Cooper and Shephard (1975).



Note: Graph shows response times (ms) plotted as a function of image rotation (degrees). Response times increase in line with image rotation to 180° then decrease.

1.7.1 A Model for Hand laterality Judgment.

Parson's (1987;1984) is widely credited with the development of a model for hand laterality judgement but the earlier work of Sekiyama (1982) should also be acknowledged.

Sekiyama (1982), conducted an HLJ test, consisting of dorsal (back); palmar (palm); radial (thumb); and ulnar (little finger) views with fifteen participants. Response times varied depending on the hand view. Responses to dorsal and ulnar views were significantly slower at 180°rotations ($p<.01$) but those to palmar and radial views, were slower at 135° for right hands and 225° for left hands ($p<.01$ both sides). Additionally, response times were significantly faster when images were medially rotated from upright than when laterally rotated ($p<.01$). In agreement with Cooper and Shepard (1975), images with that were most difficult to achieve physically, produced the slowest response times (Sekiyama, 1982).

Parsons (1987) found similar differences related to hand view and rotation in a series of laterality experiments including images of hands and feet. The first study (n=11) replicated Cooper and Shepard's (1975) experiment, finding in addition that response times to palmar views were significantly slower than to dorsal views ($p\leq.00$) and those to images of left hands slower than to those of right hands

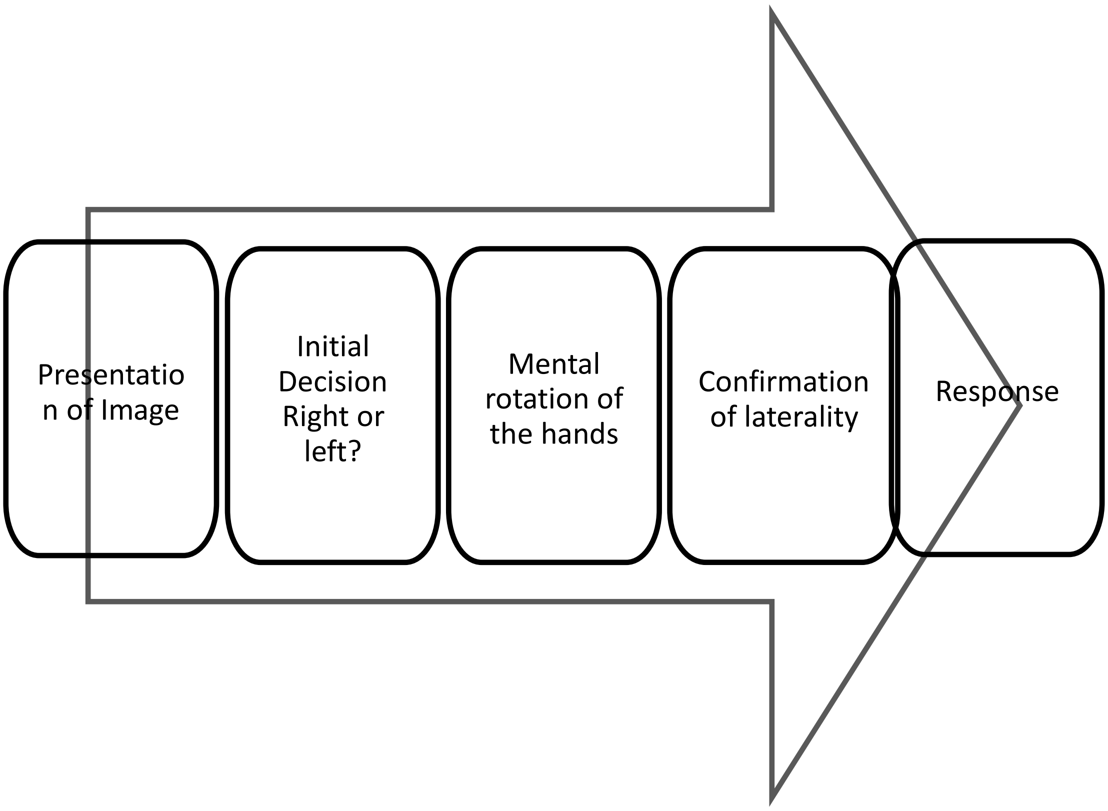
($p \leq .00$). The slowest response times occurred for dorsal images rotated to 180°; palmar images rotated to 120° and laterally rotated images ($p > .01$ for all comparisons). A further experiment (n=8) examined participants responses to four additional views (palms from viewed from the fingers and wrist; radial and ulnar). As found in previous studies, the images judged the most difficult to perform physically had the slowest response times ($p \leq .00$ for all comparisons). In the final experiment (n=15), participants imagined moving their hands into the positions depicted by the images. Mean response times were highly correlated with those of the HLJ test ($r = .85$) suggesting similarities between explicit and implicit motor imagery.

The findings of these early studies suggested that HLJ involves implicit motor imagery through a process that mentally matched the hand to the image. Response times reflected the physical ease of moving the hand into the depicted position. In later studies, the temporal and kinaesthetic features of HLJ were examined (Parsons 1994). The first experiment (n=20), found high correlations between HLJ response times and the time to physically move the hand into the depicted position ($r = .98$, $p \leq .00$). Response times were slower in response to the most awkward hand positions. Similarities between real, implicit and explicit motor imagery were shown in a further experiment where eleven participants imagined moving their hand to the positions depicted in the HLJ test. Two final experiments examined whether participants mentally moved their hand from its actual or from an imagined position (hand upright with the palm down). Participants (n=24) completed the HLJ test with either their palms resting flat down or with their hands back to back. HLJ response times were slowest for palmar views and when the hands were placed back to back ($p \leq .00$). The final experiment (n=15) found a high correlation ($r = .97$) between the time taken to physically match the hand from each of the above stating positions with the time taken to determine its laterality. It was concluded that participants mentally moved their hand from its actual position and not from an imagined upright position.

Figure 1.2 shows a model for HLJ based on the findings of the above studies. The initial decision about laterality is made from visual recognition of the image. This is then confirmed by mentally rotating the corresponding hand from its actual resting position to the position dictated by the image, followed by the response. The response time reflects the whole process and increases relative to the difficulty of mentally rotating the hand into the position depicted by the image. This model was based on experiments with small samples of healthy young adults, so may not be generalisable to wider populations.

Figure 1.2*.*

A Model of Hand laterality Judgement after Cooper and Shepard (1975), Sekiyama (1982) and Parsons (1987, 1994)



Note: The image depicts a continuous process following the presentation of the image. Response times reflect the whole process including making the response.

The processes underpinning HLJ have not been confirmed, so there may be other explanations for the findings. Longer visual processing times, at the initial stage, may explain the slower response times to images with more awkward hand positions. Additionally, those with advanced visuospatial skills may not need to match their hand to the image to confirm laterality. Recently, the knowledge of HLJ has been expanded by further studies in young healthy populations and there is general support for the earlier findings and agreement that HLJ involves implicit motor imagery.

1.7.2 HLJ in Young, Healthy Populations

Table 1.2 summarises eleven studies, examining HLJ in young healthy populations, published between 2007 and 2013. In addition to examining response times related to image rotation and view, the effects of handedness and external proprioceptive feedback have been explored. All studies included young, right-handed (except where indicated) healthy participants, aged between eighteen and thirty. Sample sizes ranged from twelve to sixty.

There were many variations in HLJ tests but only two studies included more than dorsal and palmar views (Ionta, Fourkas and Aglioti, 2007; Ionta and Blanke 2009). The number of trials ranged from 96 to 864 and responses were recorded via manual right and left response keys, footswitches or verbally. These variations limit direct comparisons as differences in findings could be attributed to numerous variables.

Table 1.2.

HLJ Studies in Young Healthy Populations.

Author / Year	Study	Participants (n)	HLJ task images (n) views/ mode	Response times (ms)	Error Rate	Slowest response at 180˚?	lateral slower?	Right slower ?	Findings
Ionta et al. (2007).	Effects of Hand Position	20: 7 F Age: 20-35	96/ Hands and Feet DPRU/Verbal	1186	7%	D only.	NR	yes	Mean response times Increased when hands placed behind back.
Ionta and Blanke (2009).	Effects of Placing hand behind back	16: 6 F Age :18-29	96/ Hands and Feet DPRU/Verbal	1206	8%	D and R	NR	Yes	Mean response times Increased to R handed images with R hand behind back but not left.

Author / Year	Study	Participants (n)	HLJ task images (n) views/ mode	Response times (ms)	Error Rate	Slowest response at 180°?	lateral slower?	Right slower ?	Findings
Ter horst et al. (2010).	Effects of increasing axes of image rotation	12: 8F Age:22-25	110/ D P3 axes of rotation/R /L button	1006	6%	P and D	D and P	NR	Response times and errors Increased with increase axes of rotation.
Ni-Choisede albha et al. (2011)	Exp 1: Differences between R and L handed	60: 32 F 30 R 30 LH mean age = 26	96 / 4 D; 1 P;1R /footswitc h	Range 672- 4470	6%	D and R	Yes	yes, RH	RH Faster response except when placed behind back. LH use visual imagery more.
	Exp 2: perspective self vs other.	20 RH 29 LH: 29 F mean age = 26	96/ 4 D; 1 P;1R/ R/L button	Range 672- 4470	NR	NR	NR	NR	More awkward views seen as "others" hands.
Ishibashi and Saito. (2011)	Exp 1 Effects of hand position	16: 8 F Age 18 -26	32/ D; P hand in fist / verbal	1153	3 %	P and D	NR	yes	P slower with incompatible hand position. D not affected by posture.

Author / Year	Study	Participants (n)	HLJ task images (n) views/ mode	Response times (ms)	Error Rate	Slowest response at 180°?	lateral slower?	Right slower ?	Findings
	Exp 2 Effects of semantics	16: 11 F Age 18-28	32/ D P hand in fist/ Verbal.	1496	6%	yes	NR	No	D and P slower with incompatible hand position Saying right or left facilitates HLJ.
Conson et al. (2011)	Exp 1 Effects of hand/body contact	36:18 F 18 RH 18 LH mean age= 25	12/ D P / R and L Footswitch	1587	6%	NR	NR	NR	RH Faster with hand in neutral position.: LH no difference
	Exp 2 Effects of both arms in same posture.	28:14 F 15 RH;13 LH mean age = 26	12/ D P R and L Foot switch	1501	9%	NR	NR	NR	RH Faster response times with hand in neutral. Body contact and arm position affect response times.

Author / Year	Study	Participants (n)	HLJ task images (n) views/ mode	Response times (ms)	Error Rate	Slowest response at 180°?	lateral slower?	Right slower ?	Findings
Brady et al (2011)	Perspective: ego vs allocentric	30: 17 F mean age= 26	96 / 4 D; 1 P;1R R and L Footswitch	1086	NR	yes, in all except P	yes P	NR	Allocentric Motor imagery explains increased response times at extreme angles.
Dalecki , Hoffman and Bock (2012)	Mental rotation of hands, bodies and scenes.	24: 12 F age 22 -24	48 / D R and L button	NR	NR	Yes	NR	NR	Egocentric and allocentric motor imagery depends on stimulus.
Ionta et al (2012)	Hands only vs hands attached to body	30: 8 F mean age =23	48/ P;D hands or hands and body / Verbal	1095	8%	Yes, in hands only	yes	Yes	Motor imagery effects with hands only images and not hands on body.

Author / Year	Study	Participants (n)	HLJ task images (n) views/ mode	Response times (ms)	Error Rate	Slowest response at 180°?	lateral slower?	Right slower ?	Findings
Blasing et al (2013)	Exp 1 Effects of thumb image on HLJ	18: 15 f mean age = 23	32/ D; P Thumb flexed/ extended/ R and L button	1252	11%	Yes	Yes P	yes	No difference between images of thumb flexed or extended.
	Exp 2 Effect of thumb posture on HLJ	18:16F mean age = 24	32 / D; P Thumb flexed/ extended/ R and L button	1315	12%	Yes	Yes P	yes	Thumb posture interfered with HLJ.
Hoyek et al (2013)	Effects of hand posture on HLJ vs same/different tasks.	n=30 15 F mean age 23	48/D; P Wrist/ Verbal	1464	NR	Yes, in both tasks	Yes, in HLJ only	NR	HLJ response times quicker with compatible hand position. Allocentric strategy used for same /different

Key: EXP = experiment F =female; D= dorsal ; P=Palmar; R =Radial ; U=Ulnar; R=right; L=left; RH = right handed LH =left handed ; NR=not reported

Mean response times ranged from 1006 ms to 1587 ms and accuracy from 88% to 97%, suggesting that the HLJ tests were easy to perform.

Response times to dorsal views were consistently faster than to other views (Ionta, Fourkas and Aglioti, 2007; Ionta and Blanke 2009; Ter Horst et al., 2010; Ishibashi, and Saito 2011; Ionta et al., 2012; Blasing et al., 2013). The dorsal view is considered the easiest to judge, as laterality can be determined by locating the position of the index finger and thumb (Ter Horst, Van Lier and Steenbergan, 2010; Blasing et al.,2013). Furthermore, the hands were usually positioned with the palm down during the HLJ test, facilitating faster response times for dorsal views (Parson's 1994). Response times were slower when hand positions were incongruent with presented images, suggesting that external proprioceptive feedback interfered with the mental rotation process (Ionta, Fourkas and Aglioti, 2007; Ionta and Blanke, 2009; Ní-Choisdealbha, Brady and McGuiness, 2011; Conson et al., 2011; Ionta et al., 2012).

Response times to dorsal and radial images rotated to 180° were significantly slower than for other angles (Ter Horst, Van Lier and Steenbergan, 2010; Ishibashi and Saito, 2011; Ionta et al., 2012; Blasing et al., 2013), replicating the earlier findings (Sekiyama, 1982; Parsons, 1984; Parsons, 1992). For palmar views the slowest response times were reported at 0°; 225°, and 270° (Ionta and

Blanke, 2009; Brady, Maguinness and Ní Choisdealbha, 2011; Ní-Choisedealbha, Brady and Maguiness, 2011) and for ulnar views at 120° (Ionta, Fourkas and Aglioti, 2007; Ionta and Blanke, 2009).

Faster response times for medially rotated images were found in response to palmar views (Ter Horst et al., 2010; Ní-Choisedealbha, Brady and Maguiness, 2011; Brady, Maguinness and Ní Choisdealbha, 2011; Bläsing et al., 2013; Hoyek et al., 2013) and not in response to radial or ulnar views (Ionta, Fourkas and Aglioti, 2007; Ionta and Blanke, 2009). These findings suggest that HLJ strategies depended on the hand view.

It can be concluded that differences in response times, related to hand view and image rotation, reflect differences in strategies used to determine laterality. The judgement of dorsal views is more dependent on visual than on motor processes, and that of palmar views more on motor than visual processes. Evidence for radial and ulnar views is limited to a few studies but radial views shared similar characteristics to dorsal ones.

1.7.3 Perspectives Taken During HLJ

There is debate whether judging images depicting more awkward hand positions, occurs from an egocentric or allocentric perspective

(Ní-Choisedealbha, Brady and Maguiness, 2011 Brady, Maguinness and Ní-Choisdealbha, 2011). Ní-Choisedealbha, Brady and Maguiness (2011), found that participants consistently judged images rotated to 135°;180°and 225°as belonging to someone else (allocentric view), whereas those rotated at less extreme angles, were judged as belonging to themselves (egocentric view). Furthermore, Brady et al (2011) found greater variations in accuracy when images were rotated to extreme angles and concluded that this was because an allocentric perspective was taken. However, both studies restricted their findings to dorsal and radial views which, as discussed previously, have a greater reliance on visual processes.

Two EEG studies, examining HLJ of medial and laterally rotated palmar images, found differences in cortical activation (Ter Horst et al., 2012; Ter Horst, Van Lier and Steenbergan, 2013). Ter Horst et al. (2012) found parietal lobe activity significantly increased during HLJ of laterally rotated images ($p \leq .00$), in a sample of fourteen participants. A further study of seventeen participants (Ter Horst, Van Lier and Steenbergan, 2013) found significantly increased activity in frontal motor areas during HLJ of medially rotated images ($p < .00$). It was concluded that activity in corticomotor areas was more pronounced when images depicted achievable hand positions. HLJ of images difficult or impossible to perform, required a switch to visually based strategies (Ter Horst et al., 2012; Ter Horst, Van Lier and

Steenbergan, 2013).These studies did not determine whether laterally rotated images were judged from an allocentric perspective, however.

It is unclear how shifting to an allocentric perspective increases response times to images of awkward hand postures. Images that are known to rely on visual imagery usually produce faster response times (Dalecki, Hoffman and Bock,2012; Ionta et al., 2012; Hoyek et al., 2013). Difficulty in recognising the image, or with switching from egocentric to allocentric perspectives, may account for the increased response times, but further research is needed.

1.7.4 Conclusions from HLJ Studies in Young, Healthy Populations

The evidence reviewed confirms that HLJ involves implicit motor imagery. The predominant strategy (motor or visual) depends on the hand view, whereas its orientation determines the perspective (egocentric or allocentric). Images of hand positions that are easier to physically attain are more likely to depend more on egocentric motor imagery than those rotated to more extreme angles.

The evidence suggests that HLJ of palmar views and medially rotated images have a greater reliance on implicit motor imagery than dorsal views and laterally rotated images. Currently, there is insufficient evidence to determine if the processes underlying HLJ of other hand views are similar.

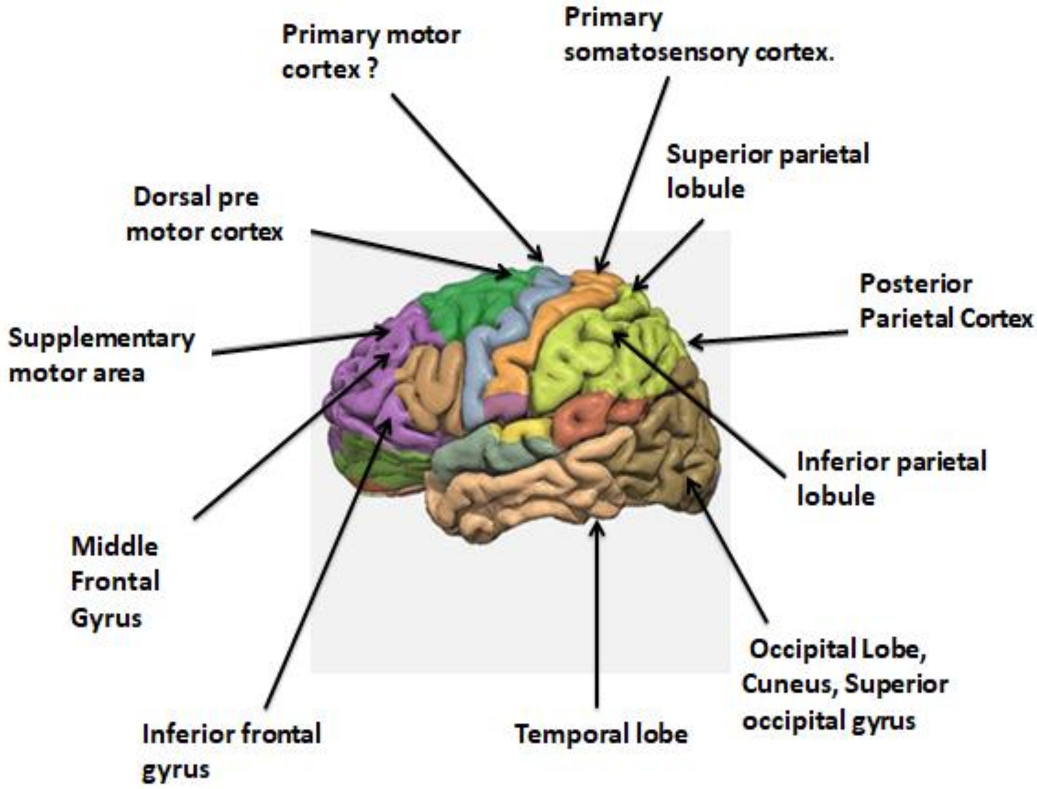
Despite the lack of a standardised HLJ test and many variations in methodologies, consistent findings have been reported. As high levels of accuracy occur in younger populations, error rates were rarely discussed. Further insights into HLJ might be gained by examining patterns of errors in addition to response times, as this may be a significant factor for other populations.

1.7.5 Cortical Activation During HLJ

Figure 1.3 shows the cortical network for HLJ identified from meta-analyses of fMRI studies (Hetu et al., 2013; Tomasino and Gremese, 2016). There is consensus that HLJ activates parietal and occipital networks, but debate whether frontal lobe networks are involved (Thayer and Johnson, 2006; Hetu et al., 2013; Tomasino and Gremese, 2016; Osuagwu and Vockovic, 2014). A meta-analysis of seventy-five studies (Hetu et al., 2013) compared cerebral activation during HLJ and explicit motor imagery. Overlapping areas of activation were only identified in the bilateral middle frontal gyrus and inferior parietal lobule. It was suggested that HLJ mostly activated parietal and occipital areas, and that the supplementary motor area was only active during explicit motor imagery.

Figure 1.3.

The Cortical Network for HLJ.



Note. The image of the brain (Shutterstock, 2019) is labelled to show the cortical areas activated during HLJ, as found by metanalyses of fMRI studies (Hetu et al 2013; Tomasino and Gremese 2016).

Conversely, a meta-analysis of 171 fMRI studies (Tomasino and Gremese, 2016) found bilateral sensorimotor activity was associated with the mental rotation of hands and other body parts, but not of objects. Increased activity in the primary motor cortex was specifically related to the mental rotation of hands.

Two TMS studies (n=10 in both), concurred that the left primary motor cortex was involved in hand but not in object mental rotation (Ganis et al., 2000; Tomasino et al., 2005). Furthermore, an EEG study (n=15) comparing HLJ of dorsal images with an explicit motor imagery task, found that areas of sensorimotor activation overlapped (Osuagwu and Vuckovic, 2014). Conversely, Sauner et al. (2006) found no effects of TMS on the sensorimotor areas during HLJ (n=12), and an EEG study, mapping the process of HLJ in sixteen participants, found increases in parietal and occipital activity, but not in frontal lobe activity (Thayer and Johnson 2006).

Hètu et al. (2013) argued that, as hand mental rotation was implicit, activation of supplementary motor areas was weak. Tomasino and Gremese (2016) contended that primary motor activation was only related to egocentric mental rotation processes. Whereas, Thayer and Johnson (2006) suggested that the motor regions only played an indirect role by providing feedback.

It is possible that frontal motor areas are indirectly stimulated during HLJ, via associated parietal networks. The posterior parietal cortex is an area of sensorimotor integration, containing neural networks related to reach and grasp, that project to the prefrontal cortex (Andersen and Buneo, 2003; Foggassi and Luppino, 2005). Parietal lesions following stroke lead to difficulties in planning and executing intended movements and shaping hands to grasp objects (Andersen and Buneo, 2003). Therefore, practising HLJ may improve upper limb function by promoting neuroplasticity in these associated neural networks.

1.7.6 HLJ in Stroke Rehabilitation

The use of HLJ in stroke rehabilitation has not been widely reported. A recent study of forty healthy, participants (Berneiser et al., 2018) found small amounts of HLJ practice lead to neuroplastic changes. Thirty-minutes of HLJ practice, carried out twice a day, for three days, led to changes in patterns of cortical activation. Compared to controls, the intervention group showed significant reductions in response times and errors ($p<.00$), and patterns of cortical activity shifted from visual to motor areas (Berneiser et al., 2018). This suggests that practising HLJ might lead to neuroplastic changes in stroke patients.

No studies, to date, have specifically examined the effects of practising HLJ after stroke. However, two randomised controlled trials, including HLJ as part of Graded Motor Imagery (Moseley et al., 2012), showed that upper limb function improved more than with exercise alone (Uttam, Midha and Arumugam, 2015; Polli et al., 2018).

Uttam, Midha and Arumugam (2015) combined Graded Motor Imagery with conventional upper limb therapy with thirteen sub-acute stroke patients. Three daily sessions of HLJ were undertaken over two weeks. Compared to controls, significant improvements were found in measures of upper limb function ($p \leq .01$). Similarly, Polli et al. (2018) found six hours of HLJ, as part of a four week of Graded Motor Imagery programme, significantly improved scores of upper limb function in fourteen subacute stroke patients ($p \leq .01$).

Neither study measured HLJ performance post-intervention so the specific effects of practising HLJ are unknown. Furthermore, both explicit motor imagery and mirror therapy have been shown to enhance the effects of physical exercise after stroke (Pollock et al 2014a), which may account for the positive findings of these studies. To date, no substantive evidence exists of any benefits in just practising HLJ following a stroke, however, several studies have found that stroke affects HLJ.

1.7.7 Effects of Stroke on HLJ

Table 1.3 summarises ten studies that examined the effects of stroke on HLJ. All except Tanaka, Yamanda and Inagaki (2010), and Yan et al. (2012), compared HLJ with other types of motor imagery. Only one neurophysiological study was identified (Yan et al. 2012).

Sample sizes for stroke groups ranged from eight to seventy and all were compared with age-matched, healthy controls, except for Johnson, Spreyn and Saykin (2003). All HLJ tests included dorsal and/or palmar views, with variations in the number of rotations and trials.

Stroke groups had slower response times than controls, with mean differences ranging from 800 ms to 1,927 ms. Accuracy ranged from 68% to 89%, compared to 80% to 95% for controls. Increased response times and errors were found for images rotated to 180°, and for laterally rotated images. Kemlin et al. (2016) reported faster response times to dorsal views ($p<.02$), and Daprati et al. (2010) higher accuracy ($p<.00$), with no differences between stroke and control groups. Studies including more views reported lower accuracy rates for stroke groups but did not examine differences between views (Amesz et al., 2016; Braun et al., 2017).

Table 1.3.

Studies of the effects of Stroke on HLJ.

Author	Study	Sample	Stroke Type	Response Times (ms)	Accuracy	180° Slower ?	Lateral Slower?	Outcome
Johnson et al. (2003)	Compared HLJ with grip selection task and explicit MI.	S=8 4 chronic 4 mild age 64 - 76	Chronic Mild RHS =7 LHS =1	Mild= 2766 Chronic= 3749 (ms)	80-85%	NR	NR	No significant differences in accuracy or response times. Chronic stroke: trend for increased accuracy and faster responses for affected upper limb. HLJ not affected by chronic stroke.
Deprati et al. (2010).	HLJ vs grip simulation and glove laterality test.	S= 20 C =12 age 46 - 70	Acute Chronic Mod/ Severe RHS=10 LHS=10	C=2676 S=3869	C= 92% S RHS = 77% LHS = 84%	NR	Yes	RHS mild lesion less accurate than LHS or RHS with severe impairment (p<.00). LHS severe impairment slower than RHS and controls (p<.00)
Tanaka, Yamanda	HLJ only	S = 31	Acute	C= 1700	NR	yes	NR	Increased response times in the stroke

Author	Study	Sample	Stroke Type	Response Times (ms)	Accuracy	180° Slower ?	Lateral Slower?	Outcome
Inagaki (2010)		C = 29 age 52 - 74	mild RHS =13 LHS =18	S= 2500				group (*p*<.01). Increased response time for images of affected side (*p*<.05). Performance related to impaired attention (*p*≤.00).
de Vries et al. (2011)	HLJ vs object rotation and explicit MI. 3 - 6 weeks post-stroke	S=12 C=12 age 48-71	Acute 3-6 weeks Mild / mod RHS=6 LHS=6	NR	3 weeks S=72% C=89% 6 weeks S=78%	NR	NR	At 3 weeks: reduced accuracy compared to controls (*p*≤.00) no difference in response times. Accuracy improved 6 weeks post-stroke (*p*≤.00).

Author	Study	Sample	Stroke Type	Response Times (ms)	Accuracy	180° Slower ?	Lateral Slower?	Outcome
Yan et al. (2012)	EEG during HLJ.	S=11 C=11 age 45 -80	Subacute mild-Mod RHS= 0 LHS=11	C= 1270 S= 3197	C=95% S=86%	yes	NR	Increased response times and reduced accuracy in stroke (*p*<.01). Decreased activation of left parietal lobe and premotor cortex in stroke(*p*≤.00)
de Vries et al. (2013)	HLJ vs explicit MI.	S=16 C=16 age 41 -61	Sub acute / chronic mild/ mod /severe RHS=7 LHS=9	C= 1704 S= 2568	C=93% S=89%	Yes	NR	No significant differences in accuracy. Stroke patients only slower on laterally rotated images (*p*≤.00).
Amesz et al. (2016)	HLJ vs object rotation.	S=32 C=36 age 41 - 77	sub-acute/ Chronic RHS= 17 LHS= 15	C= 1860 S= 2960	C=80% S=69%	NR	NR	Increased response times and reduced accuracy (*p*≤.00). No differences between affected / unaffected hand.

Author	Study	Sample	Stroke Type	Response Times (ms)	Accuracy	180° Slower ?	Lateral Slower?	Outcome
Kemlin et al. (2016)	HLJ vs explicit MI.	S = 24 C=24 age 51 - 77	Acute Mild RHS =12 LHS =12	C = 2900 S = 4500	C= 81% S= 68%	Yes	Increase time and error for "non-anatomical views"	Increased response times and errors ($p \leq .00$). LHS = slower than RHS ($p \leq .00$) Increased errors for images of affected hand(P=.05). No correlation with impairment measures.
Liepart et al. (2016)	HLJ vs mental chronogr-aphy with sensory loss.	S = 70 C= 23 age 54 -74	sub-acute mild RHS=31 LHS= 39	C= 2600 S = 3970 – 4290	C= 87% S= 82%	NR	NR	Increased response times ($p<.02$). No effect of sensory deficit. No differences in accuracy.
Braun et al. (2017)	HLJ vs explicit MI and Biofeedback.	S=20 C=20 age 50 - 68	Chronic Mod /severe RHS =12 LHS =8	NR	C=87% S=79%	NR	NR	Reduced accuracy in stroke group($p<.04$). No relationship to side of stroke. Sensory loss related to performance.

KEY S= stroke group; C = control group; LHS= left hemisphere stroke; RHS = right hemisphere stroke; NR=not reported.
MI =motor imagery

The findings suggest that stroke participants used similar strategies to controls to determine hand laterality but were impaired by stroke. However, evidence of a direct relationship between upper limb impairment and HLJ performance is limited. Only three studies found slower response times and more errors for images corresponding to the affected upper limb (Tanaka, Yamanda, and Ihagaki., 2010; Daprati et al., 2010; Kemlin et al., 2016). Those with left hemisphere strokes (LHS) and severe impairment had the slowest response times ($p \leq .00$), whereas, those with right hemisphere stroke (RHS) and mild impairment were the least accurate ($p \leq .00$) (Daprati et al., 2010; Kemlin et al., 2016). However, there were no significant relationships between HLJ performance and measures of upper limb function or stroke severity (Kemlin et al., 2016; Braun et al., 2017; Johnson, Spreyn and Saykin., 2003).

Yan et al. (2012) examined cortical activation, during HLJ of dorsal images. Compared to controls, stroke participants had reduced activation in bilateral frontal, and ipsilesional parietal motor areas, and increased activity in occipital and posterior parietal areas. It was concluded that impaired spatial information processing affected mental rotation of the hand, leading to longer response times (Yan et al.,2012). These findings were based on a small sample of stroke participants with LHS, so may not be transferrable to other stroke populations.

1.7.8 Conclusions from Stroke Studies

There is consensus that stroke increases HLJ response times and reduces accuracy but only limited evidence that HLJ performance is related to upper limb impairment or the site of stroke. The lack of standardisation in HLJ tests limits direct comparisons. Trials ranged from sixteen (Tanaka, Yamanda and Inagaki, 2010) to 288 (de Vries et al 2011) with variations in the number of views and image rotations. It is questionable whether Tanaka, Yamanda and Inagaki (2010), gained valid findings from just sixteen trials, so the results of this study should be treated with caution.

There were many variations in study design, with most comparing HLJ performance with other types of motor imagery. None considered whether cognitive fatigue affected results, although Daprati et al. (2010) reported that their stroke group had high levels of fatigue. De vries et al. (2011) found HLJ accuracy significantly improved by six-weeks post-stroke but other studies of acute stroke patients did not consider the effects of spontaneous recovery on their findings.

No study considered the effects of normal ageing on HLJ. Although all included age-matched controls, there were wide variations in age ranges, and none specifically controlled for age. Greater differences in performance may have been found when comparing younger aged participants than when comparing older ones. As most strokes occur in later life, the effects of normal ageing on HLJ need to be distinguished from those of stroke.

1.7.9 Effects of Age on HLJ

Table 1.4 summarises four studies that examined the effects of age on HLJ (Saimpont et al., 2009; Delvin and Wilson, 2010; De Simone et al., 2013; Zapporeli et al., 2016). The mean ages of older groups ranged from sixty-one (Zapporeli et al., 2016) to seventy-eight (Saimpont et al., 2009). There were variations in the HLJ tests and all except Delvin and Wilson (2010), included palmar and dorsal views. Three studies also compared HLJ performance with other mental rotation tasks (Delvin and Wilson, 2010; De Simone et al., 2013; Zapporelli et al., 2016).

Response time characteristics were consistent with those reported in the studies of young healthy groups, suggesting that older participants used similar strategies to determine hand laterality. Compared to young healthy controls, significant increases in response times and errors were found in groups aged over seventy but not in those in their sixties (Saimpont et al., 2009; Delvin and Wilson., 2010; De Simone et al., 2013 Zaporreli et al., 2016). This suggests that HLJ performance is only impaired in later old age.

Saimpont et al. (2009), suggested that impaired visuospatial and motor imagery processes explained their findings, reflecting the general cognitive and physical declines experienced in old age. Accordingly, Devlin and Wilson (2010) found age had a greater effect on the mental rotation of hands than on that of objects ($p \leq .00$). Furthermore, De Simone et al. (2013) found that age had a greater effect on egocentric on than allocentric motor imagery, suggesting that visual processes were less affected. Zapporeli et al. (2016) also concluded that visual compensation supported HLJ performance in their older group. Compared to the younger group, fMRI revealed increased activity in occipital and parietal areas, consistent with visual processing.

In summary, the studies reviewed found that healthy older people can perform HLJ to a high level. Impaired performance, compared to young populations, may not be apparent until more advanced old age. Deficits in implicit motor imagery ability may be compensated by visual compensation, which is less affected by ageing processes. These findings are limited by the small number of studies, highlighting that further research is needed. However, as results are similar to those found in stroke groups, the age of participants should be controlled in future studies of HLJ in stroke.

Table 1.4.

Studies examining the effects of age on HLJ

Author	Study	Partici-pants (n)	Mean age (yrs)	Response times (ms)	Accuracy (%)	180° slower?	Lateral slower?	Outcome
Saimpoint et al. (2009)	HLJ	39 Y=20 O=19	Y=3 O=78	Y=00 – 1400 O=200 - 3000	Y≥ 98% O≤ 90%	Yes	Yes P	Older group slower and less accurate (*p*≤.00).
Delvin and Wilson (2010)	Mental rotation of letters; hands; body.	40 Y=20 0=20	Y=20 O=74	Y =1552 O =2641	Y=94% O=91%	Yes	NR	Older significantly slower (p≤.00). no significant difference in errors.
De Simone et al (2013)	HLJ versus visual task.	30 Y=15 O=15	Y=26 O=71	Y = 1500 -1900 O= 1700 – 2400	Y=93% O=88%	Yes	Yes	Older slower and less accurate P≤.05) Better for visual task. Worse for lateral rotations overall.
Zappor-eli et al. (2016)	HLJ versus letters and fMRI	46 Y=27 O=29	Y=31 O=61	Y and O= 400ms – 1300ms	Y=92% O=89%	Yes D	Yes P	No differences in response times or errors. fMRI showed increased activation in visual processes.

Key Y = young; O=Old; D= dorsal view; P = palmar view. NR= not reported.

1.7.10 Conclusions from HLJ Research

The studies of HLJ, in young healthy individuals, showed it involves a complex combination of visuospatial and motor imagery processes. Visual recognition of hand laterality is confirmed, by mental rotation of the subject's hand, to the position depicted by the image. There is general agreement that implicit motor imagery occurs during this process, which differs from object mental rotation. Response times show reproducible patterns related to the degree of image rotation and are highest for images most awkward to physically attain. Error rates are low in younger people indicating that HLJ is easy to perform.

The extent to which implicit motor imagery occurs depends on the hand view and its orientation. Although Parson's (1994) showed that HLJ response times were similar to the time taken to move the hand into the image's position, neurophysiological evidence suggests that the images most awkward to physically attain, are processed visually (Ter Horst et al., 2012; Ter Horst, Van Lier and Steenbergan, 2013). This supports the argument that HLJ of these images occurs from an allocentric perspective (Ní-Choisdealbha, Brady and McGuiness, 2011; Brady, Maguinness and Ní-Choisdealbha, 2011). However, increased response times for laterally rotated images were mostly reported for HLJ of palmar views, which were also found to stimulate greater cortico-motor activity than dorsal views (Zapporelli et al., 2013).

It can be concluded that the predominant strategy (either visual or motor), is likely to depend on the hand view, whereas the angle of rotation determines the perspective. HLJ of palmar views may be more effective at stimulating implicit motor imagery, except at the most biomechanically awkward angles. Whereas, visual imagery may predominate during the HLJ of dorsal views. Few studies have examined HLJ for other hand views, but similar strategies are likely.

Neurophysiological studies consistently report activation of the parietal and occipital cortices during HLJ, with frontal lobe activation mostly limited to the premotor and supplementary motor areas. This suggests that HLJ may have an indirect effect on motor function and be less effective than explicit motor imagery. However, activation of posterior parietal areas, involved in reach and grasp, may maintain neural pathways for those functions, which would otherwise be lost following a stroke.

There was insufficient evidence to determine the effects of stroke on HLJ. Although there was agreement that response times and errors increased, few studies reported response times related to hand view or rotation. Only three studies found a relationship between stroke location and HLJ performance (Daprati et al 2010, Tanaka et al 2010; Kemlin et al 2016) and there was little evidence of a relationship with upper limb impairment. It is unclear whether the findings for stroke were due to impaired implicit motor imagery or general cognitive impairment.

The findings from studies examining the effects of age on HLJ were similar to those found in stroke, with increased response times and errors occurring in later old age (Saimpont et al., 2009; Delvin and Wilson., 2010; De Simone et al., 2013). As none of the stroke studies was limited by age, it cannot be ruled out that findings reflected normal ageing processes.

2.0 Research Rationale Aims and Questions

The factors affecting upper limb recovery post-stroke are complex. In addition to the severity of the initial impairment, recovery depends on the availability of therapy at enough intensity to drive neuroplastic changes. Limited health care resources restrict access to rehabilitation, and there is a need for effective therapies that stroke survivors can use independently.

Motor imagery has potential as a therapy that stroke survivors could use regardless of the degree of upper limb impairment. However, research to date has focused on explicit motor imagery and evidence of its effectiveness is limited to studies of its use with conventional upper limb therapy. Furthermore, the use of explicit motor imagery is restricted to those who have the cognitive capacity to purposely imagine movement. HLJ involves both implicit motor and visuospatial imagery and could be an easier means of practising motor imagery after a stroke.

The literature review confirmed that HLJ is affected by stroke, but it is not known if practising it could enhance the effects of post-stroke upper limb rehabilitation. Initially, the researcher sought to explore this, but the literature review highlighted gaps that required further investigation.

The first aim was to design a more complex HLJ test than that used in previous studies. It was anticipated that this would provide new insights into the effects of both age and stroke on HLJ. The HLJ tests used in previous stroke and ageing studies were limited to dorsal and palmer views. As it was found that dorsal views primarily stimulated visuospatial processes, the inclusion of more views should place greater demands on motor imagery processes (Ter horst et al., 2010).

The second aim was to distinguish between the normal effects of age and the effects of stroke on HLJ. It is unclear how stroke effects HLJ beyond normal ageing processes, as no previous study limited the age range of participants. Furthermore, few studies have examined the effects of healthy ageing on HLJ, and only one examined it in early old age (Zapporelli et al., 2016). A further study comparing HLJ in healthy early and late old age was indicated to provide more insight into the effects of normal ageing. The results were used to inform a subsequent stroke study, which was limited to those aged sixty years and over.

The final aim was to explore the effects of practising HLJ after a stroke. Only one previous study has examined the effects of practising HLJ in healthy populations (Berneiser 2018) and no studies have investigated if those with stroke can improve performance with practice.

2.1 Research Questions

The first experiment, examining the effects of healthy ageing on HLJ asked the following:

1. What are the differences in HLJ response times and accuracy between healthy young and older-aged adults?
2. What are the differences in HLJ response times and accuracy between those in early and those in advanced old age?

The second experiment examined the effects of stroke on HLJ and asked the following:

1. What are the differences in HLJ response times and accuracy between a group of stroke survivors and healthy controls aged ≥ 60?
2. What are the relationships between HLJ performance and the ability to move the stroke-affected upper limb?
3. What are the relationships between HLJ performance and the site of stroke?

Experiment three explored the effects of practising HLJ in a small sample of stroke survivors and asked the following:

1. What are the effects on of practising HLJ on response times and errors after a stroke?

2. Does practicing HLJ improve upper limb impairment?

3.0 Methodology

3.1 Introduction

This chapter discusses the methodology and methods common to the three experiments. The development of a bespoke HLJ test is described and justified with reference to previous studies. A standardised procedure was developed and tested in a group of healthy adults. Changes made following the pilot test are discussed. The methods of data analysis are described.

3.2 Research Design

The designs of previous HLJ research in older and stroke populations were reviewed. Most common were cross-sectional and quasi-experimental designs, comparing HLJ performance in different populations. The first two experiments in this thesis were quasi-experimental cross-sectional studies, comparing HLJ in the target population with a control group. The third experiment was a before and after study examining the effects of practice in a small group of stroke survivors.

3.3. Development of the HLJ Test

It was intended to use Recognise™, a commercially available on-line HLJ test (Neuro Orthopaedic Institute, no date). However, this test only reports total response times and errors and not those for different views or rotations. There is no other standardised HLJ test, so a bespoke one was developed. This needed to be sufficiently challenging, to stimulate motor imagery, and be achievable for both older and stroke groups.

Table 3.1 shows the composition of HLJ tests used in previous studies of stroke and aged populations. Most studies included dorsal and palmar views but there were variations in the numbers of rotations and trials. It was decided that a more complex HLJ test than previously used, would be developed. It was anticipated that this would enhance the use of implicit motor imagery, as suggested in studies of healthy, young populations (Sekiyama, 1982; Parsons, 1987; Ter horst, Van Lier and Steenbergan, 2010).

Table 3.1.

Designs of HLJ Tests used in Previous Ageing and Stroke Studies.

Author	Study	Subjects	Response Mode	Views	Rotations (n) (degrees)	Blocks (n)	Practice trials (n)	Total trials (n)
Johnson et al. (2003)	Stroke	S=8	1 handed R and L Keypress	D/P	8 (45)	2	8	120
Saimpont et al.(2009)	Ageing	Y=20 O=19	2 handed R and L Keypress	D/P	4 (90)	6	16	192
Delvin and Wilson (2010)	Ageing	Y=20 O=20	1 handed R and L Keypress	D	6 (60)	1	10	96
Deprati et al. (2010)	Stroke	S=20 C=12	1 handed R and L Keypress	D/P	4 (90)	4	Not stated.	256
Tanaka, et al. (2010)	Stroke	S=31 C=29	1 handed R and L Keypress	D/P	4 (90)	1	Not Stated	16
Devries et al. (2011)	Stroke	S=12 C=12	1 handed R and L Keypress	D/P	6 (60)	4	48	288
Yan et al. (2012)	Stroke	S=11 C=11	2 handed R and L key press	D	6 (60)	2-6	Not Stated	192
Devries et al. (2013)	Stroke	S=16 C=16	1 handed R and L Keypress.	D/P	6 (60)	4	48	288

Author	Study	Subjects	Response Mode	Views	Rotations (n) (degrees)	Blocks (n)	Practice trials (n)	Total trials (n)
De Simone et al. (2013)	Ageing	Y=15 O=15	I handed R and L key press	D/P	8 (45)	2	20	288
Amesz et al. (2016)	Stroke	S=32 C=36	1 handed R and L Keypress	NS Used recognise™	NS Used recognise ™	4	NS	120
Kemlin et al. (2016)	Stroke	S=24 C=24	Computer mouse.	D/P	6 (60)	1	Yes, but not standardised.	72
Liepart et al. (2016)	Stroke	S=70 C=23	1 handed R and L Keypress	D/ P	8 (45)	4	Not stated	160
Zapporeli et al. (2016)	Ageing	Y=27 O=29	2 handed R and L key press	D/ P	8 (45)	2	32	128
Braun et al. (2017)	Stroke	S=20 C=20	Verbal	D/ P Hands and feet	6 (60)	1	not stated	136

Key**:** S = stroke; Y= young; O=old; R = right; L = left; D=dorsal; P=palmar; NS=not stated.

3.3.1. Hand Views and Orientations

Figure 3.1 shows the right-hand views and orientations used in the HLJ test. Ulnar (little finger side) and radial (thumb side) views were created in addition to dorsal and palmar ones. These views were included in the earlier HLJ experiments (Sekiyama, 1982; Parsons, 1987). As previously discussed, hand images rotated over more than one axis, are thought to increase the use of motor imagery (Ter horst, Van Lier and Steenbergan, 2010).

The dorsal view has only one axis of rotation, about the sagittal plane, whereas the other views are also rotated about a longitudinal axis. With the hand in the dorsal upright position, 90° of rotation in the longitudinal plane produces the radial view; 180° the palmar view, and 270° the ulnar view.

Digital images of the four views were created from a volunteer's right hand. Each right-handed image was reversed to produce the left-hand ones. The images were enhanced to reduce distinguishing features and reduced to 60% of actual size. Images of real hands were most common in previous HLJ experiments (Ionta, Fourkas and Aglioti, 2007; Ishibashi and Saito, 2011; Choisedealbha, Brady and Maguiness, 2011).

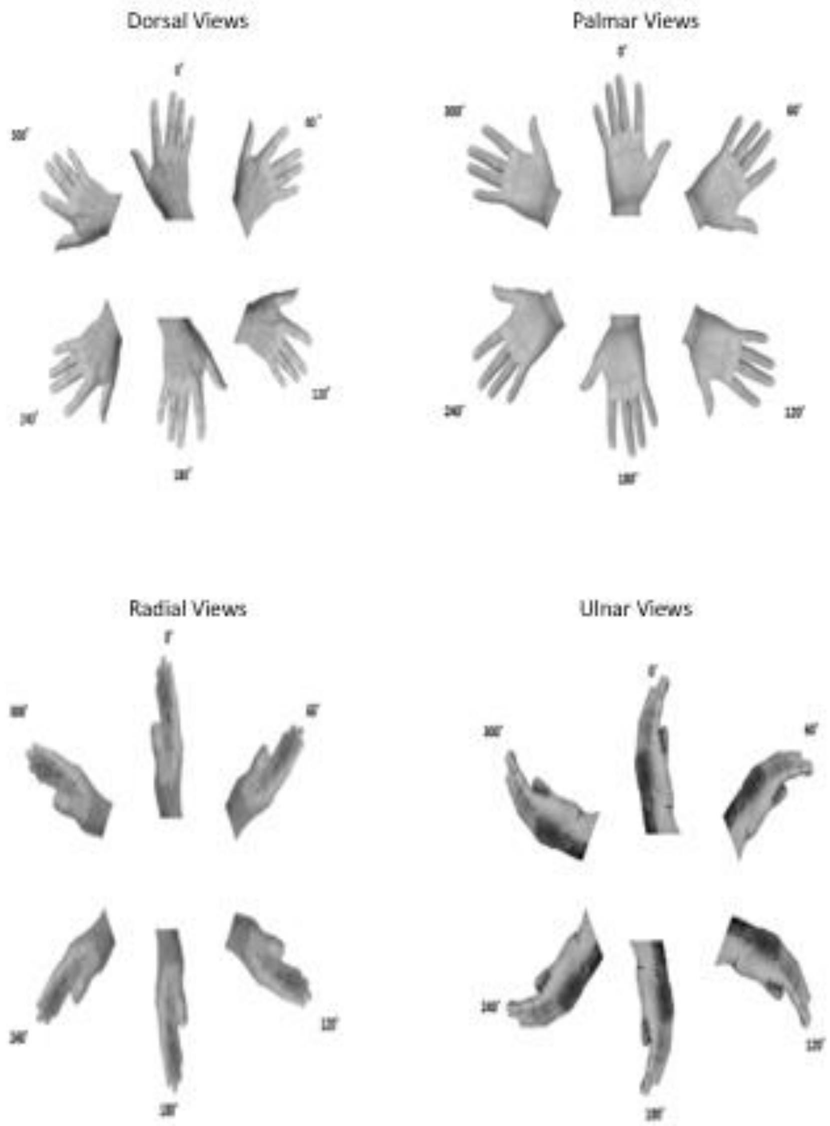
In line with most of the previous studies, the hand images were rotated in the sagittal plane at 60° intervals. Forty-eight images were produced, in orientations from 0° to 300°, which were randomised into nine blocks. The first block was a practice block, to allow the participants to become familiar with the procedure, and to reduce initial response variations (Sternberg, 2010). The total number of trials (432) was higher than in previous studies, but this was due to the inclusion of the two additional views and was needed to reduce the practice effect (Hirschfield et al., 2013; Boonstra et al., 2012).

3.3.2 Response mode

Figure 3.2 shows the keys initially used to respond to the HLJ test. Key four was pressed for responses to left-sided images and key six for right-sided ones. Most previous studies used either a unimanual or bimanual right and left key press. Alternatives were the computer mouse (Kemlin et al., 2016) or by a verbal response (Braun et al., 2017). The unimanual method was chosen to enable the widest participation of stroke participants. A verbal response mode was considered but would have excluded stroke participants with speech impairments.

Figure 3.1.

Images of Right-Hand Views and Orientations used in the HLJ test.



Note. Figure showing the rotated dorsal, palmar radial and ulnar images used in the HLJ test. Each image was included in the randomised blocks.

Figure 3.2.

Response keys initially chosen for HLJ test.

Note. Figure shows the laptop keyboard with the initial response keys circled.

3.3.3 Software

The HLJ test was run with Presentation® software Version 18.0, (Neurobehavioral Systems Inc., no date). Presentation® software was selected as the most cost-effective means of conducting the experiments. Previous studies have either used Presentation® or E prime® software.

Presentation® software runs on standard PC hardware and the Windows™ operating system, it provided an accessible means of delivering the HLJ test. The software produces optimal timing accuracy, regardless of the hardware (Neurobehavioral Systems Inc, no date). A bespoke programme to run the HLJ experiment was commissioned from the company.

There are limitations to the accuracy of any software package designed to run on standard personal computers. The effects of computer hardware and operating systems on timing accuracy, cannot be dampened (Garaizar et al., 2014; Neurobehavioral Systems Inc., 2018). Furthermore, the software only reports the time it detects the response and may vary depending on the hardware (Neurobehavioral Systems Inc., 2018). To minimise timing differences, the same Sony™ Viao laptop computer was used throughout and all other applications were shut down.

As in previous studies, the HLJ experiment was self-paced, the image staying on the screen until a response was recorded. Before each image, a black fixation cross was presented in the centre of the screen for 992 ms. This prompted participants to focus attention and stabilise gaze in preparation for the image (Thaler et al., 2013).

3.4. Reliability and Validity of the HLJ Test

The HLJ test includes several variables that might affect reliability. As previously stated, response times and error rates can differ in relation to image laterality, view, and angle of rotation. Additionally, variations in arm and hand position and different response modes can influence results. Individuals' responses can also be affected by fatigue, poor concentration, increased anxiety levels, and boredom

(Sternberg, 2010; Bolshinova et al., 2017). To date, only one study has examined the reliability of HLJ tests (Hirschfield et al., 2013).

Hirschfield et al. (2013), examined internal consistency and test-retest reliability of four mental rotation tasks including HLJ, in ninety-nine healthy participants. Slower response times were found at the beginning of each block of trials, but response times for blocks of the same task were more stable than when they were mixed (Hirschfield et al., 2013). Intra- subject reliability was low and split-half reliability was only acceptable within blocks of the same task (0.79). Based on these findings, it would be expected that the HLJ test had an acceptable level of reliability. However, Hirschfield et al (2013) used a simplified version of the test with a fewer number of trials.

A further consideration is that response time experiments are prone to error (Ratcliffe and Rouder, 1998). Dutilh et al. (2010) identified two sources of error, participants either guessed, or the error was related to the stimulus. In a two-choice reaction time experiment such as HLJ, a percentage of responses are likely to be guessed.

Response time experiments are also prone to speed-accuracy trade-offs, where faster response times result in reduced accuracy (Bolshinova et al 2017; Dutilh et al 2010). However, in HLJ studies, slower response times are usually related to increased errors. It is unclear if this is due to the stimulus characteristics, or the instructions given to participants. Fewer errors occur if participants are told to be as accurate as possible, but this usually results in increased response times (Dutilh et al., 2010). A rest period was included between blocks to reduce the effects of fatigue on accuracy. Time pressured responses were not used, as these can be less accurate (Kvam 2019), however, this allowed for erroneously long responses.

Face validity for the HLJ test has been demonstrated by the consistently reported response time characteristics. However, convergent validity with other measures of motor imagery has not been found. For example, Devries et al. (2013), found no correlation between scores of the Revised Movement Imagery Questionnaire (Gregg et al., 2010) and the HLJ performance in sixteen stroke patients or age-matched healthy controls.

3.5 Bias

The HLJ test is vulnerable to the practice effect. Boonstra et al (2012) demonstrated that this could occur if the HLJ test was repeated, which was a consideration for experiment three. Participants might also recall their answers for preceding images during the test. The practice effect was reduced by increasing the number of trials and randomising them into blocks.

A further source of bias is the response mode. Cocksworth and Punt (2013), showed that responses to HLJ tests varied, depending on the mode used. In a study of thirty – eight young, healthy participants, verbal responses were more accurate (91%; $p<.01$) and faster (1,270 ms; $p<.00$) than unimanual response modes. There were no significant differences in responses using right and left uni-manual response modes, but responses were slower when the image corresponded to the responding hand. It was concluded that mentally rotating the hand, concurrently with planning the response, disrupted the process. These potential biases needed to be considered when interpreting the results of the HLJ test.

3.6 Procedure for Conducting the HLJ Test

The same standardised procedure was used for all the experiments. Participants were seated 40 cm from the laptop display screen. The left, or affected hand (stroke participants), was placed on their laps. Participants were instructed not to move or look at their resting hand. Their right, or unaffected hand (stroke participants), was placed on the response keys (see figure 3.1). Participants were instructed to press the number four key (left arrow), with their index finger, for left-sided images and the number six key (right arrow), with their middle finger, for right-sided images. The nine blocks of forty -eight randomised images were presented, with a three-minute break between each block.

3.7 Data Analysis

Data were analysed using IBM SPSS version 24. The dependant variables were response time and accuracy. The independent variables were group, laterality, views, and angles.

Response times were defined as the interval between the appearance of the image, and the activation of one of the response keys. Accuracy was defined as the number of incorrect responses. In accordance with previous studies, an accuracy rate of above 60% was considered above chance level (Saimpont et al., 2009; Zapparoli et al., 2016). Any uncompleted trials were entered as missing data.

For each participant, mean response times and errors were calculated for the whole test and separately for each image; right and left-sided images; separate views, and angles. Response times for medial rotations were calculated from left- hand images rotated to 60° and 120° and right-hand images rotated to 240° and 300°. Response times for lateral rotations were calculated from left-hand images rotated to 240° and 300° degrees, and right-hand images rotated to 60° and 120° degrees.

The Shapiro-Wilk test was used to test for normality. Whelan (2008) suggested that response time data was unlikely to be normally distributed, and suggested that either data should be transformed, or non-parametric tests used. Previous studies removed outliers to improve distribution. For example, Devries et al (2011) removed response times below 350 ms and above 10,000 ms and Saimpont et al. (2009) discarded response times greater than 8,000 ms.

It was decided not to apply arbitrary cut-offs, as real and spurious response times may have overlapped reducing power and introducing bias (Ratcliffe, 1993). Instead, data two standard deviations from the mean were removed where indicated. In all experiments, the data were not normally distributed, so non-parametric statistics were used. Data in the text are presented as medians (interquartile ranges) throughout. Where distributions were dissimilar, mean ranks rather than medians are reported for the Mann-Whitney U test. Graphs of median response times plotted against angles of image rotation are included where appropriate to illustrate the response time patterns.

The Kruskal-Wallis test was used for comparisons between more than two groups and the Mann-Whitney-U, adjusted with Holm-Bonferroni for post hoc pairwise comparisons. The Friedman's test was used to calculate within-group differences for more than two groups and the Wilcoxon Signed-Rank test, adjusted with Holm-Bonferroni, used for post- hoc pairwise comparisons.

For all other comparisons, the Mann-Whitney-U test was used for between-group comparisons and the Wilcoxon signed-rank test within-group comparisons, both adjusted with Holm-Bonferroni. Spearman's Rank Order correlation was used to test for associations between dependant and independent variables. The alpha level was set at $p \leq .05$ for all calculations.

3.8 Pilot Test

The HLJ test was piloted in a convenience sample of healthy participants, who did not take part in the main studies. This was to ensure that the test performed as expected and results were in line with previous studies.

3.8.1 Participants

Ten participants (four male) aged between 35–58 years were recruited. All were right-handed and had no hand impairments or a previous history of stroke. Ethical procedures were carried out as detailed in chapter four.

3.8.2 Procedure

A consent form (see appendix 1) and the Edinburgh Handedness Score–short form (Veale, 2013) (see appendix 2) were completed before commencing the HLJ test. The HLJ test was carried out as detailed in section 3.6.

3.8.3. Data Analysis

Data analysis was carried out as described in Section 3.7. The Wilcoxon signed-rank test adjusted with Holm-Bonferroni was used for all comparisons.

3.8.4 Results.

Table 3.2 shows the median response times and errors for all trials, for right and left-sided images, and for separate views. All participants completed the HLJ experiment within one hour, with an accuracy rate of 87%. There were no significant differences in response times or errors to right and left-sided images, so results for both sides were combined (Response times, z=-1.274; p=.20; errors, z=-.918; p=.35)

Response times to ulnar views were significantly slower than to all other views (dorsal, p<.01, z=-2.803; palmar, p=.02, z=-2.203; radial, p<.01; z=-2.803). There were no significant differences in response times between any other views.

Errors were significantly higher for ulnar views than for dorsal and radial views (dorsal, p=.05, z=-1.933; radial, p=.02, z=-2.253). There were no significant differences in errors between other views.

Table 3.2.

Median Response Times and Errors (interquartile ranges) to All, Right and Left Sided images and to Images of Each View.

Variable	All	Right	Left	Dorsal	Palmar	Radial	Ulnar
Time (ms)	2612 (1534)	2549 (1631)	2676 (1471)	2331 (1685)	2440 (1036)	2281 (1633)	3221 (1685)
Errors (n)	50 (50)	27 (34)	18 (15)	8 (12)	12 (13)	6 (16)	15 (24)

Table 3.3 and figures 3.3 – 3.7 show the median response times to each angle of image rotation for all trials and for separate views. Response times to all trials were significantly slower for images rotated to 180° compared to all other angles (0°, *p*<.01, *z*=-2.803; 60°, *p*<.01; *z*=-2.803; 120°, *p*<.01, *z*=-2.803; 240°, *p*=.02, *z*=-2.191; 300°, *p*<.01, *z*=-2.803).

Response times to 180 ° dorsal rotations were significantly slower than to all other angles (0°, *p*<.01, *z*=-2.803; 60°, *p*<.01, *z*=-2.701;

120°, $p=.02$, $z=-2.293$; 240°, $p=.04$, $z=-1.988$; 300°, $p<.01$, $z=-2.701$). Response times to 180° radial rotations were significantly slower to all except 240° rotations (0°, $p<.01$, $z=-2.803$; 60°, $p<.01$, $z=-2.803$; 120° $p=.01$; $z=-2.497$; 300°, $p<.01$, $z=-2.80$). There were no significant differences between response times to 180° palmar or ulnar rotations and any other angle.

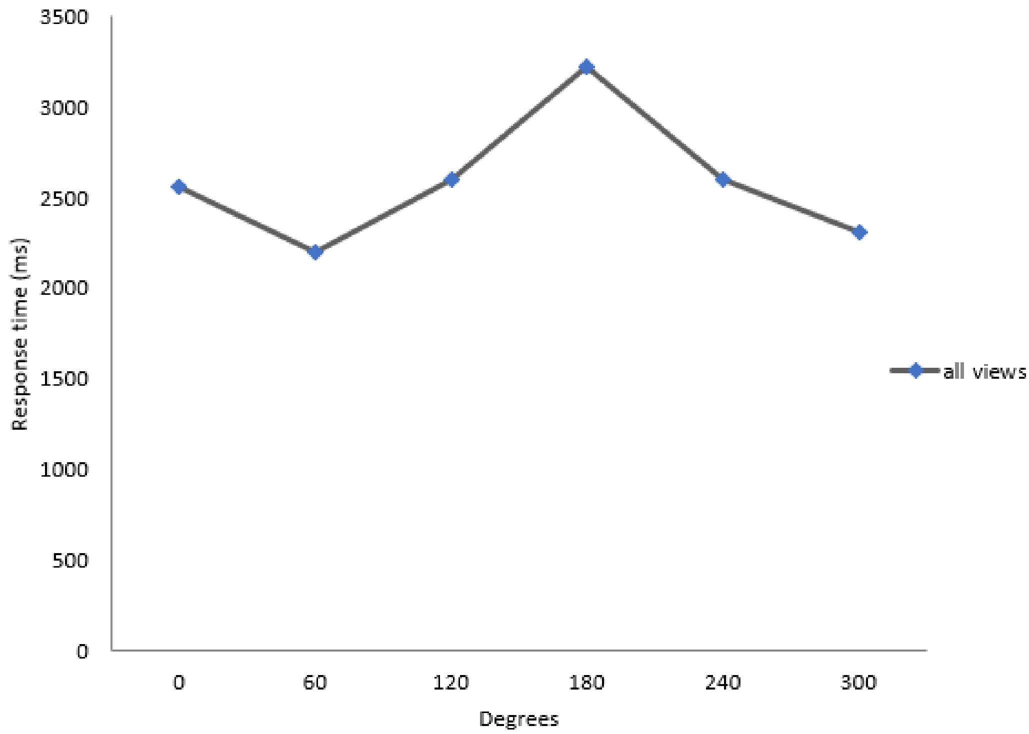
Table 3.3.

Median Response Times (ms) (interquartile ranges) to each Angle of Image Rotation (degrees) for all Trials and for Separate Views.

View	0°	60°	120°	180°	240°	300°
All	2559 (1543)	2200 (1212)	2599 (1605)	3225 (2199)	2605 (1904)	2313 (1417)
Dorsal	1754 (1358)	1912 (1457)	2415 (1874)	2926 (1987)	2386 (1939)	2082 (1859)
Palmar	2335 (1340)	2260 (1374)	2233 (1652)	2259 (2131)	2406 (1799)	2368 (1409)
Radial	1912 (1223)	1854 (1393)	2230 (1665)	3133 (2242)	2244 (2021)	1956 (1482)
Ulnar	4093 (3039)	2953 (2181)	3032 (1577)	3628 (2928)	3071 (2041)	2660 (1860)

Figure 3.3.

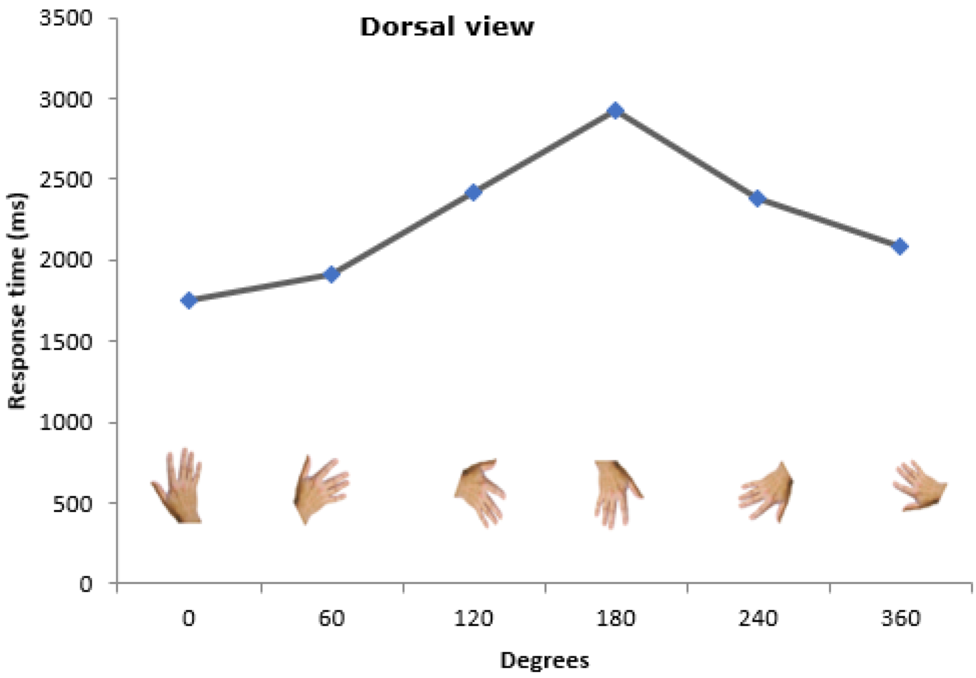
Median response times (ms) to each angle of Image rotation (degrees) for all views



Note: Median response times (ms) plotted as a function of image orientation (degrees) for all trials. The graph shows the typical pattern of slower response times to increasing angles of image rotation up to 180°.

Figure 3.4.

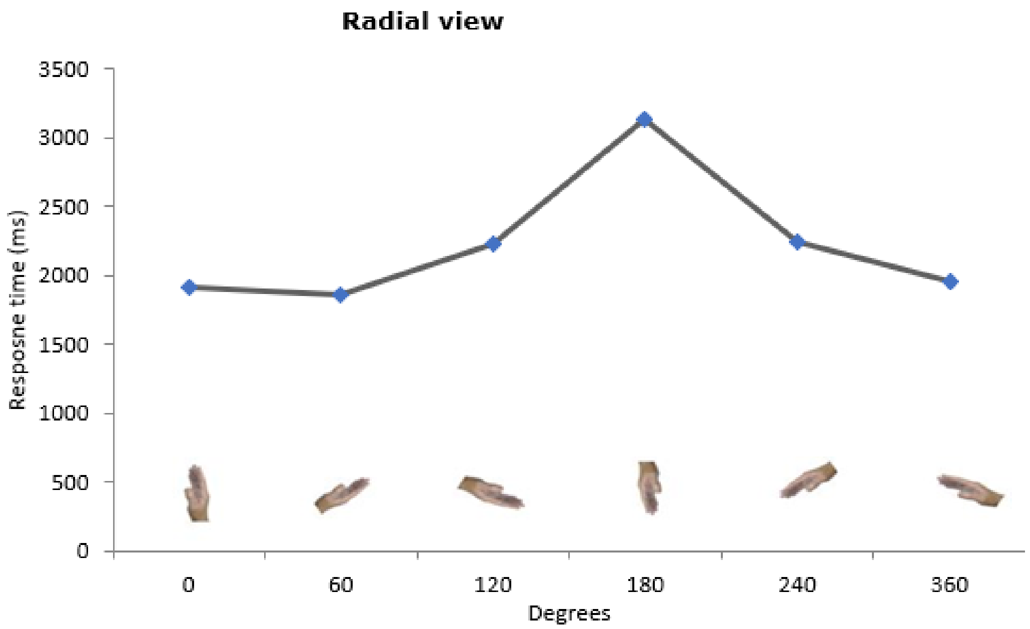
Median response times (ms) to each angle of Dorsal rotation



Note. Median response times (ms) plotted as a function of image orientation (degrees) for dorsal images. The graph shows the typical pattern of slower response times to increasing angles of image rotation up to 180°.

Figure 3.5.

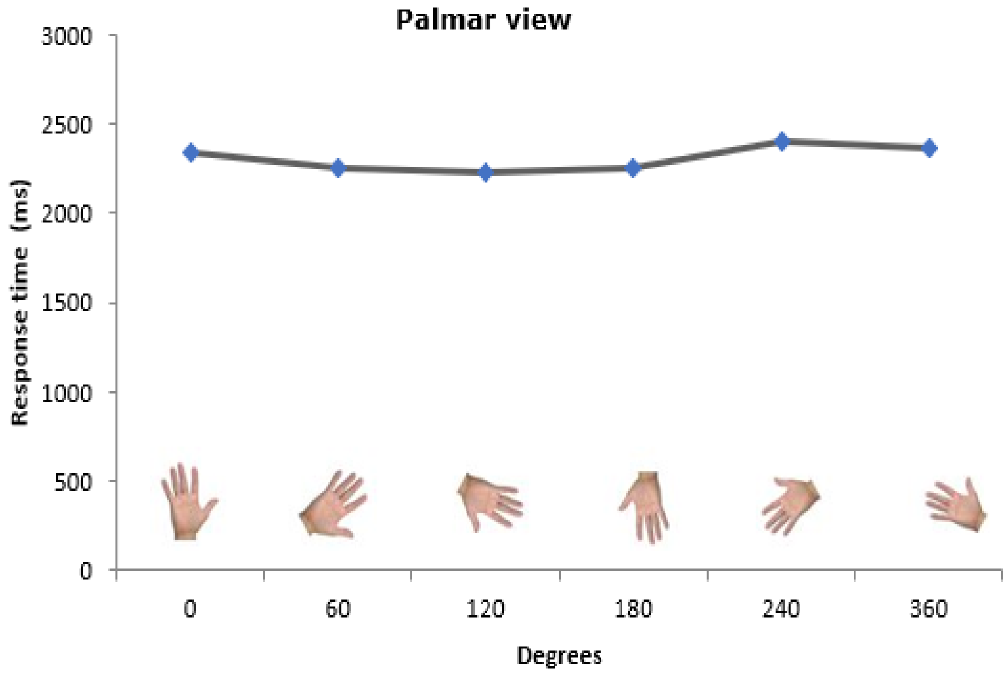
Median Response Times (ms) to each Angle of Radial Rotation (degrees)



Note. Median response times (ms) plotted as a function of image orientation (degrees) for radial images. The graph shows the typical pattern of slower response times to increasing angles of image rotation up to 180°.

Figure 3.6.

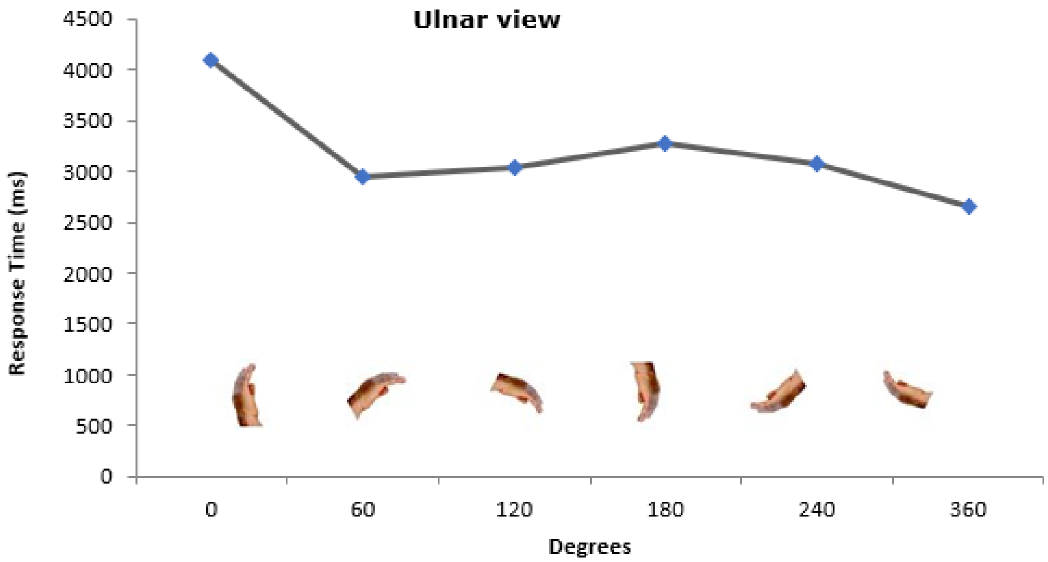
Median Response Times (ms) to each Angle of Palmar Rotation (degrees)



Note. Median response times (ms) plotted as a function of image orientation (degrees) for palmar images. Response times did not increase in line with image rotation to 180° and were slower to 240° rotations.

Figure 3.7.

Median Response Times (ms) to each Angle of Ulnar Rotation (degrees)



Note. Median response times (ms) plotted as a function of image orientation (degrees) for ulnar images. Response times did not increase in line with image rotation to 180° and were slowest at 0°.

Table 3.4 shows the response times to medially and laterally rotated images for all trials and for separate views. There were no significant differences between medially and laterally rotated images overall or between medial and laterally rotated dorsal or ulnar views. Response times to laterally rotated palmar and radial views were significantly slower than to medially rotated ones (palmar, $p<.01$, $z=-2.803$; radial, $p<.01$, $z=-2.599$).

Table 3.4.

Median Response times (ms) (interquartile ranges) to Medial and Laterally rotated images of all and separate views.

Rotation	All Views	Dorsal	Palmar	Radial	Ulnar
Medial	2246 (1310)	2330 (1473)	1909 (1134)	1912 (1651)	3070 (1632)
Lateral	2655 (1674)	2010 (1793	2900 (2241)	2314 (1766)	2923 (2541)

3.8.5 Participant Feedback.

Several participants found the experiment was too long and reported losing concentration during the final two blocks. All participants found the test more challenging than anticipated with ulnar views and images rotated to 180° the most difficult to judge.

3.8.6 Discussion.

The pilot HLJ test showed similar response time characteristics to those used in previous HLJ studies. Response times and errors were in acceptable ranges but were greater than in studies of young, healthy populations. This can be explained by ulnar views having significantly higher response times and errors than other views. Additionally, when responses from a participant with an error rate of 30% were excluded, accuracy increased to 91%.

Response times and errors were slower for images awkward to physically perform, demonstrating a link with the biomechanical constraints on actual movement. These included dorsal and radial images at 180°; laterally rotated palmar and radial views, and ulnar views. This suggests that the HLJ test stimulated implicit motor imagery processes.

In contrast to previous studies, there were no significant differences in response times to the right and left-sided images. The use of the unimanual response mode may have reduced response time differences as in previous studies differences were found when using either bimanual or verbal response modes.

Although response times to palmar views were slower than for dorsal and radial views, the difference was not significant. Faster response times to dorsal views were consistently found in previous studies, (Ionta et al 2007; Ionta and Blanke 2009; Ter horst, Van Lier and Steenbergan, 2010; Bläsing et al., 2013).

3.9 Changes Made Following the Pilot Test

Feedback from participants indicated that the HLJ test should be shorter so that older or stroke participants could complete it within one hour. To examine the effects of reducing the number of blocks, response times and errors were compared between the first and second half of trials. Response times were significantly slower for the first half of trials (2822 (1670) ms) than for the second half (2372 (1389) ms) (p<.01; z=-2.803) but there were no significant differences in the number of errors. The faster response times for the second half of trials may indicate there was a practice effect, with participants recalling previous answers as the experiment progressed.

It was concluded that the HLJ test could be shortened to six blocks of forty-eight images, including the practice block. This produced 288 trials with 240 for analysis, as in previous stroke studies (Devries et al 2011; Devries et al 2013; De Simone et al 2013).

Responding with the left and right arrow keys on the laptop keyboard did not cause participants any difficulty. However, it was decided that a separate numerical keypad would improve accessibility for stroke participants as it could be optimally positioned for use by the right or left hand. Figure 3.8 shows the keypad and response keys used for the HLJ test in the subsequent experiments. The procedure detailed in section 3.6 was amended to incorporate the changes.

Figure 3.8.

Numerical Keypad and Response Keys used in the HLJ test.

Note. The figure shows the keypad used as the unimanual response mode. Key 4 was pressed for a left response and 6 for a right response.

4.0 Ethical Considerations

This chapter details the ethical considerations and procedures undertaken for each experiment. Copies of all relevant documents can be found in appendix one. This research was carried out in compliance with University of Cumbria's Research Code of Practice (University of Cumbria 2014a) and the University of Cumbria's Post Graduate Research Code of Practice (University of Cumbria 2014b).

Ethical approval was gained from The University of Cumbria research ethics committee for all experiments. As NHS stroke patients were recruited for experiment two, ethical approval was gained from the NHS Health Research Authority. NHS approval was unnecessary for experiment three as all participants were recruited from a voluntary stroke group.

The first two experiments were carried out by the author of this thesis. The author was the principal researcher for experiment three, but recruitment and data collection were carried out by a student on an MSc (pre-registration) physiotherapy programme. The student was supervised by the author during all data collection activities.

4.1 Service User Consultation

The HLJ test was demonstrated to two groups of stroke survivors, who were also consulted about the planned experimental procedures.

Following this, amendments to participant information sheets were made. Comments about the study were positive, although there were some reservations about whether stroke participants would be able to fully complete the HLJ test as it was thought to be demanding.

4.2 Participant recruitment

4.2.1 Healthy Participants

The young group consisted of university students who were made aware of the study through announcements on the internal virtual learning platform and via their programme leaders. They were invited to contact the researcher via email, after which they were sent the participant information sheet. Participants were contacted to confirm their participation.

The older participants were recruited from the community. Information about the study was sent directly to participants on an existing university database of older people who had expressed an interest in participating in research. Additionally, information sessions were given at meetings for active retired people, including local University of the Third Age groups and a university group for retired academics. Interested participants were invited to contact the researcher for more information. An information sheet was sent to all potential participants before further contact to confirm participation.

4.2.2. Stroke Participants

Following research ethics and local research and development department approvals, stroke participants were indirectly approached via third parties or as a result of information sessions at voluntary sector stroke support groups. The third parties included clinicians and coordinators of voluntary stroke services. These individuals were supplied with information flyers to distribute to potential participants either directly or via mail.

The researcher held information sessions at community stroke groups and information flyers were given to potential recruits. Participants were invited to contact the researcher directly if they were interested in taking part. Once contact had been made, participants were sent a participant information sheet before further contact to confirm participation.

4.3 Consent

Informed consent was obtained before any data collection. The participant information sheet was reviewed, and participants were able to ask questions before giving consent. Each participant initialled and signed two copies of the consent form. One copy was taken by the participant and one retained for the researcher's records. Where stroke participants were not able to initial and sign the consent form, verbal consent was given and witnessed by a third party. Participants were informed that they did not have to complete any of the experimental procedures and could leave at any time. Participants for experiment two were also asked to consent for the researcher to access their medical records to confirm their stroke diagnosis.

Participants were informed that no benefits were to be expected from taking part in the research. Expenses for parking or transport were reimbursed and refreshments were provided.

4.4 Confidentiality

A password-protected database of identifying information such as name, contact details or date of birth, was only accessible by the researcher and supervisors. Participants were allocated a unique identification number only known to the researcher and supervisors. This was used for all data inputting analysis. No information identifying participants has been included in any outputs from this thesis.

4.5 Risk Assessment and Management

It was not anticipated that taking part in any of the experiments would be harmful. As the research involved participants using computer equipment, the University of Cumbria code of practice for the use of display screen equipment (University of Cumbria 2011) was adhered to. The laptop computer was positioned on a suitable surface and a suitable chair was provided.

As the studies included older and stroke participants, care was taken to ensure their safety and well-being. All data collection sessions took place on university premises within normal working hours. External participants reported to reception as per university procedures. It was anticipated that some stroke participants would have mobility difficulties and any needs were discussed before attendance. Rooms were chosen that were easily accessible and located in areas where help could be accessed in the event of an emergency.

Consultation with the stroke groups highlighted that some participants may have found the procedures tiring. To counter this, opportunities to rest were given throughout the data collection period and refreshments were offered. Participants were able to stop the test at any time and it was stopped after one hour and fifteen minutes if it had not been completed.

It was considered that discomfort might be experienced by stroke participants when undertaking range of motion measurements. These were taken by the researcher who is an experienced neurological physiotherapist and skilled at safely handling the upper limbs of stroke survivors. Anyone with significant pain or spasticity affecting the upper limb was excluded from the study. Range of movement measures were only taken for positions that could be safely and comfortably be attained by the participant. No participants expressed any discomfort as a result of these procedures. No adverse events occurred.

For experiment three, the student was supervised by the researcher during all data collection and undertook all handling of the stroke-affected upper limb during measurement.

4.6 Data Management

All data collection was completed before the implementation of the General Data Protection Regulations in 2018. The researcher received data protection training and ensured that all data was kept in compliance as per the University of Cumbria information security policy (Hurst 2015). All electronic data were kept on password protected, secure university systems.

Any identifying data will be destroyed by one year after the completion of this thesis. Any hard copy information such as consent forms were kept in a locked filing cabinet in a locked office at the University of Cumbria. All hard copy information will be destroyed one year after thesis completion.

5.0 Experiment One: The Effects of Age on Hand Laterality Judgement

This experiment addressed the following questions:

1. What are the differences in HLJ response times and accuracy between healthy young and older-aged adults?

2. What are the differences in HLJ response times and accuracy between those in early and those in advanced old age?

It was hypothesized that healthy adults aged ≥60 years would be slower and make more errors than healthy adults ≤30 years. Additionally, those aged ≥70 years would be slower and make more errors than those aged 60-70 years. It was expected that all groups would use similar HLJ strategies, suggestive of implicit motor imagery and visuospatial hand mental rotation.

5.1 Participants

Participants were recruited as described in section 4.2 and divided into three groups according to age: Young, aged between 18-30 years; Older 1 aged between 60-69 years, and Older 2 aged 70 years and over. They were included if they were right-handed; had not previously had a stroke; had no impairments affecting hand function; normal or corrected to normal vision; were able to give consent and understand the procedures. They were excluded if they were left-handed; aged between 31-59 years; had any hand impairment; a diagnosed neurological condition such as stroke or dementia or could not see the computer screen.

5.2 Procedure

The participant information sheet was reviewed, and the consent form completed, followed by The Edinburgh Handedness Score – Short Form (Veale, 2013). The HLJ test was completed as described in section 3.6. Data were analysed as described in section 3.7

5.3 Results

5.3.1 Participants

Table 5.1 shows the participant characteristics. Sixty-two participants met the inclusion criteria and were divided into three groups according to age: Young=19-29 years; Older 1=61-71 years; Older 2=72-91 years. All participants were healthy and reported taking part in regular physical activity. They were all right-handed and had normal or corrected to normal vision. One participant in the Older 2 group had an accuracy rate of below 60% and was excluded from further analysis.

Table 5.1.

Participant Characteristics of the Young, Older 1 and Older 2 Groups

Group	Gender m/f	n	Age (yrs) Mean (sd)	Age Range (yrs)
Young	10/10	20	22 (2)	19 -29
Older 1	4/16	20	67 (3)	61- 71
Older 2	5/17	22	77 (5)	72 -91

5.3.2 Response times and Accuracy

Table 5.2 shows the response times and errors for each group. There were no significant differences in response times or errors to right and left images, so data for both sides were combined (response times, z=-0.37 p=.97; errors, z=-1.19, p=.23). Accuracy rates were 92% for Young, 86% for Older 1, and 81% for Older 2.

There was a significant difference in the number of errors ($\chi^2_{(2\ n=61)} = 13.78$, $p \leq .00$) but no significant difference in response times ($\chi^2_{(2\ n=61)} = 5.37$ p=.06).

Young made significantly less errors that Older 1, (Young mean rank =14.69, Older 1, mean rank =25.05, U=108.0, p=.01) and Older 2 (Young mean rank =13.24, Older 2, mean rank= mean rank=27.97, U=78.5, $p \leq .00$). There was no significant difference in the number of errors between Older 1 and Older 2 (Older 1, mean rank=17.85, Older 2, mean rank=24.00, U=147.00, p=.10).

There was a moderate positive correlation between age and the number of errors,(r_s (60) = 0.46, $p \leq .00$), a weak positive correlation between response times and age (r_s (60) =.28, p=.02), and a weak positive correlation between response times and errors (r_s (60) = 0.27, p=.03).

Table 5.2.

Group Median Response Times and Errors (Interquartile Ranges) for All, and Right and Left-Sided Images.

Group	All-time (ms)	R time (ms)	L time (ms)	All Errors (n)	R Errors (n)	L Errors (n)
Young	2200 (1674)	2259 (1463)	2146 (1526)	17.0 (23.0)	9.0 (6.0)	10.0 (11.0)
Older 1	3001 (1557)	2896 (1751)	3090 (1432)	33.0 (28.0)	14.0 (18.0)	16.0 (10.0)
Older 2	3254 (2298)	3477 (2223)	3165 (2165)	45.0 (30.0)	25.0 (17.0)	10.0 (11.0)

Key: ms=milliseconds; n=number; R= right; L=left

5.3.3 Effects of Image View on Response Times and Accuracy

Table 5.3 shows each group's response times and errors to separate views. There was a significant difference in response times to dorsal images ($\chi^2_{(2\ n=61)}$ = 6.42, p=.04) but not to palmar($\chi^2_{(2\ n=61)}$ = 4.52, p=.10); radial ($\chi^2_{(2\ n=61)}$ = 5.13, p=.07) or ulnar images ($\chi^2_{(2\ n=61)}$ = 5.22, p=.07). Compared to Young, Older 2 had significantly slower response times to dorsal images (Young, mean rank=16.8, Older 2, mean rank=25.00, U=126.00, p=.02). There were no significant differences in response times to dorsal images between Young and Older 1 (Young mean rank=16.90, Older 1, mean rank=24.10, U=128.00, p=.05) or between Older 1 and Older 2 (Older 1, mean rank=19.20, Older 2 mean rank=22.71, U=174.00, p=.34).

There were significant differences in the number of errors in response to dorsal images ($\chi^2_{(2\ n=61)}$ = 8.20, p=.01), palmar images ($\chi^2_{(2\ n=61)}$ = 6.73 p=.03), radial images ($\chi^2_{(2\ n=61)}$=10.6, $p \leq .00$), and ulnar images ($\chi^2_{(2n=61)}$=12.30,$p \leq .00$). Compared to Young, Older 1 made significantly more errors in response to palmar images (Young, mean rank=16.38, Older 1, mean rank=24.63, U=117.50, p=.02) and to ulnar images (Young, mean rank=15.68; Older 1, mean rank=25.33; U=103.50, p=.00). There were no significant differences in the number of errors between Young and Older 1 in response to dorsal images (Young, mean rank=18.95, Older 1, mean rank=22.05

U=169.00, *p*=.41) or to radial images (Young mean rank=17.60, Older 1 mean rank=23.40, *U*=142.00, *p*=.12).

Compared to Young, Older 2 made significantly more errors in response to dorsal images (Young, mean rank=15.90, Older 2, mean rank 25.86, *U*=108.00, *p*≤.00), palmar images (Young, mean rank=16.40, Older 2,mean rank=24.60, *U*=118.00, *p*=.02), radial images (Young, mean rank=14.60, Older 2, mean rank=27.00, *U*=82.00 *p*≤.00) and ulnar images (Young, mean rank=14.70, Older 2, mean rank=27.00, *U*=84.00,*p*≤.00).

Older 2 made significantly more errors in response to dorsal images than Older 1 (Older 1, mean rank=17.03, Older 2 mean rank=24.79, *U*=130.50, *p*=.03). There were no significant differences between Older 1 and Older 2 in response to palmar images, (Older 1 mean rank=20.08, Older 2, mean rank=20.93, *U*=191.00, *p*=.81), radial images (Older 1 mean rank=17.30, Older 2 mean rank=23.70, *U*=136.00*, p=.08)* or ulnar images (Older 1, mean rank=19.33, Older 2, mean rank= 22.57, *U=177.00, p=.38)*.

There were significant within-group differences in response times (Young, $\chi^2(3)$=46.82, *p*≤.00; Older1, $\chi^2(3)$=47.23, *p*≤.00; Older 2, $\chi^2(3)$ =37.70, *p*≤.00) and in the number of errors to each view (Young, $\chi^2(3)$ =18.22, *p*≤.00; Older 1, $\chi^2(3)$ = 30.97, *p*≤.00; and Older 2, $\chi^2(3)$ =18.04(3), *p*≤.00). Table 5.3 shows the *z* and *p* values for each pairwise comparison.

Table 5.3.

Group Median Response Times (ms) and Errors (n) (interquartile ranges) to Separate Views

Group	Dorsal Time	Palmar Time	Radial Time	Ulnar Time	Dorsal Errors	Palmar Errors	Radial Errors	Ulnar Errors
Young	1827	2157	1846	2733	4.0	3.0	2.0	8.5
	(1246)	(1462)	(1320)	(2161)	(6.5)	(4.7)	(4.0)	(8.7)
Older 1	2695	2783	2555	4122	5.0	6.0	5.5	15.0
	(1391)	(1390)	(1553)	(2584)	(5.7)	(9.2)	(6.0)	(11.7)
Older 2	2886	3050	3070	3942	11.0	4.0	7.0	14.0
	(2303)	(1218)	(1741)	(3116)	(9.7)	(9.0)	(9.5)	(8.5)

Key: ms= milliseconds; n=number

Table 5.4.

Results of Within Group Pairwise Comparisons of Median Response Times (ms)

Variable	Group	Wilcoxen sign-rank test	Dorsal /Palmar	Dorsal/ Radial	Dorsal / Ulnar	Radial/ Palmar	Ulnar/ Palmar	Ulnar /Radial
Response times	Young	*z*	-1.34	-0.44	-3.92	-1.53	-3.58	-3.92
		p	.17	.65	.00*	.12	.00*	.00*
	Older 1	*z*	-0.48	-0.52	-3.92	-0.97	-3.92	-3.92
		p	.62	.60	.00*	.33	.00*	.00*
	Older 2	*z*	-0.08	-0.12	-4.01	-0.33	-3.73	-3.86
		p	.93	.90	.00*	.73	.00*	.00*
Errors	Young	*z*	-1.37	-1.62	-2.84	-0.41	-3.13	-3.44
		p	.16	.10	.00*	.67	.00*	.00*
	Older 1	*z*	-0.08	-0.48	-3.48	-1.32	-3.92	-3.58
		p	.93	.62	.00*	.18	.00*	.00*
	Older 2	*z*	-1.15	-0.63	-2.81	-1.62	-2.55	-3.58
		p	.24	.52	.00*	.10	.01*	.00*

*Statistically significant difference.

5.3.4 Effects of Image Rotation on Response Times

Table 5.5 and Figure 5.1 show the group response times to each image rotation. There were significant differences in response times to images rotated to 0°($\chi^2_{(2\ n=61)}$=6.26, *p*=.04), 60°($\chi^2_{(2\ n=61)}$= 7.21, *p*=.02), and 120°($\chi^2_{(2\ n=61)}$ =6.42, *p*=.04). There were no significant between group differences to images rotated to 180°($\chi^2_{(2\ n=61)}$ = 5.24, *p*=.07), 240°($\chi^2_{(2\ n=61)}$ = 3.70, *p*=.15) or 300°($\chi^2_{(2\ n=61)}$ = 3.86, *p*=.14).

Compared to Young, Older 1 had significantly slower response times to images rotated to 0°(Young, mean rank 16.60, Older 1, mean rank 24.40, *U*=122.00, *p*=.03), 60°(Young, mean rank=16.15, Older 1 mean rank=24.85, *U*=113, *p*=.01) and 120°(Young, mean rank=16.60, Older 1, mean rank=24.40, *U*=122.00, *p*=.03).

Compared to Young, Older 2 had significantly slower response times to images rotated to 0°(Young, mean rank=16.80, Older 2, mean rank=25.00, *U*=126, *p*=.02), 60°(Young, mean rank=16.65, Older 2, mean rank=25.14, *U*=123.00, *p*=.02) and 120° (Young, mean rank=16.75, Older 2, mean rank=25.05, *U*=125, *p*=.02).

There were no significant differences between Older 1 and Older 2 in response times to images rotated to 0° (*U*=196.00, *p*=.71), 60° (*U*=193.00, *p*=.65) or 120° (*U*=189.00, *p*=.58).

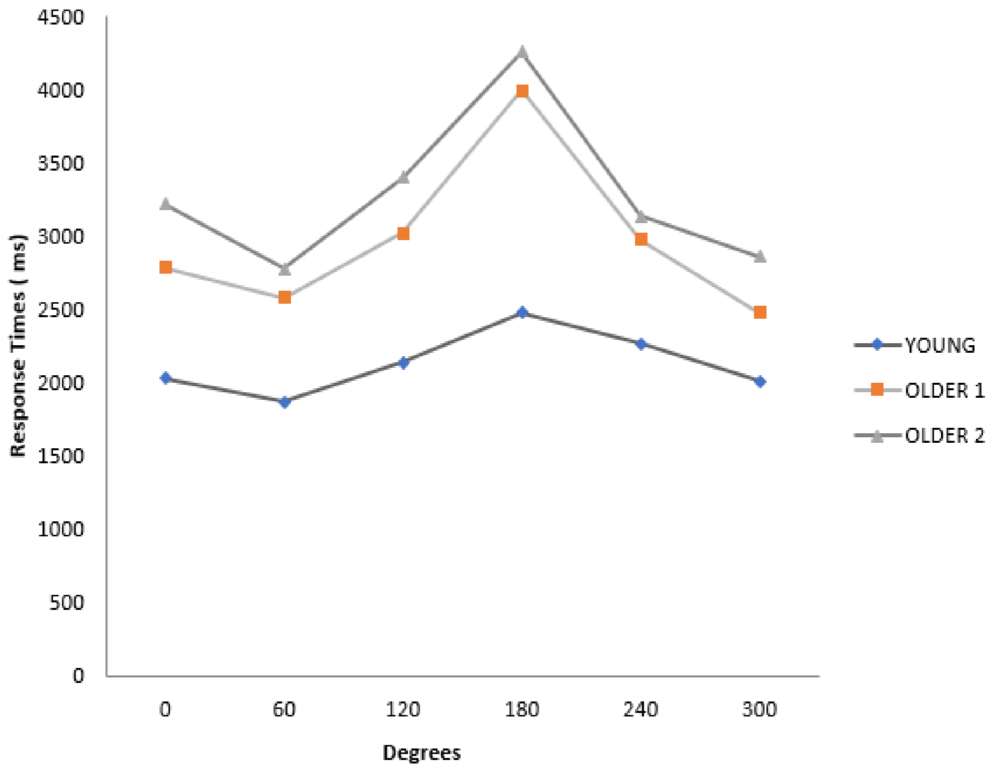
Table 5.5.

Group Median Response Times (ms) (Interquartile Ranges) to each Angle (degrees) of Image Rotation

Group	0°	60°	120°	180°	240°	300°
Young	2031 (1484)	1870 (1185)	2136 (1587)	2480 (1512)	2267 (1713)	2008 (1369)
Older 1	2786 (2027)	2583 (1185)	3019 (1777)	3997 (2588)	2978 (1798)	2481 (1529)
Older 2	3291 (2239)	2777 (2537)	3400 (2517)	4260 (3031)	3137 (2350)	2860 (1953)

Figure 5.1.

Comparison of Group Response Times (ms) to each Angle (degrees) of Image Rotation.



Note: Median response times (ms) plotted as a function of image orientation (degrees) for Young, Older 1 and Older2. Response times increased with the angle of rotation to 180° in all groups.

There were significant within-group differences in response times to angles of image rotation (Young, $\chi^2(3) = 44.2$, $p \leq .00$; Older 1, $\chi^2(3) = 43.40$, $p \leq .00$; Older 2, $\chi^2(3) = 46.55$.$p \leq .00$). Table 5.6 shows the *z* and *p* values for each pairwise comparison.

Table 5.6.

Results of Within Group Pairwise Comparisons of Response Times (ms) to each Angle of Image Rotation (degrees)

		Image Rotation														
Group	Wilcoxen sign-rank	0/ 60	0/ 120	0/ 180	0/ 240	0/ 300	60/ 120	60/ 180	60/ 240	60/ 300	120/ 180	120/ 240	120/ 300	180/ 240	180/ 300	240/ 300
Young	*z*	-3.17	-1.60	-3.28	-1.60	-2.31	-2.46	-3.69	-3.02	-2.01	-3.36	-2.05	-1.18	-3.09	-3.62	-2.94
	p	.00*	.10	.00*	.10	.02*	.01*	.00*	.00*	.04*	.00*	.04*	.03*	.00*	.00*	.00*
Older 1	*z*	-1.60	-.26	-3.72	-.48	-2.65	-1.41	-3.65	-2.42	-2.50	-3.43	-1.41	-3.36	-3.21	-3.88	-3.62
	p	.10	.79	.00*	.62	.00*	.15	.00*	.01*	.01*	.00*	.15	.00*	.00*	.00*	.00*
Older 2	*z*	-.95	-.78	-3.31	-1.58	-2.76	-1.99	-4.01	-1.89	-2.20	-3.91	-.85	-3.11	-3.66	-4.01	-3.11
	p	.33	.43	.00*	.11	.00*	.04*	.00*	.05*	.02*	.00*	.39	.00*	.00*	.00*	.00*

*Statistically significant difference.

5.3.5 Effects of Dorsal Image Rotation on Response times

Table 5.7 and figure 5.2 show the group response times to rotated dorsal images. There were significant differences in response times to 0° ($\chi^2_{(2n=61)}$=6.18,*p*=.04), 60° ($\chi^2_{(2n=61)}$=11.01,*p*≤.00), 120°($\chi^2_{(2n=61)}$=10.77, *p*≤.00), and 300°($\chi^2_{(2n=61)}$ =6.85, *p*=.03) rotations.

Compared to Young, Older 1 had significantly slower response times to dorsal images rotated to 120° (Young mean rank=16.65, Older 2 mean rank=24.35, *U*=123.00, *p*=.03). Compared with Young, Older 2 had significantly slower response times to dorsal images rotated to 0°(Young, mean rank=16.65, Older 2, mean rank=25.14, *U*=123.00, *p*=.02), 60°(Young, mean rank=15.00, Older 2, mean rank=26.71, *U*=90.00, *p*≤.00), 120°(Young, mean rank=15.00, Older 2, mean rank=26.71, *U*=90.00, *p*≤.00), and 300°(Young mean rank=16.20, Older 2, mean rank=25.57, *U*=114.00,*p*=01). There were no significant differences between Older 1 and Older 2 (0°, *U*=164.00, *p*=.23; 60°, *U*=143.00, *p*=.08; 120°, *U*=157.00, *p*=.16; 300°, *U*=146.00, *p*=.09).

There were significant within-group differences in response times to dorsal rotations (Young, χ^2(5) =71.48, *p*≤.00; Older 1, χ^2(5) =66.18, *p*≤.00; Older 2, χ^2(5) = 59.75, *p*≤.00). Table 5.8 shows the *z* and *p* values for each pairwise comparison.

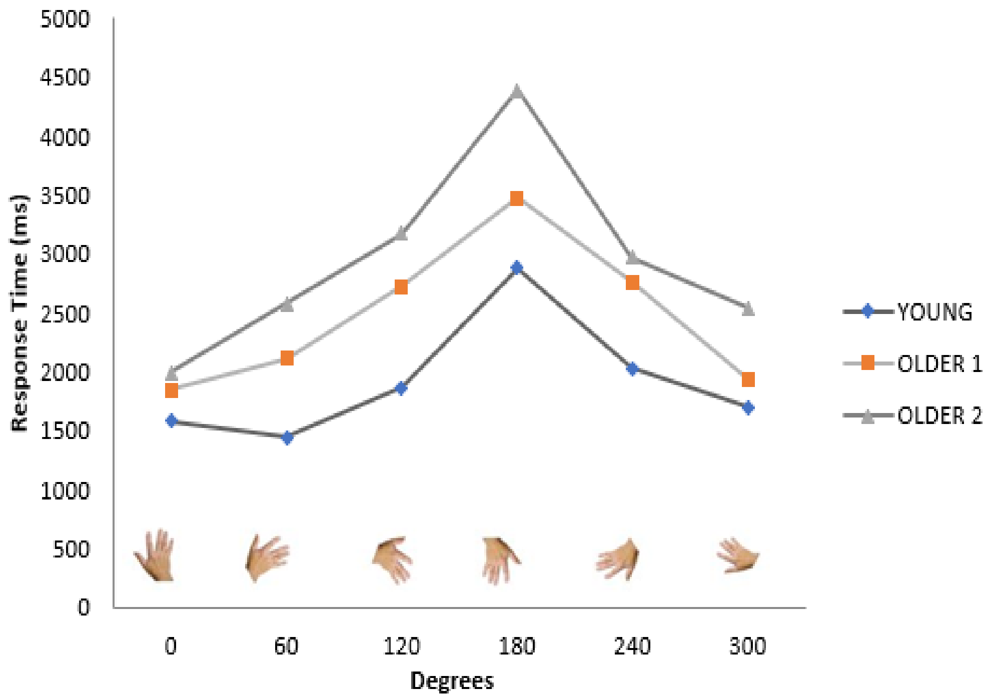
Table 5.7*.*

Group Median Response Times (ms) (Interquartile Ranges) to each Angle (degrees) of Dorsal Rotation

Group	0°	60°	120°	180°	240°	300°
Young	1587(849)	1449 (915)	1863 (1207)	2880 (1790)	2028 (1745)	1699 (1121)
Older 1	1844 (686)	2110 (965)	2723 (1507)	3474 (2119)	2759 (1745)	1941 (1135)
Older 2	1992 (1304)	2577 (1781)	3173 (2299)	4392 (3452)	2970 (2734)	2541 (1139)

Figure 5.2.

Comparison of Group Response Times (ms) to each Angle (degrees) of Dorsal Rotation



Note. Median response times (ms) plotted as a function of dorsal image rotation (degrees) for Young, Older 1 and Older 2. In all groups, response times increase with angle of rotation to 180°.

Table 5.8.

Results of Within Group Pairwise Comparisons of Response Times (ms) to each angle of Dorsal Rotation (degrees).

		Dorsal Image Rotation.														
Group	Wilcoxen sign- rank	0/ 60	0/ 120	0/ 180	0/ 240	0/ 300	60/ 120	60/ 180	60/ 240	60/ 300	120/ 180	120/ 240	120/ 300	180/ 240	180/ 300	240/ 300
Young	*z*	-.74	-3.43	-3.92	-3.88	-1.64	-3.73	-3.92	-3.92	-1.12	-3.69	-2.65	-2.72	-3.32	-3.92	-3.62
	p	.45	.00*	.00*	.00*	.10	.00*	.00*	.00*	.26	.00*	.00*	.00*	.00*	.00*	.00*
Older 1	*z*	-1.79	-3.84	-3.92	-3.84	-1.71	-3.58	-3.92	-3.62	-.44	-3.54	-1.74	-3.28	-2.73	-3.88	-3.73
	p	.07	.00*	.00*	.00*	.08	.00*	.00*	.00*	.65	.00*	.07	.00*	.00*	.00*	.00*
Older 2	*z*	-2.86	-3.88	3.98	-3.87	-2.31	-2.97	-3.98	-3.31	-.91	-3.45	-.60	-3.11	-3.70	-3.28	-2.79
	p	.00*	.00*	.00*	.00*	.02*	.00*	.00*	.00*	.32	.00*	.54	.00*	.00*	.00*	.00*

*Statistically significant difference.

5.3.6 Effects of Radial Image Rotation on Response Times

Table 5.9 and figure 5.3 show the group response times to radial rotations. There were significant between-group differences in response times to 0° ($\chi^2_{(2n=61)}$=8.44, *p*=.01), 60°($\chi^2_{(2n=61)}$=8.75, *p*=.01), and 120°($\chi^2_{(2n=61)}$= 7.09, *p*=.02) rotations.

Compared with Young, Older 2 had significantly slower response times to radial images rotated to 0° (Young, mean rank=15.90, Older2, mean rank=25.86, *U*=108, *p*≤.00), 60° (Young, mean rank=15.45, Older 2, mean rank=26.29, *U*=99.00, *p*≤.00), and 120° (Young, mean rank=16.05, Older 2, mean rank=25.71, *U*=111.00, *p*=.01).

There were no significant differences between Young and Older 1 (0°, *U*=147.00, *p*=.15; 60° *U*=140.00, *p*=.10; 120°, *U*=135.00, *p*=.08). There were no significant differences between Older 1 and Older 2 (0°, *U*=138.00, *p*=.06; 60°, *U*=156.00, *p*=.15; 120°, *U*=176.00, *p*=.37).

There were significant within-group differences in response times to radial rotations (Young, $\chi^2(5)$=46.60, *p*≤.00, Older1, $\chi^2(5)$=46.25, *p*≤.00, Older 2, $\chi^2(5)$=28.40, *p*≤.00). Table 5.10 shows the *z* and *p* values for each pairwise comparison.

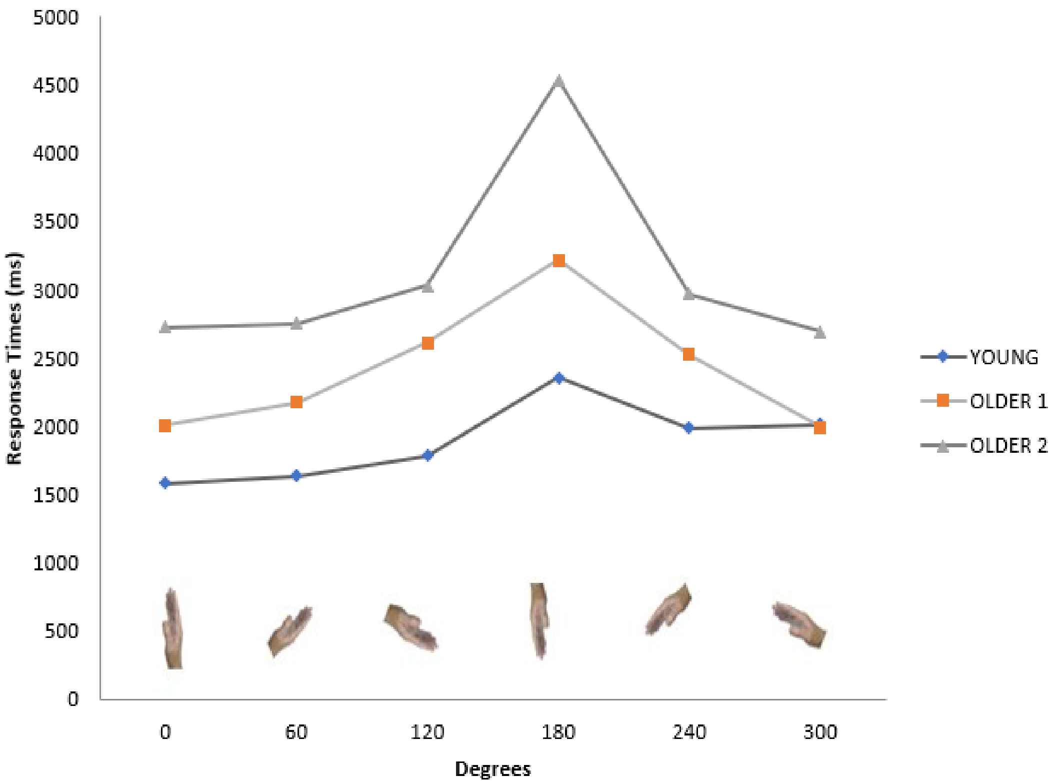
Table 5.9.

Group Median Response Times (ms) (Interquartile Ranges) to each Angle (degrees) of Radial Rotation

Group	0°	60°	120°	180°	240°	300°
Young	1582 (960)	1638 (1046)	1787 (1518)	2356 (1087)	1989 (1969)	2013 (1187)
Older 1	2005 (941)	2176 (1401)	2615 (1668)	3217 (3281)	2523 (1878)	1991 (1511)
Older 2	2727 (1619)	2753 (1493)	3028 (2231)	4536 (2909)	2971 (2248)	2691 (1511)

Figure 5.3.

Comparison of Group Response Times (ms) to each Angle (degrees) of Radial Rotation



Note. Median response times (ms) plotted as a function of radial image rotation (degrees) for Young, Older 1 and Older 2. Response times increase with angle of rotation to 180°.

Table 5.10.

Results of Within Group Pairwise Comparisons of Response Times (ms) to each Angle of Radial Rotation (degrees).

		Radial Image Rotation														
Group	Wilcoxen sign- rank	0/ 60	0/ 120	0/ 180	0/ 240	0/ 300	60/ 120	60/ 180	60/ 240	60/ 300	120/ 180	120/ 240	120/ 300	180/ 240	180/ 300	240/ 300
Young	*z*	-.97	-2.42	-3.92	-3.54	-1.15	-2.50	-3.88	-3.54	-1.38	-2.80	-2.72	-1.60	-1.97	-3.54	-2.72
	p	.33	.01*	.00*	.00*	.24	.01*	.00*	.00*	.16	.00*	.02*	.10	.04*	.00*	.00*
Older 1	*z*	-1.60	-3.21	-3.84	-3.54	-1.49	-3.09	-3.58	-2.98	-.18	-2.72	-.37	-3.02	-2.65	-3.32	-3.50
	p	.10	.00*	.00*	.00*	.13	.00*	.00*	.00*	.85	.00*	.70	.00*	.00*	.00*	.00*
Older 2	*z*	-1.19	-2.58	-3.73	-2.38	-.08	-2.34	-3.52	-2.48	-.53	-2.83	-.08	-2.31	-2.72	-3.25	-1.89
	p	.23	.01*	.00*	.01*	.93	.01*	.00*	.01*	.59	.00*	.93	.02*	.00*	.00*	.06

* statistically significant difference.

5.3.7 Effects of Palmar Image Rotation on Response Times

Table 5.11 and figure 5.4 show the group response times to palmar rotations. There were significant between-group differences in response times to 180° rotations ($\chi^2_{(2\ n=61)}$ =7.47, *p*=.02). Compared with Young, Older 1 had significantly slower response times to palmar images rotated to 180° (Young, mean rank=16.00, Older 1, mean rank=25.00, *U*=110, *p*=.01). Compared with Young, Older 2 had significantly slower response times to palmar images rotated to 180° (Young, mean rank =16.60, Older 2, mean rank =25.19, *U* =122, *p*=.02). There were no significant differences between Older 1 and Older 2 (*U*=207, *p*=.93).

There were significant within-group differences in response times to palmar rotations (Young, $\chi^2(5)$=18.85, *p*≤.00; Older 1, $\chi^2(5)$=42.75, *p*≤.00, Older 2, $\chi^2(5)$=35.72, *p*≤.00). Table 5.12 shows the *z* and *p* values for each pairwise comparison.

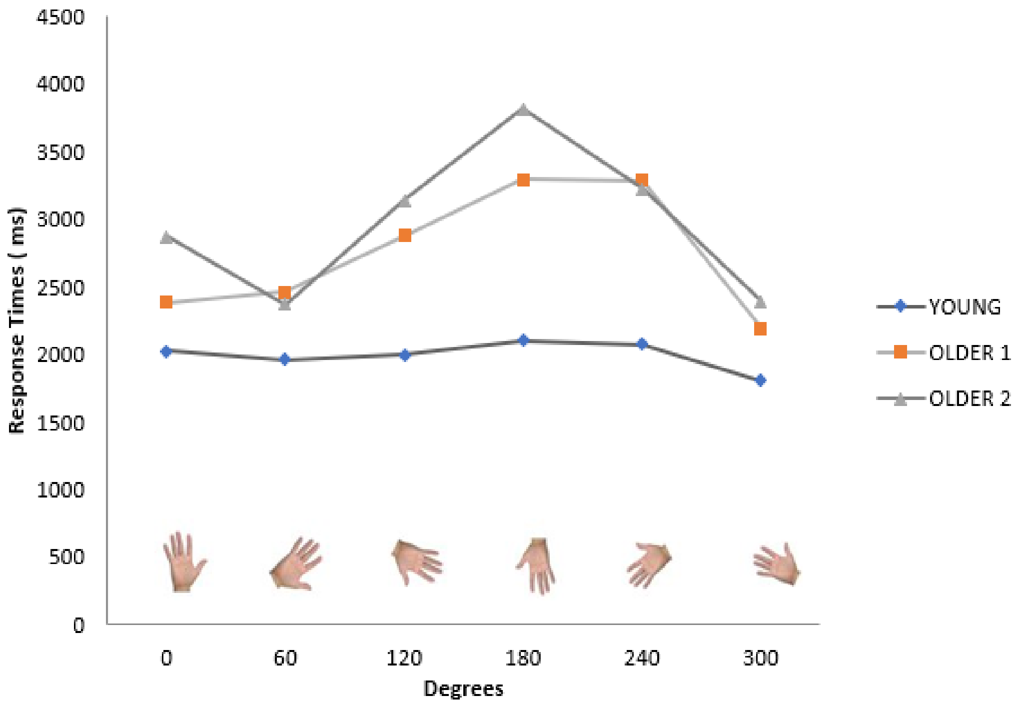
Table 5.11.

Group Median Response Times (ms) (Interquartile Ranges) to each Angle (degrees) of Palmar Rotation

Group	0°	60°	120°	180°	240°	300°
Young	2025 (1157)	1963 (986)	1995 (1697)	2099 (1730)	2073 (2070)	1806 (1493)
Older 1	2388 (741)	2460 (1200)	2881 (943)	3292 (2501)	3286 (1438)	2194 (1322)
Older 2	2873 (1251)	2371 (1357)	3138 (2314)	3821 (2287)	3225 (1743)	2389 (1234)

Figure 5.4.

Comparison of Group Response Times (ms) to each Angle (degrees) of Palmar rotation.



Note. Median response times (ms) plotted as a function of palmar image rotation for Young, Older 1, and Older 2. Response times for Older 1 and 2 increase in line with image rotation to 180°.

Table 5.12.

Results of Within Group Pairwise Comparisons of Response Times (ms) to each Angle of Palmar Rotation (degrees).

		Palmar image Rotation														
Group	Wilcoxen sign- rank	0/ 60	0/ 120	0/ 180	0/ 240	0/ 300	60/ 120	60/ 180	60/ 240	60/ 300	120/ 180	120/ 240	120/ 300	180/ 240	180/ 300	240/ 300
Young	*z*	-2.09	-1.12	-1.71	-1.79	-.07	-2.46	-2.83	-2.68	-1.86	-1.30	-.78	-2.18	-.70	-2.35	-2.09
	p	.03*	.26	.08	.07	.94	.01*	.00*	.00*	.06	.19	.43	.03*	.47	.01*	.03*
Older 1	*z*	-.11	-3.23	-3.54	-3.21	-.84	-3.62	-3.21	-3.13	-.72	-2.27	-.56	-2.49	-2.12	-3.09	-2.63
	p	.91	.00*	.00*	.00*	.37	.00*	.00*	.00*	.46	.02*	.57	.01*	.03*	.00*	.00*
Older 2	*z*	-1.68	-2.20	-3.91	-2.34	-.53	-3.42	-3.45	-3.11	-.12	-2.13	-.57	-2.65	-2.52	-3.45	-2.79
	p	.09	.02*	.00*	.01*	.59	.00*	.00*	.00*	.90	.03*	.56	.00*	.01*	.00*	.00*

*Statistically significant difference.

5.3.8 Effects of Ulnar Image Rotation on Response Times

Table 5.13 and figure 5.5 show the group response times to ulnar rotations. There were significant differences in response times to 0°($\chi^2_{(2\ n=61)}$ = 7.98, p=.01) and 60° rotations ($\chi^2_{(2\ n=61)}$ =7.74, p=.02). Compared to Young, Older 1 showed significantly slower response times to ulnar images rotated to 0°(Young, mean rank=15.75, Older 1, mean rank=25.25, U=105.00, $p \leq .00$) and 60°(Young, mean rank=15.85, Older 1, mean rank=24.57, U=107.00, p=01). Compared to Young, Older 2 showed significantly slower response times to 0°, (Young, mean rank=16.60, Older 2, mean rank=25.19, U=122.00, p=.02) and 60° rotations (Young, mean rank=16.30, Older 2, mean rank=25.19, U=116.00, p=.01). There were no significant differences in response times between Older 1 and Older 2 at 0° (U=200.00, p=.79) or 60° (U=190.00, p=.79).

There were significant within-group differences in response times to ulnar rotations (Young, $\chi^2(5)$=16.68, $p \leq .00$; Older 1, $\chi^2(5)$ =30.60, $p \leq .00$; Older 2, $\chi^2(5)$ =23.20, $p \leq .00$). Table 5.14 shows the z and p values for each pairwise comparison.

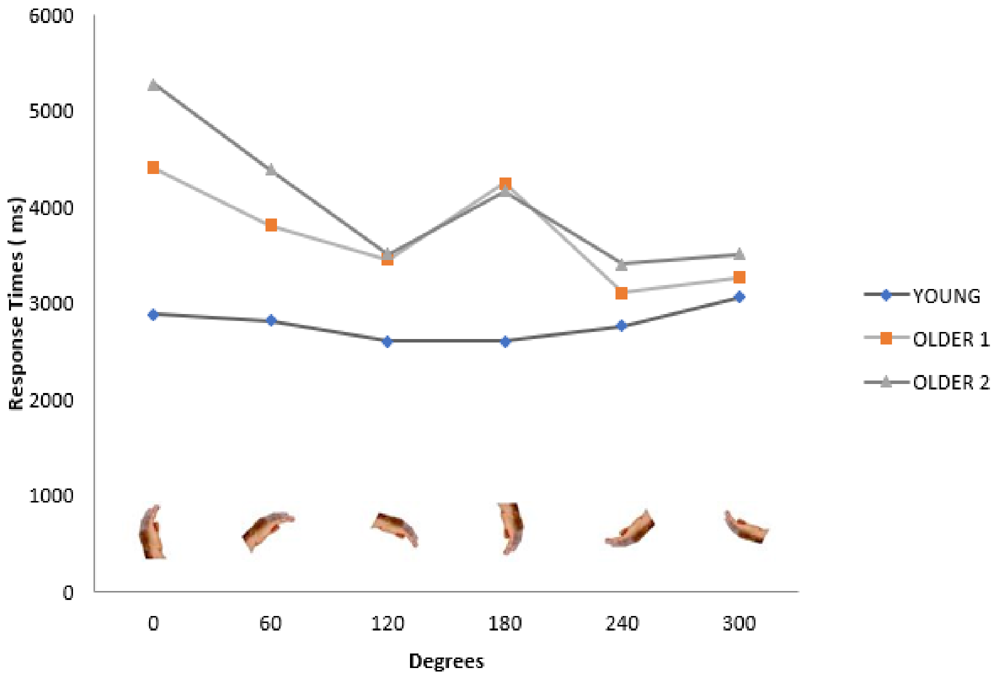
Table 5.13.

Group Median Response Times (ms) (Interquartile Ranges) to each Angle (degrees) of Ulnar Rotation

Group	0°	60°	120°	180°	240°	300°
Young	2884 (3224)	2822 (1801)	2609 (2262)	2604 (2148)	2767 (1760)	3066 (1525)
Older 1	4414 (3818)	3810 (2551)	3456 (2334)	4252 (2763)	3110 (1651)	3273 (2663)
Older 2	5279 (5102)	4391 (2913)	3518 (2704)	4169 (2923)	3408 (3276)	3511 (3214)

Figure 5.5.

Comparison of Group Response Times (ms) to each Angle (degrees) of Ulnar Rotation



Note. Median response times (ms) plotted as a function of ulnar image rotation (degrees) for Young, Older 1 and Older 2. Response times decrease in line with image rotation to 120° for Older1 and Older 2 and to 180° for young.

Table 5.14.

Results of Within Group Pairwise Comparisons of Response Times (ms) to each Angle of Ulnar Rotation (degrees)

		Ulnar Image rotation														
Group	Wilcoxen sign- Rank score	0/ 60	0/ 120	0/ 180	0/ 240	0/ 300	60/ 120	60/ 180	60/ 240	60/ 300	120/ 180	120/ 240	120/ 300	180/ 240	180/ 300	240/ 300
Young	*z*	-2.68	-2.91	-2.94	-2.57	-2.27	-1.90	-.82	-.85	-1.49	-1.38	-.52	-1.30	-.70	-.44	-.37
	p	.00*	.00*	.00*	.00*	.02*	.06	.41	.39	.88	.16	.60	.16	.47	.65	.70
Older 1	*z*	-2.45	-3.73	-3.21	-3.57	-3.34	-2.97	-.12	-2.45	-1.72	-2.57	.00	-.56	-1.94	-1.56	-.48
	p	.00*	.00*	.00*	.00*	.00*	.00*	.90	.01*	.80	.01*	1.0	.57	.05*	.11	.62
Older 2	*z*	-1.58	-3.21	-2.48	-3.38	-2.97	-2.45	-.81	-1.23	-1.82	-1.19	-.50	-.36	-1.01	-.64	-.46
	p	.11	.00*	.01*	.00*	.00*	.00*	.41	.21	.68	.23	.61	.71	.31	.52	.63

*Statistically significant difference.

5.3.9. Response Times to Medial and Laterally Rotated Images

There was a significant difference in response times to medially rotated images ($\chi^2_{(2\ n=61)}$ =6.53, p=.03), but not to laterally rotated ones ($\chi^2_{(2\ n=61)}$ =4.61, p=.09). Compared to Young, Older 2 had significantly slower response times to medially rotated images (Young, mean rank=16.40, Older 2 mean rank=25.38, U=118, p=.01). There were no significant differences in response times between Young, and Older 1 (U=132.00, p=.06) or between Older 1 and Older 2 (U=180.00, p=.43).There were no significant within-group differences between medially or laterally rotated images, (Young, $\chi^2(1)$ =.80, p=.37; Older 1,$\chi^2(1)$ =.00 p= 1.00; Older 2, $\chi^2(1)$ =1.19, 0=.27).

When separate views were examined, there was a significant difference in response times to medially rotated dorsal Images ($\chi^2_{(2\ n=61)}$=6.81, p=.03); laterally rotated dorsal images ($\chi^2_{(2\ n=61)}$=6.48 p=.03), and laterally rotated palmar images ($\chi^2_{(2\ n=61)}$=6.71, p=.03). Compared to Young, Older 2 had significantly slower response times to medially rotated dorsal images (Young, mean rank=16.35, Older 2 mean rank=25.43, U=117, p=.01); laterally rotated dorsal images (Young, mean rank=16.30, Older 2, mean rank=25.48, U=115.00, p=.01), and laterally rotated palmar images (Young, mean rank=16.25, Older 2, mean rank=25.52, U=115, p=.01).

There were no significant differences between Young and Older1 in response times to medially rotated dorsal images, (U=130.00, p=.06); laterally rotated dorsal images (U=155, p=.32), or laterally rotated palmar images (U =131.00, p=.06). There were no significant differences between Older 1 and Older 2 in response times to medially rotated dorsal images (U=117, p=.39); laterally rotated dorsal images (U=140, p=.11), or laterally rotated palmar images (U=140, p=.11).

There were significant within-group differences in response times to medially and laterally rotated images (Young, $\chi^2(8)$ =101.34, $p \leq .00$; Older 1, $\chi^2(8)$ =91.42, $p \leq .00$; Older 2, $\chi^2(8)$ =78.89, $p \leq .00$). The Young group had significantly slower response times to laterally rotated palmar images (Lateral rotations=2252 (1269) ms; medial rotations=1787 (1269) ms, z=-3.13, $p \leq .00$) but there were no significant differences in response times to medially and laterally rotated dorsal images (z=-.79, p=.07); medially and laterally rotated radial images, (z=-1.60, p=.10) or medially and laterally rotated ulnar images (z=-1.41, p=.15).

Older 1 had significantly slower response times to laterally rotated palmar images (lateral rotations = 2980 (1830) ms; medial rotations =1906 (932) ms, z=-3.82.$p \leq .00$), and to medially rotated ulnar images (medial rotations=3908 (1978) ms, lateral rotations =2726 (1978) ms, z=-3.46, $p \leq .00$). There were no significant differences in response times to medially and laterally rotated dorsal (z =-1.56, *p*=.11) or radial images (z=-.92, *p*=.35).

Older 2 had significantly slower response times to laterally rotated palmar images (lateral rotations=3090 (1212) ms, medial rotations =2257 (1841) ms, *z*= 3.73, *p*≤.00). There were no significant differences in response times to medially and laterally rotated dorsal images (*z*=-1.33, *p*=.18), radial images (z=-.56, *p*=.57) or ulnar images (z=-1.37, *p*=.17).

5.4 Discussion

Contrary to the hypothesis there were no differences in overall response times between the young and older groups, although Older 2 had slower response times to dorsal images. There were no differences in response times between the two older groups. All groups had significantly slower response times to images rotated to 180° and to laterally rotated palmer images, suggesting that participants used implicit motor imagery to judge laterality (Parsons, 1994). However, Older 2 were slower than Young in response to medially and laterally rotated dorsal images, and laterally rotated palmar images. Responses to ulnar images were the slowest in all groups.

As hypothesized, both older groups made significantly more errors than the young group. Older 1 was less accurate in response to palmar and ulnar images, whereas Older 2 made a similar number of errors across all views. There was a moderate positive correlation between age and the number of errors. There was only difference between the two older groups was that Older 2 made more errors in response to dorsal images.

Response times related to angles of dorsal and radial rotations were similar in all groups and increased in line with image rotation to 180°. Both Older groups showed this pattern in response to palmar rotations suggesting similar strategies were used. There was no significant increase in response times to 180° palmar rotations in the Young group, suggesting that their strategy differed from that used for dorsal and radial views. All groups were slowest in response to 0° ulnar rotations, with response times decreasing in line with image rotation to 120° in both older groups, and 180° in the young group. This indicates that all groups found ulnar images at 0° the most difficult to judge and used similar strategies.

The findings of this experiment extend those of Zaporreli et al. (2016) that in early old age, impairments in implicit motor imagery are compensated with increases in visuospatial imagery. Although in this experiment, Older 1 made more errors than Young, this can be explained by the more challenging HLJ test. Errors were only higher in response to palmar and ulnar images, which are considered to rely more on implicit motor imagery (Ter Horst, Van Lier and Steenbergan, 2010; Blasing et al., 2013; Zapporelli et al., 2014). In contrast, Older 2 demonstrated impairments in both motor and visuospatial imagery with increased errors across all views, and slower response times to dorsal images.

The findings for Older 2 are comparable to those of Saimpont et al. (2009) and De Simone et al. (2013), who had similarly aged participants. Although these studies only included palmar and dorsal images, the older groups were significantly less accurate in both, suggesting that implicit motor and visuospatial imagery were impaired. De Simone et al. (2013), also found increased response times to laterally rotated dorsal and palmar images in their older group, suggesting that similar strategies were used.

Studies of the effects of age on other types of motor imagery, also indicate that both visual and motor abilities decline by the seventh decade. It has been suggested that these changes reflect age-related reductions in physical capacity (Saimpont et al., 2013). Reductions in egocentric motor imagery ability and reduced capacity for visuospatial imagery have been associated with ageing, leading to a compensatory shift towards allocentric imagery (Mulder et al., 2007; Malouin, Richards and Durand, 2010). Neurophysiological evidence to support these findings is limited. Saimpont et al. (2013), suggested that compensatory increases in cortical activity helped maintain motor imagery function in older adults. Whereas, during visual imagery, age-related reductions in functional connectivity between the visual cortex and prefrontal areas have been found (Kalkstein et al.,2011).

As no measures of cognitive ability were undertaken, it is unknown if general cognitive decline explains the older groups' performance. Bourellier et al. (2015) found mild cognitive impairment resulted in increased HLJ response times in twelve participants. Furthermore, a recent meta-analysis of spatial function, found a large age-related effect, thought to reflect general cognitive declines (Techentin, Voyer and Voyer, 2014). However, as all the older participants in this experiment were community-dwelling and independent, normal cognitive ability was assumed.

5.5 Conclusions

The results of experiment one showed that age affected HLJ performance. These results expand those of previous HLJ studies by identifying a decline in visuospatial imagery in advanced old age. Declines in implicit motor in early old age were compensated for by a greater reliance on visuospatial imagery, which also became impaired by more advanced old age.

The findings of this experiment suggest that using HLJ to induce implicit motor imagery may not be as effective with older people. Consideration should be given to the number of views and orientations included in tests to promote the best outcomes. Those in more advanced old age may benefit from HLJ tests with fewer views and angles of rotation.

6.0 Experiment 2: The Effects of Stroke on Hand Laterality Judgement

Experiment two compared the HLJ performance of a group of stroke participants aged ≥ 60 years with age-matched controls. The aim was to determine if results found in previous studies could be explained by normal ageing rather than stroke. A secondary aim was to examine whether HLJ performance was related to the impairment of the stroke-affected upper limb or the site of the stroke. The experiment addressed the following questions:

1. What are the differences in HLJ response times and accuracy between a group of stroke survivors and healthy controls aged ≥ 60?
2. What are the relationships between HLJ performance and the ability to move the stroke-affected upper limb?
3. What are the relationships between HLJ performance and the site of stroke?

It was hypothesized that the stroke group would have slower response times and make more errors than the control group. Within the stroke group, it was hypothesized that those with moderate upper limb impairment would have slower response times and make more errors than those with mild upper limb impairment and that differences would be found between those with LHS and RHS.

6.1 Method

6.1.1 Participants

Stroke participants were recruited and compared with healthy age-matched controls taken from experiment one. Table 6.1 shows the inclusion and exclusion criteria for the stroke group. Recruitment procedures were carried out as described in section 4.2. The inclusion and exclusion criteria for the control group were as described in section 5.1.

6.1.2 Measures

The HLJ test was as described in sections 3.6 and 3.9. The Edinburgh Handedness Score Short Form (Veale 2013) was used to establish hand dominance. The secondary measures for stroke participants were the Motricity Index (Demeurisse, Demol and Robaye, 1980), and active range of movement (AROM) of shoulder internal and external rotation; elbow flexion, extension, pronation and supination; wrist flexion, extension, radial and ulnar deviation. These movements were chosen as ones required to physically move the hand into the positions depicted by the HLJ test.

Screening assessments were undertaken to determine the effects of stroke and eligibility to take part. The Frenchay Aphasia Screening Test (Enderby et al 2012) was used to ensure participants had sufficient understanding to give informed consent. For this experiment, the writing test was excluded, and participants were rejected if they scored less than fifteen out of twenty -five. The line bisection test and double letter cancellation tests, from the Behavioural Inattention Test (Wilson, Cockburn, & Halligan, 1987), were used to identify those with unilateral spatial neglect.

To identify those with hemianopia, a screening test of the visual fields was undertaken (Bickley and Szilagyi, 2017). Subjective measures of pain, sensory deficits and upper limb recovery were made using a visual analogue scale scored from 1 to 10 where 10 was the most severe impairment. Details the measurements and procedures can be found in appendix two.

Table 6.1.

Inclusion and Exclusion Criteria for Stroke Participants

Inclusion	**Exclusion**
Aged $\geq$60	Aged <60
Right-handed	Previous history of stroke or other neurological conditions
First-ever Stroke	< 3 months post-stroke
$\geq$3 months post-stroke	No upper limb impairment (compared to unaffected limb)
Able to understand instructions.	Bilateral upper limb impairment.
Upper limb impairment (compared to unaffected limb)	Severe hand/ arm pain.
Able to understand the purpose of the research.	Severe upper limb spasticity
Able to give informed consent.	Non-stroke related upper limb/hand impairment affecting function.
	Unable to see the computer screen.
	Unable to operate keypad with unaffected hand.
	Frenchay Aphasia screening Score <15.

6.1.3 Reliability and Validity

The Motricity Index (Demeurisse, Demol and Robaye 1980) is a measure of motor impairment. The upper limb subscale is a brief, weighted ordinal scale of overall motor strength after stroke. (Demeurisse, Demol and Robaye 1980). The measure is weighted to the recovery of muscle strength at a specific joint over time. The Motricity Index is a reliable and valid scale and has concurrent validity with measures of grip strength and several stroke-specific upper limb measures (Colin and Wade 1990, Hsieh et al., 1998; Wade 1989; Croarkin, Danoff and Barnes 2004; Bertrand et al., 2015). Colin and Wade (1990) produced detailed guidelines for performing the test which can be found in appendix two.

The Biometrics Ltd E link ™ N 400 digital goniometer (Biometrics Ltd 2018) is an electronic goniometer used in a similar way to the traditional universal goniometer. Studies using the analogue universal goniometer have consistently found high levels of intra and interrater reliability, with favourable comparisons to other measures of range of movement (Hayes et al., 2001; Carey et al., 2010; Kolber et al., 2012; Cools et al., 2014; Tajali et al.,2016). Hayes et al. (2001) found good levels of intra-rater (r=.64) and inter-rater reliability (r=.69) with measurement of impaired upper limb movements.

To increase reliability, all range of movement measures were taken by one person with the mean of three measures used for analysis.

6.1.4 Trial of Measures with Stroke Volunteers

The HLJ test and range of movement measurement were trialled separately by two female stroke volunteers (> 2 years post-stroke) who did not subsequently take part in the experiment. Both had a moderate left-sided weakness, with difficulty performing left upper limb movements. Participant A. completed the HLJ test and participant B. the range of movement measures.

The HLJ test was completed in forty-five minutes. There were no complaints of fatigue, and participant A. reported enjoying the test. Table 6.2 shows the mean response times and errors for right and left-sided images. The accuracy rate was 83% and the mean response time was 2687ms, which were within the range of previous stroke studies.

Table 6.2.

Participant A. Mean Response Times (ms) and Errors (n) to Right and Left-Sided Images

Views	Right		Left	
	Errors	Time	Errors	Time
All	28	2656	15	2718
Dorsal	3	2043	0	2023
Palmar	11	2662	7	3535
Radial	6	2343	1	2258
Ulnar	8	3575	7	3057

Note: The table shows responses to all images and to separate views.

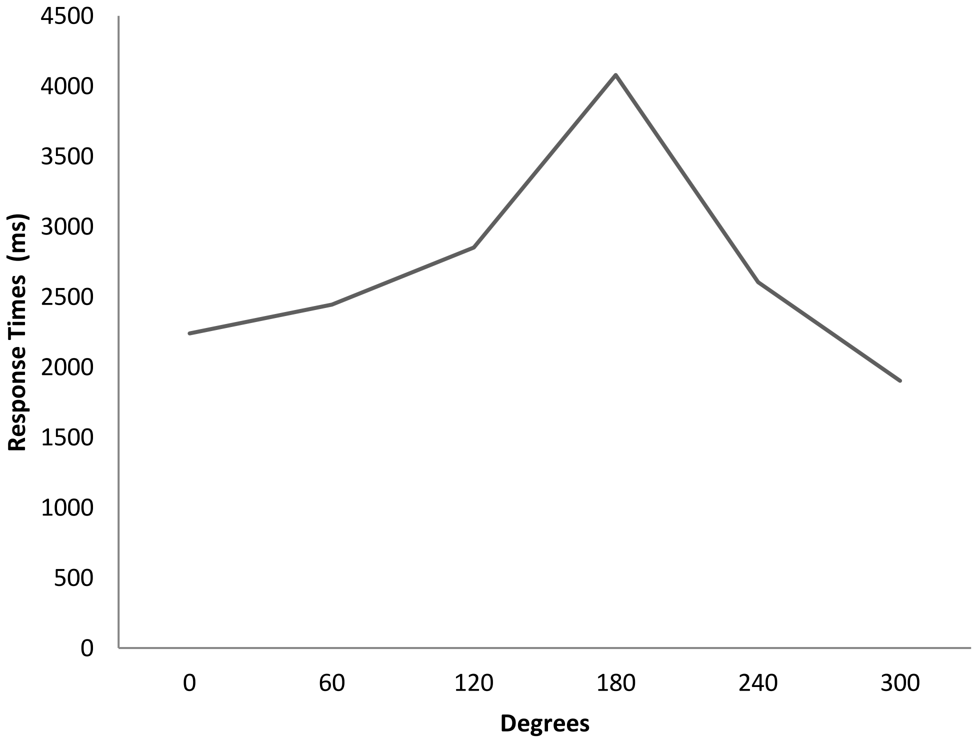
More errors were made in response to right-sided than to left-sided images. The highest number of errors were made in response to palmar views. Response times were slowest for left-sided palmar and ulnar images.

Figure 6.1 shows the mean response times to each angle of image rotation. It was concluded that Participant A's responses were consistent with hand mental rotation. No changes were made to the HLJ test following this trial.

Participant B. underwent passive and active range of movement measurements as detailed in appendix two. Each measure was repeated three times. All measures were taken without discomfort, but the procedure took forty minutes to complete. Following the trial, the method of wrist measurement was adjusted to be taken from the lateral as opposed to the dorsal side. It was concluded that passive range of motion measurements were unnecessary, and the duration of measurement was reduced to twenty minutes.

Figure 6.1.

Participant A. Response Times (ms) to each Angle (degrees) of Image Rotation



Note: Mean Response times (ms) plotted as a function of image orientation (degrees) for participant A. Response times increased in line with image rotation to 180°.

6.2 Procedure

All sessions took place at university premises and lasted no more than two hours, including time taken for breaks. The participant information sheet was discussed, and the consent form completed. Demographic details including information about the stroke were taken, followed by the screening assessments. The HLJ test was then completed according to the procedure detailed in sections 3.6 and 3.9. Following this, the range of movement measures and Motricity Index scores were completed. All measures were carried out in the same order for all participants.

6.3 Data Analysis

Data were analysed as described in section 3.7. For the stroke group, additional independent variables were the range of movement (degrees) and Motricity Index scores. Responses of those with mild and moderate upper limb impairment and those with RHS and LHS were compared. Those with Motricity Index scores ≥85 for the affected upper limb were categorized as mild impairment and those with <85 as moderate impairment. Cohen's d was calculated for pairwise comparisons within the stroke group.

6.4 Results

6.4.1 Participants

Thirteen participants with stroke met the inclusion criteria and were recruited. Following data collection, medical records revealed that one participant had a previous stroke, so this participant's data were removed from the analysis. A second participant had an accuracy rate of 50% for the HLJ test and was also removed from further analysis. The remaining eleven stroke participants were compared with eleven age-matched participants taken from experiment one.

Table 6.3 shows the participant characteristics. All except one of the stroke participants were male and were in the chronic stages of stroke recovery (≥ 3 months post-stroke). There were insufficient numbers of age-matched, healthy male participants, so three female participants were included. There were no significant differences in age between the stroke and control groups, (U=54.00, p=.48).

Table 6.3.

Participant Characteristics for the Stroke and Control Group

Group	n	Mean Age (yrs.)	Age Range (yrs.)	Gender m/f
Control	11	70 (6)	62-83	7/4
Stroke	11	69 (6)	60-84	10/1

Table 6.4 shows additional characteristics for each stroke participant. Six had LHS and five RHS. Seven had either partial or total anterior circulation ischaemic infarcts, two had ischaemic posterior circulation infarcts and two had haemorrhagic strokes. The specific brain areas affected by the stroke could only be identified for three participants.

Table 6.5 shows the results of the screening tests undertaken by the stroke group. Four participants had positive signs of hemianopia, affecting the left visual field in three. One participant had reduced scores on the line bisection and letter cancellation task, indicative of left inattention. Two participants had expressive language deficits as indicated by the Frenchay Aphasia Screening Test but were able to understand sufficiently to provide consent and complete the experiment. Upper limb scores on the Motricity Index ranged from 26–100, indicating that all participants had some movement in their affected upper limb. Table 6.6 shows the stroke groups measures of AROM of the affected and the unaffected upper limbs. All participants had some reduction in AROM of the affected upper limb.

Table 6.4.

Stroke Group: Individual Characteristics

Participant	Age	Sex (M/F)	Time since stroke (months)	Side of stroke (hemisphere)	Type of Stroke	Location
1	65	M	6	L	Isch/ MCA / PACS	No data
2	65	M	16	R	Isch/MCA/ PACs	Frontal / parietal /internal capsule/basal ganglia
3	68	M	26	L	Isch/POCS/PCA	Medial/posterior temporal lobe; occipital lobe; thalamus
4	84	F	79	L	Isch/PACS	No data
5	60	M	4	R	Haemorrhage	No data
6	71	M	156	L	Isch / POCS	Cerebellum / occipital lobe
7	77	M	53	R	TACS/ MCA	No data
8	72	M	14	R	Isch PACS	No data
9	71	M	19	L	Haemorrhage	No data
10	69	M	5	L	Isch PACS	No data
11	64	M	7	R	Isch PACS	No data

Key: Isch= Ischaemic; MCA = middle cerebral artery; PACS= partial anterior circulation stroke; POCS= posterior circulation stroke; PCA = posterior cerebral artery.

Table 6.5.

Stroke Group: Individual Scores for Screening Tests

Participant	Pain	Sensation	Mobility	Hemianopia	Inattention	Frenchay Index	Motricity index
1	0	8	4	N	N	22	65
2	0	10	2	left	left	24	45
3	5	5	5	right	N	15	85
4	0	10	10	N	N	25	85
5	0	10	10	N	N	25	100
6	1	10	8	N	N	23	100
7	1	0	3	N	N	25	62
8	5	5	5	N	N	24	56
9	3	2	2	left	N	17	26
10	0	7	7	N	N	25	85
11	0	8	7	N	N	25	88

Key: N = None; 0 = no problems; 10 = Worst possible problems.

Table 6.6.

Stroke Group: Range of Movement Measures (in degrees) of the Shoulders, Elbows, and Wrists

Participant	Wrist Flex		Wrist Ext		Radial Deviation		Ulnar Deviation		Pronation		Supination		Elbow Flex		Elbow Ext		Shoulder MR		Shoulder LR	
	A	U	A	U	A	U	A	U	A	U	A	U	A	U	A	U	A	U	A	U
1	52	58	47	68	27	38	38	48	82	84	44	62	108	109	6	11	57	48	36	76
2	41	57	5	43	0	26	0	33	74	93	0	50	72	137	0	14	26	61	0	54
3	63	79	47	65	30	26	44	48	75	81	33	65	101	124	-8	3	54	42	46	52
4	64	64	45	23	17	23	27	34	97	86	55	67	136	133	5	1	49	53	63	67
5	70	67	50	56	29	31	47	47	79	80	54	57	128	135	10	16	57	58	66	73
6	72	53	54	54	23	20	35	33	78	81	68	58	128	125	7	6	68	62	78	77
7	40	59	25	41	21	19	30	24	33	80	36	51	87	131	-18	16	24	58	29	42
8	46	62	52	57	21	41	25	41	83	99	53	46	97	132	-12	10	50	68	52	67
9	25	81	0	57	0	26	0	42	50	91	0	64	0	132	0	20	0	76	0	76
10	69	44	32	26	20	17	37	20	73	71	46	34	125	127	10	19	68	58	65	69
11	64	54	28	51	18	26	28	29	68	71	55	49	135	136	12	6	54	54	56	48

Key: A = Stroke Affected Upper Limb ; U = Unaffected Upper Limb. Flex= flexion; Ext = extension; MR= Medial Rotation ; LR= Lateral Rotation

6.4.2 Response times and accuracy

Table 6.7 shows the response times and errors for the stroke and control groups. There were no significant differences in response times or errors to right and left-sided images in either group, so results for right and left-sided images were combined for further analysis. Accuracy rates were 82% for the stroke group and 86% for the controls. There were no significant differences in response times (U=37.00, p=.13) or errors (U=55.50, p=.59) between the stroke and control groups.

6.4.3 Effects of Image View on Response Times and Accuracy

Table 6.8 shows the stroke and control groups' response times and errors to separate views. There were no significant differences between the stroke and control group in response times to dorsal (U= 56.00,p=.79), palmar (U=44.00.p=.3), radial (U= 55.00,p=.74) or ulnar images (U=29.00,p=.06). There were no significant differences between stroke and control groups in accuracy to dorsal (U=44.00, p=.29), radial (U=45.00, p=.33), palmar (U=55.5, p=.74) or ulna images (U=51.50, p=.55).

Table 6.7*.*

Stroke and Control Group Median Response Times (ms) and Errors (n) (interquartile ranges) to all and to Right and Left-Sided Images

Group	All Time	Left Time	Right Time	All Errors	Left Errors	Right Errors
Stroke	2718 (2162)	2825 (2059)	2689 (2162)	42.00 (70.00)	19.00 (36.00)	23.00 (33.00)
Control	3035 (1405)	2984 (1413)	3165 (1594)	33.00 (43.00)	14.00 (18.00)	19.00 (16.00)

Within-group pairwise comparisons of response times to each view showed the control group had significantly slower response times to ulnar images than to dorsal (z=-2.19, p=.02), palmar (z=-2.80, $p\leq$.00) and radial images (z=-2.65, $p\leq$.00). The stroke group had significantly slower response times to ulnar images than to radial images (z=-2.31, p=.02) but there were no significant differences in response times to other views.

Within-group pairwise comparisons of errors to each view showed the control group made significantly more errors in response to ulnar images than to dorsal (z=-2.19, p=.02), palmar (z=-2.80, $p\leq$.00) and radial images (z=-2.65, $p\leq$.00). The stroke group made significantly more errors in response to dorsal images than to palmar (z=-2.20, p=.02), and radial images (z=-2.10,p=.03) and significantly more errors in response to ulnar images, than to palmar (z=-2.19, p=.02), and radial Images (z=-1.96,p=.05).

Table 6.8.

Stroke and Control Group Median Response Times (ms) and Errors (n) (interquartile ranges)

Group	Dorsal Time	Palmar Time	Radial Time	Ulnar Time	Dorsal Errors	Palmar Errors	Radial Errors	Ulnar Errors
Stroke	3007 (1396)	2750 (2534)	2657 (1214)	2836 (1706)	15.00 (20.00)	8.00 (12.00)	10.00 (17.00)	14.00 (21.00)
Control	2738 (1733)	3051 (617)	3063 (1307)	4534 (2928)	9.00 (11.00)	5.00 (6.00)	5.00 (10.00)	14.00 (19.00)

6.4.4 Effects of Image Rotation on Response times

Table 6.9 and Figure 6.2 show the stroke and control groups' response times to each angle of image rotation. There were no significant differences between response times to any angle of rotation (0°, U=49.00, p=.47; 60°, U=47.00, p=.40; 120°, U=46.00, p=.36; 180°, U=37.00, p=.13; 240°, U=52.00, p=.60; 300°, U=50.00, p=.51).

Within-group pairwise comparisons of response times to each angle of image rotation showed the control group had significantly slower response times to 180° image rotations compared to all other angles (0°, z=-.29, p≤.00; 60°, z=-2.93, p≤.00; 120°, z=-2.75, p≤.00; 240°z=-2.84, p≤.00;300°, z=2.93, p≤.00). Response times to 300°rotations were significantly faster than to 120°rotations and significantly slower than to 240°rotations (120°, z=-1.95, p=.05; 240°, z=-1.95, p=.05).

The stroke group showed significantly faster response times to 60° image rotations than to 120°, 180° and 240°rotations (120°, z=-.29, p≤.00; 180°, z=-2.4, p=.04; 240°, z=-2.22, p=.02) and significantly slower response times 240°rotations than to 300° (z=-1.95, p=.05).

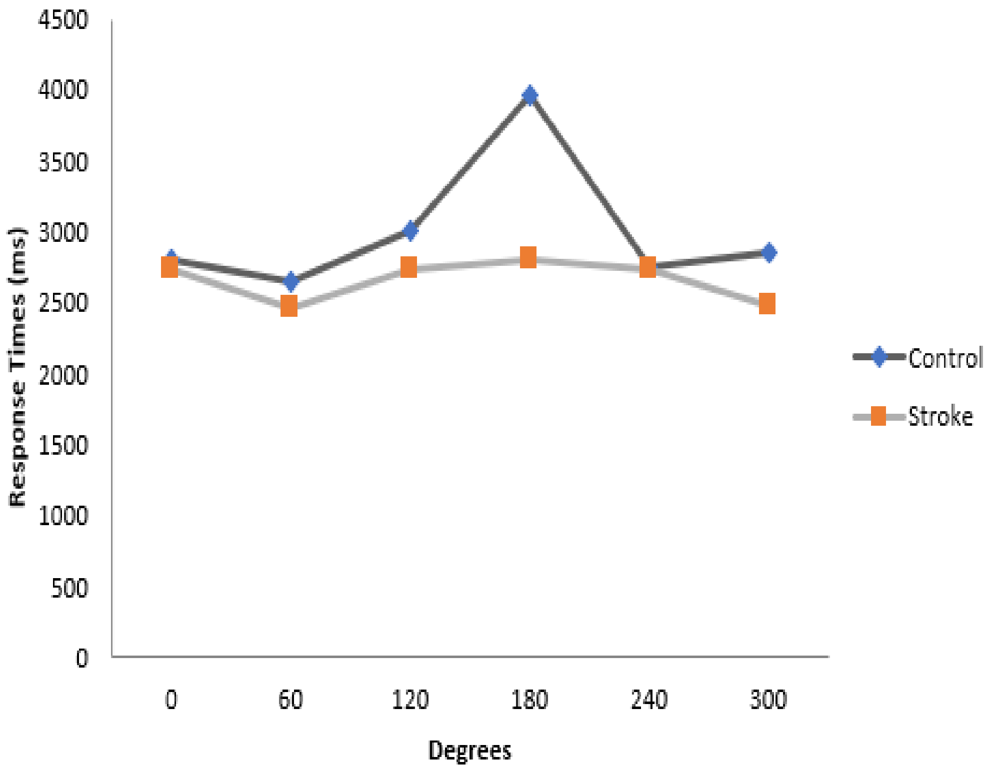
Table 6.9.

Stroke and Control Group Median Response Times (ms) (interquartile ranges) to each Angle (degrees) of Image Rotation

Group	0°	60°	120°	180°	240°	300°
Control	2797 (1758)	2652 (1463)	3008 (1287)	3970 (1981)	2750 (1928)	2860 (1486)
Stroke	2731 (2013)	2463 (1524)	2744 (1580)	2799 (3024)	2741 (1893)	2481 (1334)

Figure 6.2.

Stroke and Control Group Response Times (ms) to each angle (degrees) of Image Rotation



Note: Median response times (ms) plotted as a function of image orientation (degrees) for the stroke and control groups. Response times increased with the angle of rotation to 180° in the control group.

Table 6.10. and Figure 6.3 show the stroke and control groups' response times to each angle of dorsal rotation. There were no significant differences between response times to any angle of dorsal rotation (0°, *U*=45.00, *p*=.30; 60°, *U*=51.00, *p*=.53; 120°, *U*=53.00, *p*=.62; 180°, *U*=58.00, *p*=.87; 240° *U*=44.00, *p*=.27; 300° *U*=39.00, *p*=.15).

Within-group pairwise comparisons of response times to each angle of dorsal rotation showed the control group had significantly slower response times to 180° rotations than to 0°(*z*=-2.93, *p*≤.00); 60°(*z*=-2.93, *p*≤.00); 240°(*z*=-1.95, *p*=.05), and 300°rotations (*z*=-2.84, p≤.00). Response times to 120° rotations were significantly slower than to 0° (z=-2.93, *p*≤.00); 60° (z=-2.31, *p*=.02) and 300° (*z*=-2.57, *p*=.01). Response times to 240°dorsal rotations were significantly slower than to 0° (*z*=-2.75, *p*≤.00) and 300° (*z*=-2.66, *p*≤.00).

The stroke group had significantly slower response times to 180° dorsal rotations than to 0° (*z*=-2.13, *p*=.03), 60°(*z*=-2.40, *p*=.01) and 120° rotations (*z*=2.40, *p*=.01) and significantly slower response times to 240° rotations than to 0°(*z*=-2.13, *p*=.03), 60°(*z*=-2.40, *p*=.01), and 120° rotations (*z*=-1.95, *p*=.05).

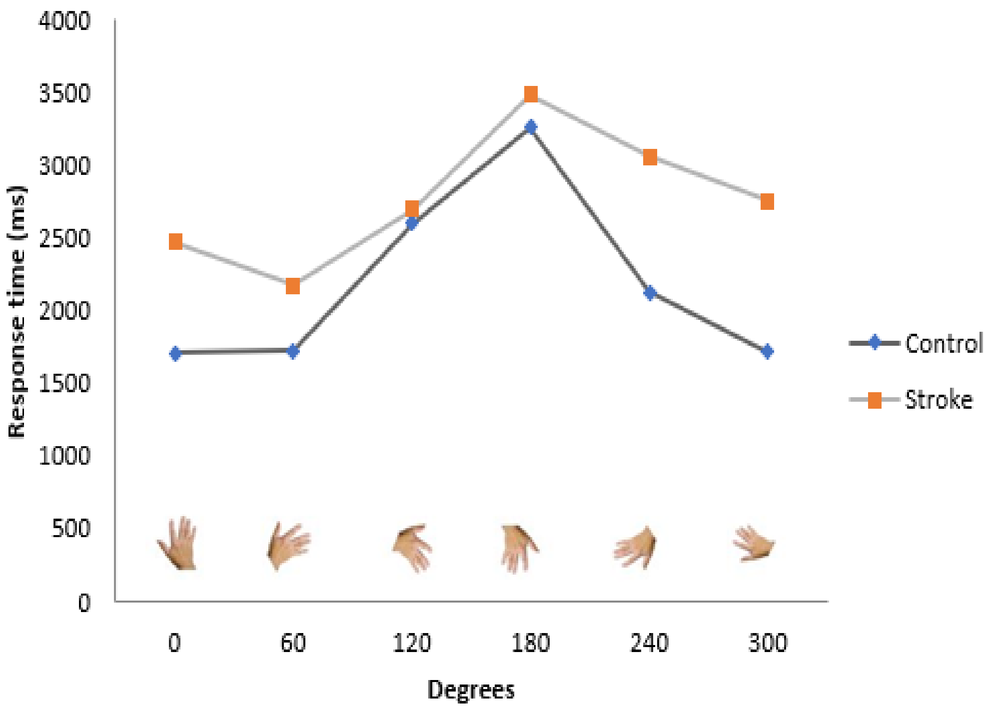
Table 6.10.

Stroke and Control Group Median Response Times (ms) (interquartile ranges) *to each Angle (degrees) of Dorsal Rotation*

Group	0°	60°	120°	180°	240°	300°
Control	1710 (964)	1722 (1267)	2605 (1215)	3264 (1621)	2125 (644)	1714 (1346)
Stroke	2473 (1689)	2178 (1439)	2702 (1131)	3485 (2755)	3058 (1586)	2758 (1212)

Figure 6.3.

Stroke and Control Group Median Response Times (ms) to each Angle (degrees) of Dorsal Rotation



Note. Median response times (ms) plotted as a function of dorsal image rotation (degrees) for the stroke and control groups. In both groups, response times increase with angle of rotation to 180°.

Table 6.11 and figure 6.4 show the stroke and control groups' response times to each angle of palmar rotation. There were no significant differences between response times to any angle of palmar rotation (0°, U=51.00, p=.53; 60°, U=54.00, p=.69; 120°, U=44.00, p=.30; 180°, U=59.00, p=.92; 240°, U=60.00, p=67; 300°, U=49.00, p=.47).

Within-group pairwise comparisons of response times to each angle of palmar rotation showed the control group had significantly slower response times to 180° rotations than to 0°(z=-2.40, p=.04), 60°(z=-2.84, p≤.00), 120°(z=-2.40, p=.01) and 300° rotations (z=-2.84, p≤.00). Response times to 120° rotations were significantly slower than to 60° (z=-2.57, p=.01) and 240° rotations (z=-2.31, p=.02). Response times to 240° rotations were significantly slower than to 60° (z=-2.75, p≤.00) and 300° rotations (z=-1.95, p=.05). Response times to 0° rotations were significantly slower than to 240°rotations (z=-2.04, p=.04).

The stroke group showed significantly slower response times to 180° rotations than to 0° (z=-2.57, p=.01), 60° (z=-2.93, p≤.00) and 300° (z=-2.04, p=.04) rotations. Response times to 120° rotations were significantly slower than to 0° (z=-2.57, p=.01), 60° (z=-2.40, p=.01) and 300° (z=-2.22, p=.02). Response times to 240°palmar rotations were significantly slower than to 0° (z=-2.66, p≤.00) and 60° (z=-2.93, p≤.00).

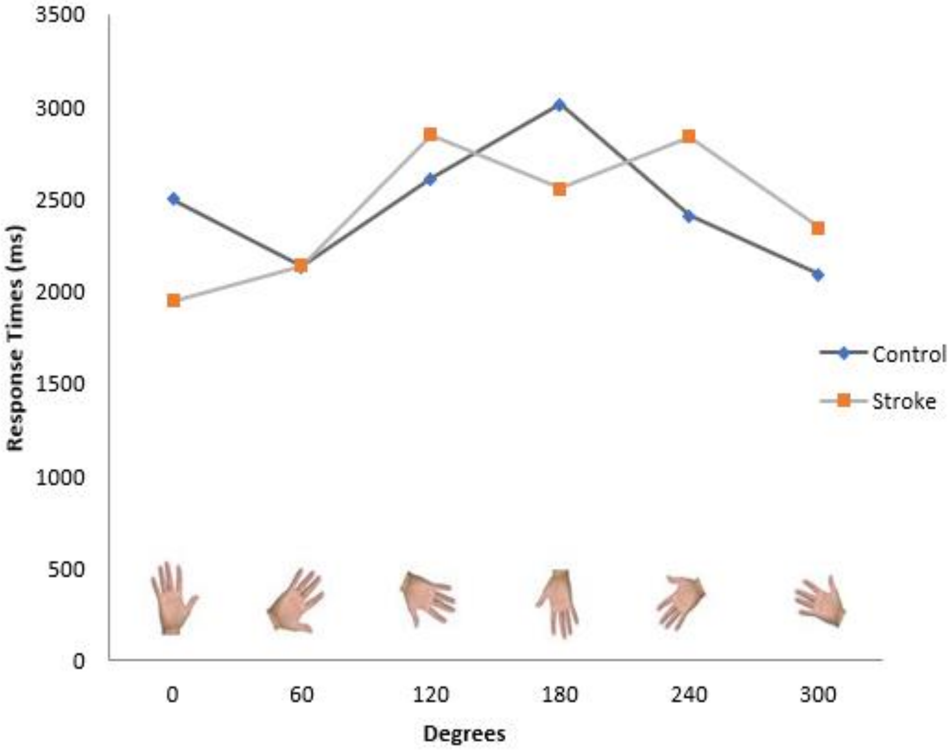
Table 6.11.

Stroke and Control Group Median Response Times (ms) (interquartile ranges) to each Angle (degrees) of Palmar Rotation

Degrees	0°	60°	120°	180°	240°	300°
Control	2501 (956)	2136 (1192)	2611 (1290)	3011 (2159)	2407 (1354)	2093 (1259)
Stroke	1947 (1942)	2141 (1715)	2849 (2647)	2558 (1488)	2835 (1827)	2347 (1094)

Figure 6.4.

Stroke and Control Group Median Response Times (ms) to each angle (degrees) of Palmar Rotation



Note. Median response times (ms) plotted as a function of palmar image rotation (degrees) for the stroke and control groups. In the control group response times increased with the angle of rotation to 180°. In the stroke group response times increased with the angle of rotation to 120° and 240°.

Table 6.12 and Figure 6.5 show the stroke and controls groups' response times to each angle of radial rotation. There were no significant differences between response times to any angle of radial rotation (0°, U=46.00, p=.36; 60°, U=53.00, p=.65; 120°, U=48.00, p=.43; 180°, U=58.00, p=.89; 240°, U =57.00, p=.84; 300°, U=56.00, p=.97).

Within-group pairwise comparisons of response times to each angle of radial rotation showed the control group had significantly slower response times to 180° rotations compared with all other angles (0°, z=-2.49, p=.01; 60°, z=-2.13, p=.03; 120°, z=-2.04, p=.04; 240°, z=-2.13, p=.03, 300°, z=-2.04, p=.05). Response times to 0° rotations were significantly slower than to 240°rotations (z=-2.22, p=.02). Response times to 240° rotations were significantly slower than to 300° rotations (z=-2.04, p=.04).

The stroke group showed significantly slower response times to 180° radial rotations than to 240° (z=-1.95, p=.05) and 300° rotations (z=-2.31, p=.05).

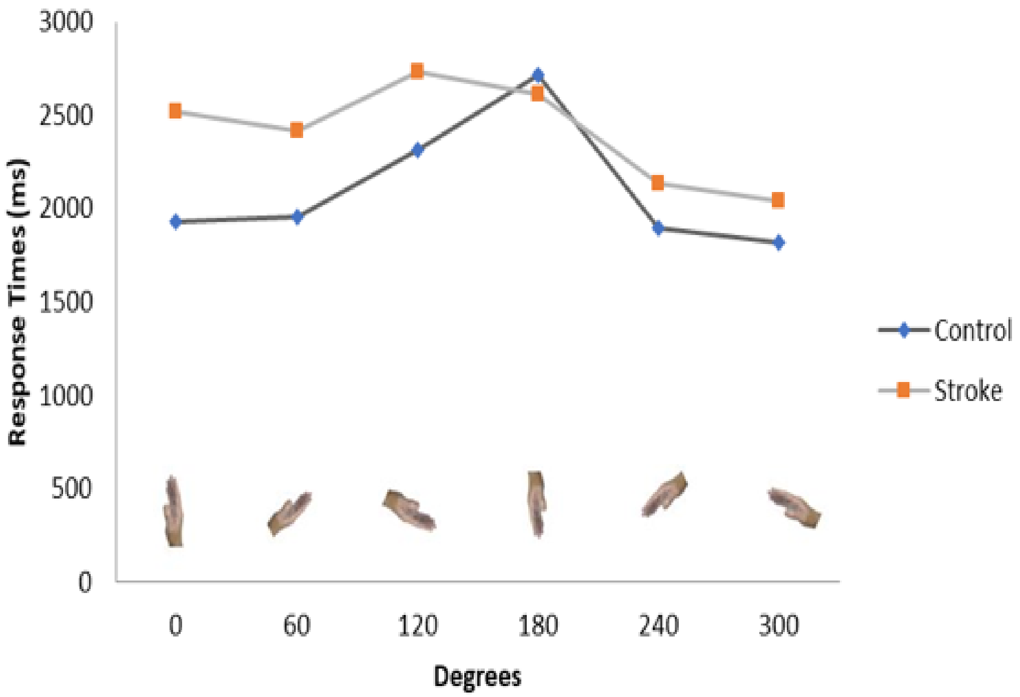
Table 6.12.

Stroke and Control Group Median Response Times (ms) to each Angle (degrees) of Radial Rotation (interquartile ranges)

Degrees	0°	60°	120°	180°	240°	300°
Control	1933 (989)	1957 (1426)	2317 (1052)	2719 (1400)	1898 (1188)	1823 (1095)
Stroke	2516 (2109)	2419 (1548)	2736 (1281)	2617 (2190)	2134 (1415)	2041 (2247)

Figure 6.5.

Stroke and Control Group Median Response Times (ms) to each angle (degrees) of Radial Rotation



Note. Median response times (ms) plotted as a function of radial image rotation (degrees) for the stroke and control groups. Response times increase with angle of rotation to 180° in the control group, and 120° in the stroke group.

Table 6.13 and figure 6.6 show the stroke and control groups' response times to each angle of ulnar rotation. There were no significant differences between response times to any angle of ulnar rotation. (0°, *U*=49, *p*=.70; 60°, *U*=53, *p*=.91; 120°, *U*=57, *p*=.84; 180°, *U*=41.00, *p*=.52; 240° *U*=52, *p*=.57; 300°, *U*=52.00, *p*=.60).

Within-group pairwise comparisons of response times to each angle of ulnar rotation showed the control group had significantly slower response times to 0° rotations than to 120° (*z*=-2.22, *p*=.02) and 240° rotations (*z*=-2.19, *p*=.02). The stroke group showed significantly slower response times to 0°rotations compared to all other angles (60°, *z*=2.22, *p*=.02; 120°, *z*=-2.13, *p*=.03; 180°, *z*=-2.29, *p*=.02; 240°, *z*=-2.40, *p*=.01; 300°, z=-2.22, *p*=.02) and significantly slower response times to 300°rotations than to 120° rotations (*z*=-2.13, *p*=.03).

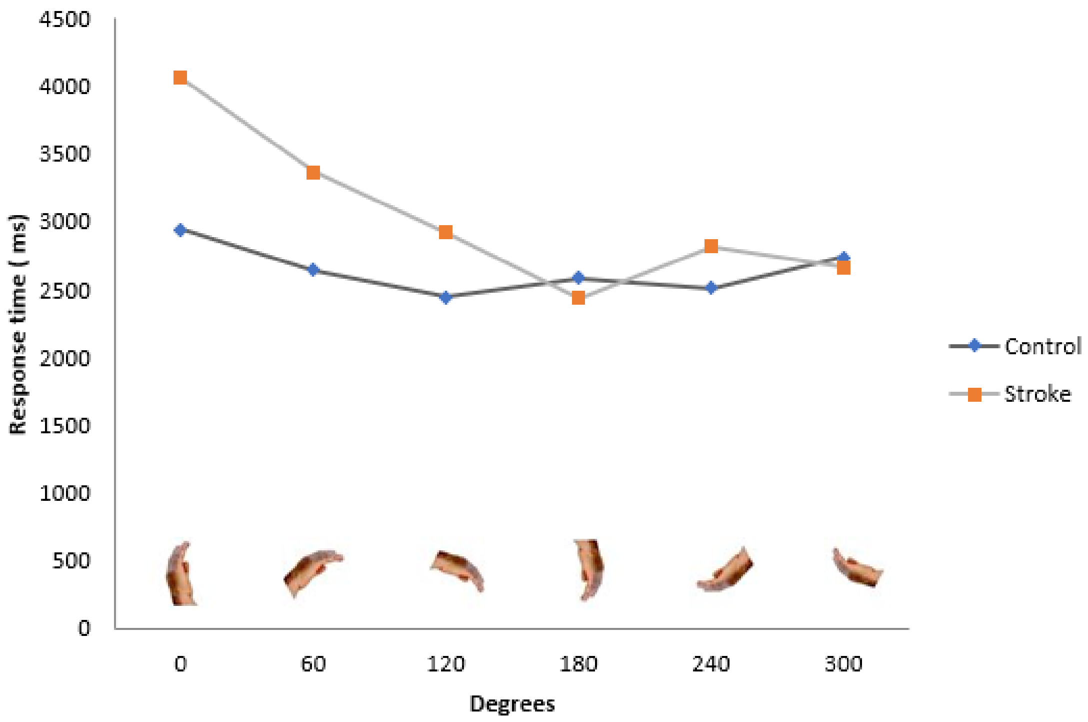
Table 6.13.

Stroke and Control Group Median Response Times (ms) to each Angle (degrees) of Ulnar Rotation (interquartile ranges in brackets)

Degrees	0°	60°	120°	180°	240°	300°
Control	2941 (1805)	2642 (2347)	2443 (1455)	2583 (2070)	2514 (1667)	2741 (2620)
Stroke	4064 (3703)	3364 (2027)	2920 (1556)	2438 (1635)	2817 (1929)	2664 (1625)

Figure 6.6.

Stroke and Control Group Median Response Times (ms) to each angle (degrees) of Ulnar Rotation



Note. Median response times (ms) plotted as a function of ulnar image rotation (degrees) for the stroke and control groups. Response times decrease with the angle of image rotation to 120° in the control group and 180° in the stroke group.

6.4.5 Response Times to Medially and Laterally Rotated Images

Table 6.14 shows the stroke and control groups' response times to medially and laterally rotated images. The stroke group had significantly faster response times to medially rotated images overall (stroke, mean rank=8.64, control, mean rank=14.36, U=29.00, p=.03), and to medially rotated ulnar views (stroke, mean rank =7.73, control, mean rank =15.27, U=19.00, $p \leq .00$). There were no significant between-group differences in response times to laterally rotated images.

Within-group comparisons showed no differences in overall response times to medial and laterally rotated images. The control group had significantly slower response times to medially rotated dorsal images (z=-2.31, p=.02), laterally rotated palmar images (lateral, z=-2.66, $p \leq .00$), and laterally rotated ulnar images (z=-2.58, p=.01). There were no significant differences in response times to medially and laterally rotated radial images.

The stroke group had significantly slower response times to laterally rotated palmar images (z=-2.66, $p \leq .00$), and laterally rotated radial images (z=-2.13, $p \leq .00$). There were no significant differences in response times between medially and laterally rotated dorsal or ulnar images.

Table 6.14.

Stroke and Control Group Response times (ms) (interquartile ranges) to Medial and Laterally rotated images

	All		Dorsal		Palmar		Radial		Ulnar	
Group	M	L	M	L	M	L	M	L	M	L
Control	3258 (1168)	2846 (1672)	2889 (1245)	2523 (649)	2257 (1307)	3090 (584)	2400 (1487)	2994 (847)	5270 (2723)	2591 (1964)
Stroke	2457 (859)	2891 (2546)	2903 (1416)	2723 (804)	2328 (913)	2654 (2711)	2364 (620)	2789 (1912)	3012 (1352)	2893 (1208)

Key: M =medial, L= lateral

Note. The table shows the stroke and control groups median response times (interquartile ranges) to all medial and laterally rotated images and to medially and laterally rotated images of each view.

6.4.6 Effects of Upper Limb Impairment on HLJ

There were no significant correlations between HLJ response times or errors and range of movement measures of the stroke-affected upper limb or Motricity Index scores.

Table 6.15 shows the response times and errors for those with mild and moderate upper limb impairment. There were no significant differences in response times or errors. There was a medium effect size for response times (d=.59) with slower response times in the moderate group. There was a small effect size for errors (d=.23) with more errors in the mild group. There were no significant differences in response times or errors to separate views. There was a large effect size for response times to ulnar views (d=.51), a medium effect size for response times to dorsal and palmar views (dorsal, d=.46; palmar, d=.51), and a small effect size for response times to radial views (d=.28), with slower response times to all views in the moderate group. There was a small effect size for errors to dorsal views (d=.30), with increased errors in the moderate group, and a small effect size for errors to radial and ulnar views (radial, d=.20; ulnar, d=.20), with increased errors in the mild group.

Table 6.15.

Median Response Times (ms) and Errors (n) (Interquartile Ranges) for Mild and Moderate Upper Limb Impairment

Group		All	Dorsal	Palmar	Radial	Ulnar
	Response Time					
Mild		2654 (1145)	2803 (1459)	2570 (1444)	2399 (1081)	2578 (838)
Moderate		3542 (2142)	3032 (2407)	3641 (2828)	2853 (1498)	3671 (2503)
	Errors					
Mild		53.00 (82.00)	17.00 (25.00)	5.00 (18.00)	10.00 (18.00)	18.00 (22.00)
Moderate		36.00 (54.00)	7.00 (16.00)	9.00 (8.00)	10.00 (14.00)	10.00 (16.00)

Note: The table shows the response time and errors for all images and separate views for those with mild and moderate upper limb impairment.

Table 6.16 and Figure 6.7 show the mild and moderate group's response times to each angle of image rotation. There was a large effect size for images rotated to 120°(d=.93) and 240°(d=.90) with slower response times to 120° rotations in the mild group and slower response times to 240° in the moderate group.

6.4.9 Effects of Stroke Location on Response Times and Errors

Table 6.17 shows the response times and errors for the RHS and LHS groups. There were no significant differences in response times or errors between those with RHS and LHS. There was a large effect size for response times (d=1.0), with slower response times in RHS, and a medium effect size for errors (d=.51) with more errors in RHS. There was a large effect size for response times to radial and ulnar views (radial, d=1.75; ulnar, d=.84), and a medium effect size for response times to dorsal and palmar views (dorsal d=.50; palmar d=.64), with slower response times to all views in RHS. There was a large effect size for errors to radial views (d=.76), and a medium effect size for errors to dorsal and palmar views (dorsal, d=.41; palmar d=.59), with more errors in the RHS group.

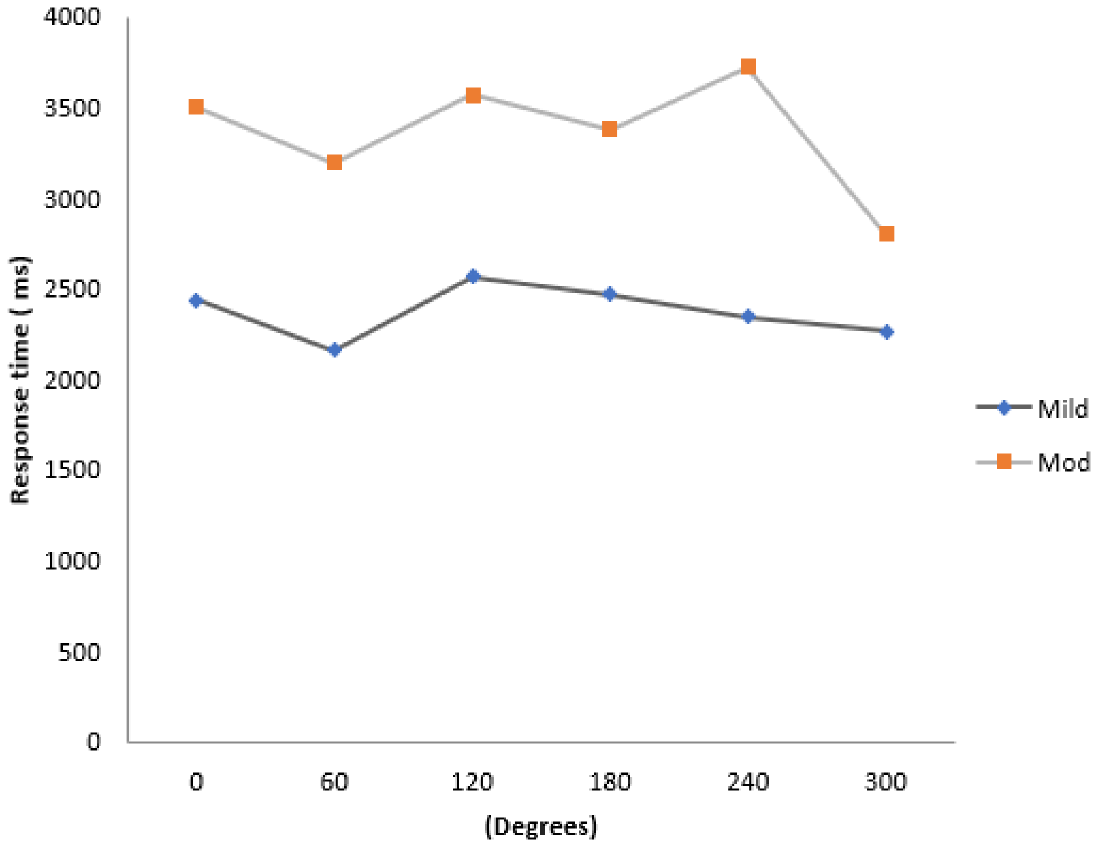
Table 6.16.

Response Times (ms) (interquartile ranges) to each Angle (degrees) of Image Rotation for Mild and Moderate Upper Limb Impairment

Group	0°	60°	120°	180°	240°	300°
Mild Impairment	2433 (1396)	2162 (1409)	2565 (1020)	2469 (1665)	2344 (1392)	2265 (1194)
Moderate Impairment	3498 (2104)	3192 (1944)	3571 (1996)	3379 (3397)	3724 (2435)	2801 (1621)

Figure 6.7.

Response Times (ms) to each Angle (degrees) of Image Rotation for Mild and Moderate Upper Limb Impairment



Note: Median response times (ms) plotted as a function of image rotation (degrees) for the mild and moderately impaired upper limb groups.

Table 6.17.

RHS and LHS Response Times (ms) and Errors (n) (interquartile ranges) to All, Right and Left- sided images and to Separate Views

Group		All	Right	Left	Dorsal	Palmar	Radial	Ulnar
	Response times							
LHS		2302 (1291)	2317 (1412)	2169 (1347)	2350 (2084)	2255 (1665)	2062 (1168)	2578 (1230)
RHS		3542 (1496)	3314 (1407)	3710 (1619)	3386 (704)	3641 (2162)	3197 (1159)	3671 (1892)
	Errors							
LHS		28.00 (58.00)	14.00 (33.00)	14.00 (25.00)	10.00 (18.00)	5.00 (10.00)	5.00 (14.00)	13.00 (21.00)
RHS		54.00 (72.00)	30.00 (40.00)	24.00 (32.00)	19.00 (22.00)	11.00 (12.00)	11.00 (17.00)	14.00 (21.00)

Table 6.18 and figure 6.8 show the RHS and LHS response times to each angle of image rotation. There were no significant differences in response times to any angle of image rotation. There was a large effect size for response times to each angle of image rotation (0°, *d*=.87; 60°, *d*=1.81; 120°, *d*=.90; 180°, *d*=.98; 240°, *d*=1.01; 300°, *d*=1.20) with slower responses in RHS.

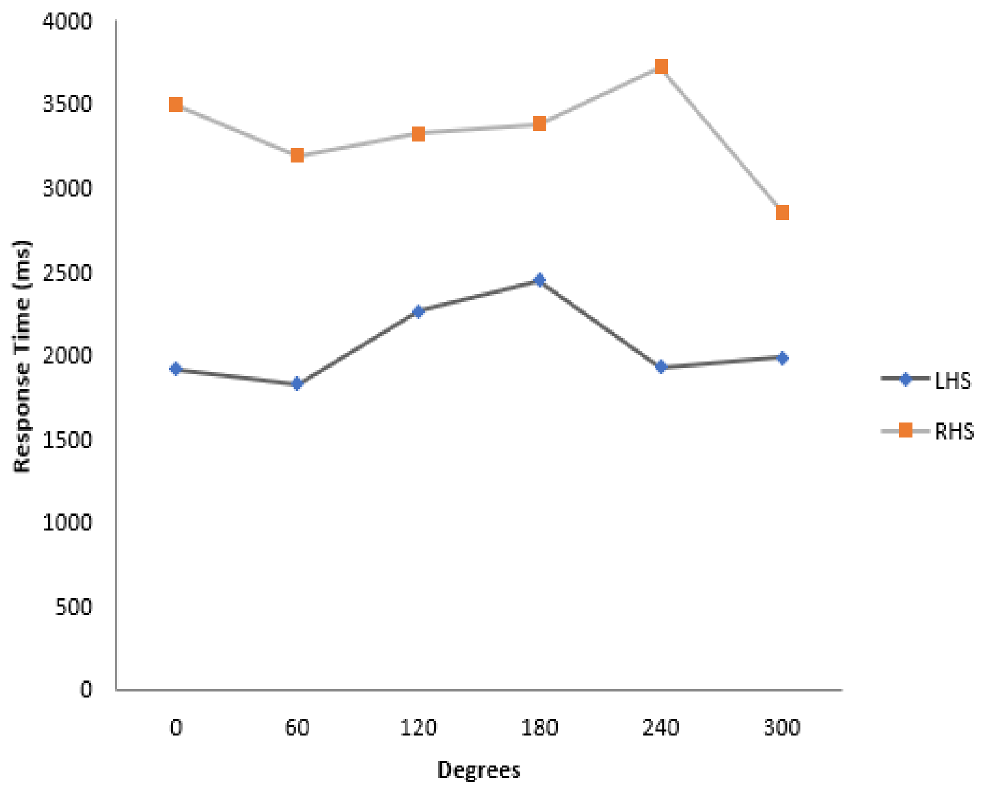
Table 6.18.

RHS and LHS Response Times (ms) (interquartile ranges). to each Angle of Image Rotation (degrees)

Group	0°	60°	120°	180°	240°	300°
RHS	3498 (971)	3192 (644)	3362 (1010)	3379 (3763)	3724 (1567)	2857 (928)
LHS	1916 (1727)	1830 (1443)	2265 (1642)	2445 (1688)	1926 (1676)	1988 (1015)

Figure 6.8.

RHS and LHS Response Times (ms) to each Angle of Image Rotation (degrees)



Note. Median response times (ms) plotted as a function of image rotation (degrees) for the LHS and RHS groups. Response times increase with angle of image rotation to 180° in LHS and 240° in RHS.

6.5 Discussion

This experiment examined the effects of stroke on HLJ performance in those aged ≥ 60 years. Contrary to the stated hypothesis, and in contrast to previous studies, there were no significant differences in response times or errors between the stroke group and age-matched controls. Furthermore, there were no significant relationships, between HLJ performance and measures of active range of movement or Motricity Index scores within the stroke group. However, effect size calculations suggested trends towards increased response times and errors for those with moderate upper limb impairments and those with RHS.

It is argued that previous stroke studies did not account for the normal effects of age on HLJ performance. The results of experiment one showed that ageing affected HLJ accuracy, but not response times, and it was proposed that older people compensated visually. Although previous stroke studies included age-matched controls, the age ranges varied. The effects of stroke may have been greater when comparing younger participants than when comparing older ones. By accounting for the effects of age, this experiment showed that stroke survivors performed as well as healthy controls.

The stroke group may have recovered HLJ ability. Devries et al. (2011) found HLJ accuracy significantly improved six weeks after stroke, and Amesz et al. (2016) reported impaired performance in only 33% of their stroke sample. Furthermore, a longitudinal study comparing twenty-four stroke patients with healthy controls, found no significant differences in HLJ accuracy by six weeks post-stroke, and no significant differences in response times by six months (Feenstra et al., 2016). As all the participants in experiment two were in the chronic stage of stroke, it would be reasonable to conclude that HLJ ability had recovered, but the use of compensatory strategies cannot be ruled out.

There is evidence that both groups used implicit motor imagery, as shown by the significantly slower response times to laterally rotated palmar images (Parsons 1994). The stroke group also had slower response times to laterally rotated radial images, indicating that implicit motor imagery occurred in response to these views. The lack of differences in response times to medially and laterally rotated dorsal or ulnar images suggest that HLJ of these viewed relied on visuospatial processes.

Within-group response times and errors to separate views differed between the stroke and control groups. The control group had significantly slower response times, and made the most errors, in response to ulnar views. Whereas, response times to ulnar views were only significantly slower than those to radial views in the stroke group with responses to both dorsal and ulnar views the least accurate. As dorsal views stimulate greater visuospatial processing (Ter Horst, Van Lier and Steenbergan, 2010), it is suggested that the stroke group were more impaired in this aspect of HLJ. This contrasts with Daprati et al. (2010), whose stroke group were more accurate in response to dorsal than to palmar views. The differences may be due to the age of the participants. Half of the stroke group in this experiment were aged over seventy, and the findings were similar to those of Older 2 in the previous experiment. However, as the control group was matched for age, this explanation is speculative.

Further evidence that stroke disrupted visuospatial mental rotation is shown by the differences in response times to image rotations. Within the control group, response times to 180° rotations were significantly slower than to all other rotations, indicative that visuospatial mental rotation had occurred (Parsons 1994). In contrast, the stroke group's response times to 180° rotations were only significantly slower than to 60°rotations, suggesting that visuospatial mental rotation was disrupted. This finding is supported by evidence from EEG studies, where reduced cortical activity in frontal, parietal and central areas was found during HLJ in stroke patients (Yan et al., 2012; Jia et al., 2018). Jia et al. (2018) concluded that stroke disrupted visual perception and mental rotation abilities.

The trend for slower response times and more errors for those with RHS suggests there was a disruption in visuospatial processes, that are common with RHS (Lincoln 2012). Iachini et al. (2008) found differences between those with RHS and LHS, in a sample of four stroke patients who undertook a battery of egocentric and allocentric visuospatial tasks. Those with RHS were only impaired in egocentric visuospatial tasks, and it was concluded that the right cerebral hemisphere was more specialized in processing egocentric visuospatial information. However, studies with larger samples have found either slower response times for LHS or no differences between RHS and LHS (Daprati et al., 2010; Kemlin et al., 2016; Amesz et al., 2016). Furthermore, three of those with RHS also had moderate upper limb impairment and the findings for this group were comparable to those with RHS.

Daprati et al.'s (2010), conclusion that implicit motor imagery was disrupted by upper limb impairment, and facilitated by visual compensation, is not supported by the findings of this experiment. The stroke group's responses times and accuracy to laterally rotated palmar and radial images suggest that implicit motor imagery processes were used and, the fewer errors in responses to these views suggest that these were effective.

As in previous studies (Johnson, Spreyn and Saykin 2006; Tanaka et al., 2011; Liepart et al., 2016), there were no statistically significant relationships between measures of upper limb impairment and HLJ performance. However, in accordance with Deprati et al. (2010), there was a trend for slower response times in those with moderate upper limb impairment and reduced accuracy in those with mild impairment.

Reduced sensory integration may explain the lack of a relationship between upper limb impairment and HLJ performance. 60% of the stroke sample subjectively reported sensory impairment. In the studies of young, healthy populations, laterality judgement of dorsal views was facilitated by the congruence of the resting hand position. Impaired proprioceptive feedback may explain the reduced accuracy in response to these views. Braun et al. (2017), reported a significant effect of sensory impairment on HLJ accuracy and impaired HLJ has also been associated with a lack of proprioceptive feedback in upper limb amputees (Nico et al 2004). However, Liepart et al. (2016), found no effect of severe sensory impairment on HLJ performance in their larger study of stroke patients.

6.6 Limitations

The difference in findings between this and previous studies may be due to the small sample size which did not allow for the heterogeneity of stroke populations or variations in HLJ ability. Low levels of recruitment are recognised as a major limitation in stroke rehabilitation research (Ferreira et al., 2019; Held et al., 2019). It was calculated that a sample size of fifty would be needed to achieve acceptable power, but the recruitment of stroke participants was more difficult than anticipated. Post hoc power calculations indicated the study was underpowered, so type II errors may have occurred.

There were no relationships between HLJ performance and Motricity Index scores or range of movement measures. A recent consensus document (Kwakkel et al., 2017) recommended that the Fugl-Meyer assessment (Fugl-Meyer et al., 1975) should be used to measure impairment in stroke trials. The upper extremity section includes measures of active and passive range of motion and sensation, so may have been preferable to the chosen measures. However, previous studies that included the Fugl-Meyer assessment also failed to find any relationship between scores and HLJ performance (Tanaka et al., 2011; Devries et al., 2011).

As suggested previously, the design of the HLJ test may also explain the differences between the findings of this and other studies. This will be discussed further in chapter eight.

6.7 Conclusion

There were no significant differences in HLJ performance between the stroke and control groups, and no relationship between impairment of the stroke-affected upper limb and HLJ performance. This indicates that either HLJ had recovered in the stroke group or compensatory strategies were used. The results suggested that visuospatial hand mental rotation was impaired in the stroke group, whereas, implicit motor imagery was preserved. This contrasts with the findings of experiment one, where ageing was associated with an increase in the use of visual compensation and a decline in implicit motor imagery.

7.0 Experiment Three: The Effects of Training HLJ after Stroke

Experiment three was a before-and-after study examining the effects of training HLJ in a small group of stroke survivors and addressed the following questions:

1. What are the effects on of practising HLJ on response times and errors after a stroke?

2. Does practicing HLJ improve upper limb impairment?

It was hypothesised that training would result in decreased response times and increased accuracy. A secondary hypothesis was that Motricity Index scores would increase after training.

7.1 Method.

7.1.1 Participants

Volunteers were recruited from a local stroke support group. Table 7.1 shows the inclusion and exclusion criteria. Participant recruitment and data collection were carried out by an MSc student under the supervision of the author.

Table 7.1.

Inclusion and Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
Aged >18.	Left-handed.
Right-handed.	Previous stroke or other neurological condition/s.
First-ever Stroke.	No upper limb impairment.
≥ three months post-stroke.	Bilateral upper limb hemiparesis.
Upper limb impairment affected side.	Severe hand/ arm pain.
Able to understand the purpose of the research.	Other upper limb impairment affecting function.
Able to give informed consent.	Unable to see the computer screen even with glasses.
	Unable to operate keypad with unaffected hand.
	Unable to give informed consent.
	Unable to follow instructions.
	Took part in experiment two.

7.1.2 Measures

The primary measure was the HLJ test and the secondary measure the Motricity Index Upper Limb Subscale. These measures were taken pre-and post-intervention. The reliability and validity of these measures have been discussed previously (see sections 3.4 and 6.1.3).

7.1.3 Intervention

Figure 7.1 shows the screen views for the Recognise, ™ mobile application used to practice HLJ (Neuro Orthopaedic Institute, no date). Ten free licence codes were supplied by the Neuro- Orthopaedic Institute. Recognise™ presents right and left-sided images of hands in various postures, records response times and errors, and tracks progress.

The “Vanilla” hands programme was selected consisting of eighty images of right and left Caucasian hands, in various postures. Fifty images were presented in each randomised block. Each image appeared on the screen until a response was made, or thirty seconds had elapsed. The maximum time to complete a block was 2.5 minutes.

Participants were instructed to practice with Recognise™ for thirty minutes a day, five days a week, for three weeks. Previous studies have used similar practice schedules over two to four weeks (Uttam, Midha and Arumugam, 2015; Bernaisier et al., 2018; Polli et al., 2018). Following the period of practice, the HLJ test and Motricity Index were repeated.

7.1.4 Procedure

All sessions took place at University premises and lasted no more than two hours, including breaks. Consent procedures were as described in chapter four. The HLJ test and the Motricity Index were completed as described in section 6.2. The same order was maintained for all participants so that responses to the HLJ test were not affected by handling the stroke-affected upper limb. The researcher, an experienced neurological physiotherapist undertook the Motricity Index measures, to ensure safe handling the upper limb.

Participants were shown how to use the Recognise™ application. It was downloaded to their mobile device (mobile phone, tablet or laptop). Three practice blocks of fifty images were completed under supervision. The participants were instructed to email their results to the researcher each week. Participants repeated the HLJ test and Motricity Index after three weeks has elapsed.

Figure 7.1.

Screen views from the Recognise™ app

Figure has been removed due to copyright restrictions.

Note. The figure shows the home screen, hand image and response keys, response recordings and set up for the Recognise™ application.

7.1.5 Data Analysis

Pair-wise comparisons of were made of median response times and errors pre-and post-training and Cohen's d was calculated from means and standard deviations. Motricity Index scores were compared pre-and post-training.

7.2 Results

7.2.1 Participants

Four male participants were recruited and took part in the study. Table 7.2 shows the participant characteristics. All had chronic strokes. Two had RHS and two LHS, three had moderate upper limb impairment (Motricity Index< 85), and one mild upper limb impairment (Motricity Index≥85).

7.1.2 Amount of practice

The amount of practice varied. Participant A completed 382 blocks of 50 images; participant B, 68 blocks; participant C, 10 blocks, and participant D, 63 blocks.

Table 7.2.

Participant Characteristics

Participant	Age	Time since stroke (yrs)	Affected Hemisphere.	Type of Stroke	Motricity Index
A	54	2	L	Isch PACS	40
B	60	1.5	L	Haemorrhage	40
C	65	2	R	Isch PACs	40
D	58	7	R	Isch PACS	92

Key: Isch= Ischaemic; PACS= partial anterior circulation stroke. L=left; R=right.

7.1.3 Response Times and Accuracy

Table 7.3 shows the pre-and post-training response times and errors to the HLJ test. There were no differences in Motricity Index scores post-training. There were no significant differences in response times or errors pre-and post-training. There were medium effect sizes for response times, with slower response times post-training. There were small effect sizes for errors to palmar, radial and ulnar views and a medium effect size for errors to dorsal views, with fewer errors post-training to all except ulnar views.

Table 7.3.

Pre-and Post- Intervention Response Times (ms) and Errors (n) (interquartile ranges)

Views	Response times			Errors		
	Pre	Post	Effect size (*d*)	Pre	Post	Effect size (*d*)
All	2215 (1422)	3574 (5059)	.46	32.00 (87.00)	26.05 (62.00)	.24
Dorsal	1957 (863)	3253 (5092)	.66	11.50 (22.00)	6.00 (12.00)	.56
Palmar	2174 (806)	3933 (5102)	.67	5.00 (19.25)	6.00 (15.50)	.07
Radial	1916 (817)	2961 (6371)	.72	6.50 (22.50)	4.50 (17.50)	.22
Ulnar	2731 (1627)	4173 (3782)	.63	8.50 (23.50)	10.50 (16.75)	.24

Key. Pre = pre- training; Post =post-training.

Note. Effect sizes were calculated from pre-and post-training means and standard deviations.

7.2 Discussion

This small-scale study found no significant differences in response times or error following three weeks of HLJ training. Effect size calculations revealed trends towards slower response times and fewer errors. This was unexpected, as it was hypothesised that practice would result in faster response times as well as fewer errors. It has been shown that stroke survivors can use recognise™ to practice HLJ, although the amount of practice varied between participants.

The findings of this experiment contrast with those of Bernaisier et al. (2018) who found faster response times and increased accuracy following practice, in their larger sample of healthy individuals. The results can be explained by individual differences in HLJ performance. Two participants increased response times post-training, and three increased accuracy. Furthermore, participant A made only three errors post-training and response times were comparable to those of young, healthy individuals.

It is unclear why increased response times resulted in greater accuracy, as in previous HLJ studies, slower response times were related to more errors. The results may be due to increased concentration on the HLJ test post-training, and a greater effort to avoid errors. Alternatively, the Recognise™ application allowed thirty-seconds time-lapse before moving onto the next image, which may have subsequently slowed participants responses to the HLJ test.

Recognise™ also gives feedback following each block of images, so participants may have focussed more on accuracy than on the speed of response.

As there were no improvements in Motricity Index scores post-training, it could be concluded that there is no benefit of practising HLJ post-stroke. However, the small sample size of this study limits such conclusions. In healthy populations, practising HLJ led to increased cortico-motor activation (Bernaisier et al. 2018), so similar neuroplastic changes might occur post-stroke.

A larger study with a longer intervention period is recommended to confirm the results of this experiment. Post-hoc power calculations indicated that a sample size of twenty-five would be needed for a power of 0.8. The amount and type of practice, instructions and feedback should be standardised. The time that images are displayed should be reduced to three seconds, which reflects the stroke group’s response time in experiment two.

In conclusion, stroke survivors can practice HLJ using the Recognise™ app but improvements in accuracy were accompanied by slower response times. A further study is required to determine if these results are replicated in a larger stroke population.

8.0 General Discussion

This chapter brings together the findings of the three experiments and presents the original contributions of this thesis. An interpretation of the findings is given within the context of previous research. The limitations are discussed, and suggestions made for improvements. Implications for clinical practice are explored, followed by recommendations for further research.

8.1. Original Contributions

This thesis offers three original contributions to the existing knowledge of the effects of age and stroke on HLJ.

1. HLJ accuracy is affected by old age. Declines in implicit motor imagery in early old age are compensated with a greater reliance on visuospatial imagery. The ability to compensate declines by more advanced old age.
2. The HLJ performance of stroke survivors aged ≥60 is comparable to similarly aged healthy individuals. Impairments in visuospatial imagery lead to a greater reliance on implicit motor imagery.
3. Training HLJ in stroke survivors increases accuracy and response times.

8.2 Discussion of the Main Findings

Contrary to the stated hypotheses, there were no significant differences in overall response times between the young and old, or the stroke and control groups. The only significant findings were slower responses to dorsal views, found for Older 2 and the stroke group. There were no significant effects of HLJ training on response times. Within the stroke groups, there were trends towards slower response times in those with moderate upper limb impairment and those with RHS, and towards slower response times following training.

As hypothesized, accuracy was reduced in the older aged groups but contrary to expectations, there were no differences in overall accuracy between the stroke and control groups. Compared with other groups, both Older 2 and the stroke group were the least accurate in response to dorsal views. Within-group accuracy varied depending on the view. Older 1 were less accurate in response to palmar views compared to dorsal and radial views, suggesting that implicit motor imagery was impaired. Both Older 2 and the stroke group were less accurate in response to dorsal views, suggesting that visuospatial processes were affected. Within the stroke groups, there were trends towards increased errors for those with moderate upper limb impairment, and those with RHS, and towards increased accuracy following practice.

All groups engaged in implicit motor imagery, demonstrated by increased response times to laterally rotated palmar images. However, response times to images rotated to 180° varied. The young group had slower response times to 180° dorsal and radial rotations, but not to palmar ones, suggesting their strategies varied with the view. Both older groups had slower response times to 180° dorsal, palmar and radial rotations, suggesting they used similar, more visually based strategies to judge laterality. Experiment two showed that overall response times to 180° were not significantly slower than to other angles in the stroke group, and responses to separate views suggested that visuospatial mental rotation was disrupted.

In summary, HLJ was affected by older age and by stroke. Stroke participants were able to perform HLJ as well as age-matched controls, but there were trends towards slower response times and reduced accuracy in those with RHS and those with moderate upper limb impairment. Following practice, accuracy improved at the expense of response time.

The lack of significant between-group differences in overall response times was unexpected, as previous studies have found slower response times in older people and those with stroke (Saimpont et al., 2009; Delvin and Wilson., 2010; Tanaka, Yamanda and Inagaki, 2010; Amesz et al., 2016; Kemlin et al., 2016). In common with previous studies (Ionta et al., 2007; Ionta and Blanke, 2009), there were significantly slower response times to ulnar views compared to all other views. This may have created a bias that reduced overall response time differences between the groups.

The slower response times and reduced accuracy to dorsal views found in advanced old age and stroke were also surprising. Previous research has indicated that HLJ of dorsal images is easier, relying more on visuospatial than on motor imagery processes (Ionta et al., 2007; Ionta and Blanke, 2009; Ter Horst, Van Lier and Steenbergan, 2010; Blasing et al., 2013). The judgement of dorsal images is also facilitated by the congruence of the hand position during the test (Shenton et al., 2004; Viswanathan, Fritz and Grafton, 2012). These results suggest that the HLJ of dorsal images were affected by the visuospatial and proprioceptive impairments commonly found in those of advanced age and those with stroke (Goble et al., 2009; Lincoln, 2012; Borrella et al.,2013; Rand, 2018).

The possibility that the stroke participants had recovered HLJ was discussed in section 6.5. The cortical network for HLJ is bilaterally distributed and likely to be partially preserved after a stroke (Hetu et al., 2013; Tomasino and Gremese, 2016). Alternatively, the stroke participants may have compensated by preferentially matching the unaffected hand to the images. This would explain why HLJ of palmar and radial views, which rely more on implicit motor imagery, were the most accurate. It would also explain why no differences were found related to the stroke-affected side or measures of upper limb impairment. Neurophysiological studies support the existence of compensatory strategies following a stroke, with increases in activity in the intact hemisphere related to the severity of upper limb impairment (Almeida et al., 2016).

It was expected that experiment three would show that HLJ improved with training. Although all participants were able to use the recognise™ app, the amounts of practice varied, and a longer period of training may have been needed. The lack of change in Motricity Index scores might be been expected as experiment two showed no relationship between this measure and HLJ performance. The trend for slower response times only related to two participants and may have been due to the longer time limit set for responses on Recognise™.

8.3 Limitations

The findings of previous HLJ research were not replicated in this thesis. The lack of a standardised HLJ test is a weakness in all HLJ research and limits direct comparisons. The researcher could be criticised for using a more complex test, further limiting the comparisons to other studies. Nevertheless, the inclusion of ulnar and radial views allowed further exploration of HLJ strategies and showed that both stroke and older participants could accurately complete a complex test.

Cocksworth and Punt (2013) demonstrated that response modes influenced HLJ response times and suggested that it was disrupted when images corresponded to the responding hand. The unimanual mode used for the HLJ test may have been faster and reduced response time differences. Additionally, no differences relating to the responding hand were found, even though those with LHS responded their non-dominant hand. Conversely, previous studies using unilateral modes, found slower response times in stroke groups (Daprati et al 2010; Liepart et al 2016).

As previously stated, the significantly longer response times to ulnar views were a potential source of bias. Several participants expressed surprise or puzzlement when first presented with this view, suggesting difficulty with the initial recognition stage of HLJ. This explains why response times were consistently slower for 0° rotations. Removing the ulnar view may have produced results more consistent with previous studies, but this would have limited the comparisons between hand views.

A further limitation was the small number of stroke participants recruited for experiments two and three. Recruitment of participants to stroke trials is known to be challenging and although adequate time was allowed, there were delays in obtaining ethical permissions.

Previous stroke rehabilitation trials reported monthly recruitment rates of between 0.3 and 1.1, which were comparable to recruitment for experiment two (Polese et al., 2015; Tyson et al., 2018; Ferriera et al., 2019). On reflection, more time, and a more flexible recruitment strategy, was needed to recruit a larger sample. Experiments two and three could also have been combined to increase the latter's sample size. The use of social media to publicise the studies, together with a less stringent inclusion and exclusion criteria, would also have improved recruitment (Elkins et al., 2004; Berge et al., 2016; Feldman et al., 2017).

8.4 Clinical Implications

It has been demonstrated that stroke survivors can accurately complete a complex HLJ test and improve with training. Currently, HLJ is used as part of the Graded Motor Imagery approach to chronic pain (Moseley et al., 2012). The findings of this thesis indicate that healthy older adults and those with stroke could use HLJ in this context. Clinicians need to be mindful that HLJ may be less effective at stimulating implicit motor imagery, and that patients in these groups may respond better to images with less complex hand postures.

Based on the findings of this thesis, HLJ cannot be recommended for post-stroke upper limb rehabilitation. There were no links between

HLJ performance and upper limb impairment, or any improvements in upper limb activity following HLJ training. However, studies of explicit motor imagery only found positive effects when it was used to supplement upper limb therapy (Guerra, Luchetti and Luchetti, 2017).

8.5 Recommendations for Further Research

The studies in this thesis have added to the knowledge regarding HLJ in older and stroke populations. The value of further research into its use in stroke rehabilitation is questionable. No evidence of beneficial effects from practising HLJ was found, although the sample size was too small for definite conclusions. It was also concluded that HLJ had recovered to the level of similarly aged healthy controls, but neurophysiological evidence is lacking to support this. The use of compensatory strategies, such as matching the unimpaired hand, cannot be ruled out.

Nevertheless, it would be unwise to dismiss the need for further research based on this thesis. It has been shown that healthy older people and those with a stroke can practice HLJ successfully. Unlike other forms of motor imagery, engagement with HLJ can be measured, and it can be delivered cheaply via an existing mobile application. Berneiser et al. (2018), demonstrated, that practising

HLJ lead to neuroplastic changes in cortical motor areas, suggesting it could benefit stroke patients.

Experiment two showed that stroke affected visuospatial mental rotation, with a trend for poorer performance in those with RHS. This is worth further investigation, as mental rotation is used in a variety of upper limb functions, to orientate the hand in three-dimensional space (de Bruin et al.,2016). Visuospatial ability in older adults has been positively related to motor learning (Vangilder et al., 2018), and it has been suggested that improving visuospatial integration might enhance motor recovery following stroke (Barret and Muzaffar, 2015).

A further exploratory study, examining the effects of HLJ practice in a larger sample of stroke patients, is recommended. This would be widened to include a lower age limit of fifty years, acute stroke patients, and those with HLJ accuracy below chance level. The Fugl Meyer upper limb scale and measures of visuospatial impairment would be compared before and after a longer period of HLJ practice. This would aid in determining any value in progressing to a larger proof of concept trial, examining the effects of HLJ practice combined with upper limb exercises.

9.0 Conclusions

The purpose of the thesis was to explore whether HLJ could be used in upper limb rehabilitation after stroke. The literature review highlighted gaps that this thesis has sought to address. Previous research in stroke had not accounted for the effects of normal ageing processes on HLJ, and research about the effects of age was limited. Moreover, it was unknown if stroke survivors could improve HLJ with practice.

It has been demonstrated that implicit motor imagery declines in early old age, with more reliance on visuospatial processes to compensate. This compensation is reduced by advanced old age. When the effects of age are considered, those with stroke perform HLJ as well as age-matched controls. However, stroke may impair visuospatial processes, causing greater reliance on implicit motor imagery.

Stroke survivors can successfully practice HLJ to improve accuracy, but the benefits of this unknown. A further study examining the effects of training HLJ in a larger stroke population is recommended.

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Outputs

Sapsford,F. (2013) 'Does Hand Laterality Recognition Involve Motor Imagery A Literature review'. Poster Presentation. *University of Cumbria Doctoral Colloquium*. University of Cumbria July 2013.

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Appendix 1. Ethical Procedures and Related Documents

(anonymised where appropriate)

Ethical Approval for Experiment 1

19 March 2014

Our Ref: IC/SB 13/15

Frances Sapsford
Faculty of Health and Science
Fusehill Street

University of Cumbria
Research Office
University of Cumbria
Lancaster Campus
Lancaster, LA1 3JD

Tel: 01524 384175
Fax: 01524 384385
[redacted]

Dear Frances

Request for Ethical Clearance – Our Ref 13/15
Project: The effects of aging Hand Laterality Judgement

Thank you for your application which has been given consideration by the Panel. The Panel are delighted to give approval for your project and wish you well. However, the panel requires a thorough copy edit which you will need to send electronically to [redacted]

Yours sincerely

[redacted]

[redacted]
Chair
Ethics Advisory Panel

Ethical Approvals for Experiment 2

1. HRA Research Ethics Committee approval part 1

NHS
Health Research Authority
North West - Lancaster Research Ethics Committee
Barlow House
3rd Floor
4 Minshull Street
Manchester
M1 3DZ

<u>Please note</u>: This is the favourable opinion of the REC only and does not allow you to start your study at NHS sites in England until you receive HRA Approval

14 November 2016

MS Frances Sapsford
University of Cumbria
Fusehill St.
Carlisle Cumbria
CA1 2HH

Dear MS Sapsford

Study title:	**The Effects of Stroke on Hand Laterality Judgement**
REC reference:	**16/NW/0776**
IRAS project ID:	**212048**

Thank you for responding to the Proportionate Review Sub-Committee's request for changes to the documentation for the above study.

The revised documentation has been reviewed and approved by the sub-committee.

We plan to publish your research summary wording for the above study on the HRA website, together with your contact details. Publication will be no earlier than three months from the date of this favourable opinion letter. The expectation is that this information will be published for all studies that receive an ethical opinion but should you wish to provide a substitute contact point, wish to make a request to defer, or require further information, please contact the REC Assistant [redacted] Under very limited circumstances (e.g. for student research which has [redacted] unfavourable opinion), it may be possible to grant an exemption to the publication of the stud

Confirmation of ethical opinion

On behalf of the Committee, I am pleased to confirm a favourable ethical opinion for the above research on the basis described in the application form, protocol and supporting documentation as revised.

Conditions of the favourable opinion

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

A Research Ethics Committee established by the Health Research Authority

IRAS Checklist XML [Checklist_04112016]		04 November 2016
Non-validated questionnaire	2	02 November 2016
Participant consent form	2	02 November 2016
Participant information sheet (PIS)	2	02 November 2016
Research protocol or project proposal [Hand Recognition After Stroke]	6	02 November 2016
Summary CV for Chief Investigator (CI)		01 September 2016
Summary CV for student		01 September 2016
Summary CV for supervisor (student research) [Dr Susan Dewhurst]		01 September 2015
Summary CV for supervisor (student research) [Dr Tim Donovan]		01 September 2016

Statement of compliance

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

After ethical review

Reporting requirements

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

- Notifying substantial amendments
- Adding new sites and investigators
- Notification of serious breaches of the protocol
- Progress and safety reports
- Notifying the end of the study

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

Feedback

You are invited to give your view of the service that you have received from the National Research Ethics Service and the application procedure. If you wish to make your views known please use the feedback form available on the HRA website: http://www.hra.nhs.uk/about-the-hra/governance/quality-assurance

We are pleased to welcome researchers and R & D staff at our NRES committee members' training days – see details at http://www.hra.nhs.uk/hra-training/

16/NW/0776	**Please quote this number on all correspondence**

With the Committee's best wishes for the success of this project.

Yours sincerely

[redacted]

[redacted]

A Research Ethics Committee established by the Health Research Authority

2 NHS HRA Approval Part 1

Health Research Authority

Ms Frances Sapsford
University of Cumbria
Fusehill St.
Carlisle
Cumbria
CA1 2HH

Email: hra.approval@nhs.net

10 February 2017

Dear Ms Sapsford

Letter of <u>HRA Approval</u>

Study title:	**The Effects of Stroke on Hand Laterality Judgement**
IRAS project ID:	**212048**
REC reference:	**16/NW/0776**
Sponsor	**University of Cumbria**

I am pleased to confirm that **<u>HRA Approval</u>** has been given for the above referenced study, on the basis described in the application form, protocol, supporting documentation and any clarifications noted in this letter.

Participation of NHS Organisations in England

The sponsor should now provide a copy of this letter to all participating NHS organisations in England.

Appendix B provides important information for sponsors and participating NHS organisations in England for arranging and confirming capacity and capability. **Please read *Appendix B* carefully**, in particular the following sections:

- *Participating NHS organisations in England* – this clarifies the types of participating organisations in the study and whether or not all organisations will be undertaking the same activities
- *Confirmation of capacity and capability* - this confirms whether or not each type of participating NHS organisation in England is expected to give formal confirmation of capacity and capability. Where formal confirmation is not expected, the section also provides details on the time limit given to participating organisations to opt out of the study, or request additional time, before their participation is assumed.
- *Allocation of responsibilities and rights are agreed and documented (4.1 of HRA assessment criteria)* - this provides detail on the form of agreement to be used in the study to confirm capacity and capability, where applicable.

Further information on funding, HR processes, and compliance with HRA criteria and standards is also provided.

It is critical that you involve both the research management function (e.g. R&D office) supporting each organisation and the local research team (where there is one) in setting up your study. Contact details

Page **1** of **8**

NHS HRA Approval Part 2

IRAS Checklist XML [Checklist_04112016]		04 November 2016
Non-validated questionnaire	2	02 November 2016
Participant consent form	2	02 November 2016
Participant information sheet (PIS)	2	02 November 2016
Research protocol or project proposal [Hand Recognition After Stroke]	6	02 November 2016
Summary CV for Chief Investigator (CI)		01 September 2016
Summary CV for student		01 September 2016
Summary CV for supervisor (student research[redacted]]		01 September 2015
Summary CV for supervisor (student research) [redacted]		01 September 2016

Statement of compliance

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

After ethical review

<u>Reporting requirements</u>

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

- Notifying substantial amendments
- Adding new sites and investigators
- Notification of serious breaches of the protocol
- Progress and safety reports
- Notifying the end of the study

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

<u>Feedback</u>

You are invited to give your view of the service that you have received from the National Research Ethics Service and the application procedure. If you wish to make your views known please use the feedback form available on the HRA website: http://www.hra.nhs.uk/about-the-hra/governance/quality-assurance

We are pleased to welcome researchers and R & D staff at our NRES committee members' training days – see details at http://www.hra.nhs.uk/hra-training/

16/NW/0776	**Please quote this number on all correspondence**

With the Committee's best wishes for the success of this project.

Yours sincerely

[redacted]

[redacted]

A Research Ethics Committee established by the Health Research Authority

Experiment 2: NHS Trust letter of access 1 Part 1

[redacted] NHS

[redacted]

Happier | **Healthier** | Hopeful

Date 9 March 2017

RE: Letter of access for research

Trust reference number: CP1702
IRAS reference: 212048

Project Title: The Effects of Stroke on Hand Laterality Judgement

Dear Ms Frances Sapsford

This letter confirms your right of access to conduct research through the[redacted]n Trust for the purpose and on the terms and conditions set out below. This right of access commences on **9 March 2017 and ends 31 May 2018** unless terminated earlier in accordance with the clauses below.

You have a right of access to conduct such research as confirmed in writing in the letter of permission for research from this NHS organisation. Please note that you cannot start the research until the Chief Investigator for the research project has received a letter from us giving permission to conduct the project.

The information supplied about your role in research a[redacted]NHS Foundation Trust for has been reviewed and you do not require an honorary research contract with this NHS organisation. We are satisfied that such pre-engagement checks as we consider necessary have been carried out.

You are considered to be a legal visitor t[redacted] premises. You are not entitled to any form of payment or access to other benefits provided by this NHS organisation to employees and this letter does not give rise to any other relationship between you and this NHS organisation, in particular that of an employee.

While undertaking research through[redacted]rust for you will remain accountable to your employe[redacted]but you are required to follow the reasonable instructions o[redacted]is NHS organisation or those given on her/his behalf in relation to the terms of this right of access.

Where any third party claim is made, whether or not legal proceedings are issued, arising out of or in connection with your right of access, you are required to co-operate fully with any investigation by this NHS organisation in connection with any such claim and to give all such assistance as may reasonably be required regarding the conduct of any legal proceedings.

You must act in accordance with[redacted] Trust for policies and procedures, which are available to you upon request, and the Research Governance Framework.

You are required to co-operate wit[redacted] discharging its duties under the Health and Safety at Work etc Act 1974 [redacted] safety legislation and to take reasonable care for the health and safety of yourself and others while on Cumbria Partnership NHS Foundation Trust for premises. You must observe the same standards of

care and propriety in dealing with patients, staff, visitors, equipment and premises as is expected of any other contract holder and you must act appropriately, responsibly and professionally at all times.

[redacted]

Experiment Two : NHS Trust letter of access 1 : Part 2

[redacted] **NHS**
[redacted]

You are required to ensure that all information regarding patients or staff remains secure and strictly confidential at all times. You must ensure that you understand and comply with the requirements of the NHS Confidentiality Code of Practice (http://www.dh.gov.uk/assetRoot/04/06/92/54/04069254.pdf) and the Data Protection Act 1998. Furthermore you should be aware that under the Act, unauthorised disclosure of information is an offence and such disclosures may lead to prosecution.

You should ensure that, where you are issued with an identity or security card, a bleep number, email or library account, keys or protective clothing, these are returned upon termination of this arrangement. Please contact R&D office before visiting Trust premises to agree arrangements for the issue of ID badge. Please also ensure that while on the premises you wear your ID badge at all times, or are able to prove your identity if challenged. Please note that this NHS organisation accepts no responsibility for damage to or loss of personal property.

We may terminate your right to attend at any time either by giving seven days' written notice to you or immediately without any notice if you are in breach of any of the terms or conditions described in this letter or if you commit any act that we reasonably consider to amount to serious misconduct or to be disruptive and/or prejudicial to the interests and/or business of this NHS organisation or if you are convicted of any criminal offence. As from 26 July 2010, your HEI employer may initiate your Independent Safeguarding Authority (IISA) registration (where applicable), and thereafter, will continue to monitor your ISA registration status via the on-line ISA service. Should you cease to be ISA-registered, this letter of access is immediately terminated. Your employer will immediately withdraw you from undertaking this or any other regulated activity. You MUST stop undertaking any regulated activity.

Your substantive employer is responsible for your conduct during this research project and may in the circumstances described above instigate disciplinary action against you.

[redacted] Trust for will not indemnify you against any liability incurred as a result of any breach of confidentiality or breach of the Data Protection Act 1998. Any breach of the Data Protection Act 1998 may result in legal action against you and/or your substantive employer.

If your current role or involvement in research changes, or any of the information provided in your Research Passport changes, you must inform your employer through their normal procedures. You must also inform your nominated manager in this NHS organisation.

Yours sincerely,

[redacted]

Interim R&D Manager

[redacted]

Experiment Two : NHS Trust letter of access 2: Part 1

[redacted] **NHS**

Ms Frances Sapsford
[redacted]

Research and Developme[redacted]
[redacted]

12 October 2017

IRAS Number: 212048
CI: Frances Sapsford
Project Title: The effects of stroke on hand laterality judgement

Dear Ms Sapsford

Re: Letter of access for research

This letter confirms your right of access to conduct research throughout the sites of [redacted] for the purpose and on the terms and conditions set out below. This right of access commences on 16 October 2017 and ends on 31 May 2018 unless terminated earlier in accordance with the clauses below.

You have a right of access to conduct such research as confirmed in writing in the letter of permission for research from this NHS organisation. Please note that you cannot start the research until the Principal Investigator for the research project has received a letter from us giving permission to conduct the project.

The information supplied about your role in research at [redacted] has been reviewed and you do not require an honorary research contract with this NHS organisation. We are satisfied that such pre-engagement checks as we consider necessary have been carried out.

You are considered to be a legal visitor to [redacted] Trust premises. You are not entitled to any form of payment or access to other benefits provided by this NHS organisation to employees and this letter does not give rise to any other relationship between you and this NHS organisation, in particular that of an employee.

While undertaking research at [redacted] you will remain accountable to your employer [redacted] but you are required to follow the reasonable instructions of the Head of Research and Development, [redacted]s NHS organisation or those given on his behalf in relation to the terms of this right of access.

Where any third party claim is made, whether or not legal proceedings are issued, arising out of or in connection with your right of access, you are required to co-operate fully with any investigation by this NHS organisation in connection with any such claim and to give all such assistance as may reasonably be required regarding the conduct of any legal proceedings.

[redacted]

CHAIR: P[redacted]

Experiment Two: NHS Trust Letter of access 2 Part 2

You must act in accordance with [redacted] policies and procedures, which are available to you upon request, and the Research Governance Framework.

You are required to co-operate with [redacted] Trust in discharging its duties under the Health and Safety at Work etc Act 1974 and other health and safety legislation and to take reasonable care for the health and safety of yourself and others while on [redacted] You must observe the same standards of care and propriety in dealing with patients, staff, visitors, equipment and premises as is expected of any other contract holder and you must act appropriately, responsibly and professionally at all times.

You are required to ensure that all information regarding patients or staff remains secure and *strictly confidential* at all times. You must ensure that you understand and comply with the requirements of the NHS Confidentiality Code of Practice (http://www.dh.gov.uk/assetRoot/04/06/92/54/04069254.pdf) and the Data Protection Act 1998. Furthermore you should be aware that under the Act, unauthorised disclosure of information is an offence and such disclosures may lead to prosecution.

You should ensure that, where you are issued with an identity or security card, a bleep number, email or library account, keys or protective clothing, these are returned upon termination of this arrangement. Please also ensure that while on the premises you wear your ID badge at all times, or are able to prove your identity if challenged. Please note that this NHS organisation accepts no responsibility for damage to or loss of personal property.

We may terminate your right to attend at any time either by giving seven days' written notice to you or immediately without any notice if you are in breach of any of the terms or conditions described in this letter or if you commit any act that we reasonably consider to amount to serious misconduct or to be disruptive and/or prejudicial to the interests and/or business of this NHS organisation or if you are convicted of any criminal offence. Your substantive employer is responsible for your conduct during this research project and may in the circumstances described above instigate disciplinary action against you.

[redacted]ill not indemnify you against any [redacted] of any breach of confidentiality or breach of the Data Protection Act 1998. Any breach of the Data Protection Act 1998 may result in legal action against you and/or your substantive employer.

If your current role or involvement in research changes, or any of the information provided in your Research Passport changes, you must inform your employer through their normal procedures. You must also inform your nominated manager in this NHS organisation.

On your first visit to this Trust please present yourself to the R&D Department and bring with you one piece of photographic ID.

Yours sincerely

[redacted]

[redacted]

Research Ethics Application

for Taught Degree (Bachelors & Masters) students

Application for study involving Human Participants

NB: This form should be submitted to your Dissertation supervisor and Dissertation Module Leader once reviewed and signed by your supervisor. The form is designed as a discussion document as well as a record of ethical approval

All fields will expand as required.

What is the Effect of Hand Laterality Judgement practice in Stroke Patients?
2. As this a student project, please indicate type of course you are on by ticking the relevant box: □ BSc □ BA X MSc □ MA □ PgC □ PgD
3. Type of study X involves direct involvement by human subjects ☐ involves existing documents/anonymised data only.

Applicant information
4. Name of applicant ([redacted]
5. Project supervisor(s) Name(s): Frances Sapsford E-mail(s):[redacted]

This completed document must be discussed with your supervisor.

Supportive Materials Checklist

Please attach all necessary supportive materials and indicate in the checklist below.

Please tick as appropriate

Research protocol or research proposal (essential)	X
Participant Information Sheet	X
Consent Form	X
Letter of invitation	
Other (please state, and explain)	

Approval: Yes

Student signature: [redacted] **Date 09/03/2018**

Project supervisor: [redacted] **Date 09/03/2018**

Comments: I have discussed this project with Magnus and will be supervising the data collection.

Programme Team/Module Leader: [redacted] **Date 12/3/2018**

Comments: Please go ahead.

Consent form One : HLJ Pilot Study

Participant Consent Form

Pilot study of HLJ Test

Name of researcher:

Participants Name

Please initial box

I confirm that I have read and understand the information sheet for the above study.

I have had the opportunity to consider the information ask questions and have had these answered satisfactorily.

I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason.

I understand that all my responses will be anonymised before they are analysed and give the research team permission to access them.

I give my permission for my anonymised responses to be used in future studies.

I understand that the results of this study may be published in appropriate journals or presented at professional conferences.

I agree to take part in this study

Your signature will certify that you have voluntarily decided to take part in this research study having read and understood the information in the sheet for participants. It will also certify that you have had adequate opportunity to discuss the study with an investigator and that all questions have been answered to your satisfaction.

Signature of participant:... **Date:**................

Name (block letters):...

Signature of investigator:....................................... **Date:**................

Please keep your copy of the consent form and the information sheet together.

Researcher Contact Information:

Frances Sapsford

Consent Form Two: Experiment One

The Effects of Age on Hand Laterality Judgement

Participant Consent Form

Please answer the following questions by circling your responses:

Have you read and understood the information sheet about this study?

YES / NO

Have you been able to ask questions about this study?

YES / NO

Have you received enough information about this study?

YES / NO

Do you understand that you are free to withdraw from this study at any time, and without having to give a reason for withdrawal?

YES / NO

Your responses will be anonymised before they are analysed. Do you give permission for members of the research team to have access to your anonymised responses?

YES / NO

Do you agree to take part in this study?

YES / NO

Your signature will certify that you have voluntarily decided to take part in this research study having read and understood the information in the sheet for participants. It will also certify that you have had adequate opportunity to discuss the study with an investigator and that all questions have been answered to your satisfaction.

Signature of participant:.. **Date:**................

Name (block letters):...

Signature of investigator:....................................... **Date:**................

Please keep your copy of the consent form and the information sheet together.

Researcher Contact Information:

Consent Form Three: Experiment Two

Hand Recognition After Stroke.

CONSENT FORM

Participant Identification Number:

Name of Researcher:

Please initial box

1. I confirm that I have read the information sheet dated Oct 2016 for the above study. ☐

2. I have had the opportunity to consider the information, ask questions and have had these answered satisfactorily. ☐

3. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason, without my medical care or legal rights being affected. ☐

4. I understand that all my responses will be anonymized before they are analysed and give the research team permission to access them. ☐

5. I give permission to the researchers to access relevant sections of my medical records to identify the type of stroke I had. ☐

6. I understand that relevant sections of my medical notes and data collected from the study may be accessed by regulatory authorities or by persons form the NHS trust where it is relevant to my taking part in this study and I give permission for these persons to have access to my information. ☐

7. I understand that the results of this study may be published in appropriate journals or presented at professional conferences. ☐

8. I understand that the information held about me by the University of Cumbria will be accessed by the research team and may be used to contact me about the research. ☐

9. I agree to take part in the above study. ☐

______________________ ______________________ ______________________

Name of Participant Date Signature

______________________ ______________________ ______________________

Name of Person Taking consent Date Signature

Witness : If participant can only give verbal consent

______________________ ______________________ ______________________

Name of person Date Signature

Relationship to participant

Researcher Contact Information:

Consent Form 4 : Experiment Three.

Participant Consent Form

Please answer the following questions by circling your responses:

Have you read and understood the information sheet about this study? YES / NO

Have you been able to ask questions and had enough information? YES / NO

Do you understand that you are free to withdraw from this study at any time, and without having to give a reason for withdrawal? YES / NO

Your responses will be anonymized. Do you give permission for members of the research team to analyze and quote your anonymous responses? YES / NO

Please sign here if you wish to take part in the research and feel you have had enough information about what is involved:

Signature of participant:.. **Date:**................

Name (block letters):..

Signature of investigator:.. **Date:**................

Name (block letters):..

Participant Information Sheet 1: Experiment 1.

Participant Information Sheet

The Effects of Age on Hand Laterality Judgement

Investigators:

Frances Sapsford, Senior Lecturer in Physiotherapy

Dr xxxxxxxxxx,

About the study

This study will form part of the researcher's work towards a PhD. This research, aims to assess the effects of ageing on the performance of the Hand laterality Judgement Task. The speed at which individual's ability to judge whether different pictures are of right or left hands will be measured. The goal of the study will be to determine whether there are differences in reaction times between younger and older people.

Some questions you may have about the research project:

Why have you asked me to take part?

You have been asked to take part because you are in one of the required age groups in this research and meet the criteria for taking part in it.

What will I be required to do?

You will be required to take part in a computer based experiment. This experiment requires you to look at different pictures of hands and decide by pressing a key whether the hands are right or left hands. In the experiment you will view a total of 288 different pictures divided into 1 practice block and 5 blocks of 48 pictures each. You will be able to have a rest between each block of 48 pictures.

Where will this take place?

The experiment will normally take place in premises owned by the University of xxxxxx.

How often will I have to take part and for how long?

You will only be required to attend one session which will last approximately 1 hour.

When will I have the opportunity to discuss my participation?

Your participation will be discussed with you prior to completing a consent form and you will have the opportunity to ask any questions.

Who will be responsible for all the information when the study is over?

The lead investigator xxxxxxxx will be responsible for ensuring all the information will be kept securely when the study is over.

Who will have access to it?

The lead investigator and supervisors from the University xxxxxxx will have access to the data.

How long will data be kept and where?

All hard copy data will be kept in a locked filing cabinet in a locked office at the University of xxxxxx and will be destroyed after one year after the study has ended. All electronic data will be password protected and be kept in accordance with the Data protection act and the University of xxxxx regulations for storage of electronic data.

What will happen to the information when this study is over?

Any papers with identifiable information such as your name or other details will be securely destroyed after 1 year. All electronic information will be anonymised so that no specific names can be attached to it.

How will you use what you find out?

This study forms the first part of a series of experiments. The results from this study will be used to inform subsequent studies with people who have had a stroke. Results from this study will therefore be compared to results from future studies.

Will anyone be able to connect me with what is recorded and reported?

All data will be anonymised. It will not be possible to identify any particular participant form the results of the research. The names or locations of the participants will not be reported in any subsequent publications or conference presentations.

How long is the whole study likely to last?

It is anticipated that this study will last 6 months from September 2014.

How can I find out about the results of the study?

You will be asked whether you wish to receive a summary of the results of the study and if so this will be sent to you.

What if I do not wish to take part?

Your participation in the study is entirely voluntary.

What if I change my mind during the study?

You are free to withdraw from the study at any time without having to provide a reason for doing so.

Will I need to sign any documentation?

You will be asked to sign a consent form before participating in the study.

Whom should I contact if I have any further questions?

Please contact the researcher directly (details below).

Complaints

All complaints from the paritipants are in the first instance to be directed to the Director of Research Office and Graduate Studies, University of xxxxxxxx

Researcher Contact Information: XXXXXXXXXX

Participant Information Sheet Two: Experiment Two.

Hand Recognition after Stroke

Participant Information.

Researchers: XXXXXXXXXXX

About This Research.

This research is part of the main researcher's doctoral studies and is for educational purposes.

This research will find out how well stroke survivors can tell the difference between pictures of right and left hands compared with people who have not had a stroke.

Research has found that when we tell the difference between pictures of right and left hands a brain process called motor imagery happens.

Practicing some types of motor imagery exercises can be beneficial after a stroke but we do not know if practicing hand recognition exercises is of any use.

From past experiments we know that it is more difficult for stroke survivors to tell the difference between pictures of right and left hands. This research will add towards knowing why this happens.

We are looking for 25 stroke survivors to take part in the research and would like to invite you to be included.

What will I need to do?

Taking part is voluntary. You can stop taking part at any time without saying why. You can choose to attend at one of the following University xxxxxx locations: xxxxxx, xxxxxx, xxxxxx or xxxxxx.

You will need to attend for 1 session. The session will last about 2.5 hours. A consent form will be completed and then you will be asked some questions about how your stroke has affected you. You will also be asked to complete some short tests of vision; speaking and reading.

These questions and tests are to make sure you are able to participate with the experiment. It is important to know that we might decide that you cannot continue with the experiment at this stage.

Next, you will be asked to complete the **hand recognition test** on a computer.

You will be shown pictures of hands and you will need to press a button on the computer to indicate if you see a right hand or a left hand.

There are 288 pictures in the test. These are divided into 6 groups of 48. There is a rest between each group. The whole test takes about 1 hour to complete. You can stop the test at any time if you cannot complete it.

We will then measure the movement and strength in both your arms. Measurements will be taken from your shoulders, elbows and wrists. This will take about 30 minutes.

There will be time to rest between the tests and refreshments will be provided.

What are the benefits of taking part?

There are no benefits to you in taking part in this research and you should not expect to experience any changes in your condition.

What are the risks of taking part?

You can stop any of the tests at any time if you do not want to carry on.

You may find that the hand recognition test is tiring.

You may find the arm measurements uncomfortable especially if you have arm stiffness. However, the measurements will be taken by an experienced physiotherapist who will avoid causing any discomfort.

Who is responsible for my care?

During your visit, you will be under the care of the main researcher who is an employee of the xxxxxx.

The University xxxxxx holds Public liability insurance to cover death or injury to any other person or damage to their property arising in the course of University business activities.

The main researcher is a Health Care and Professions Council registered Physiotherapist and has professional liability insurance provided through the Chartered Society of Physiotherapy.

What will happen to my information?

All information collected from you will be kept confidentially and securely in line with the University of xxxxxx Policies.

Your name will not be used in any reports or presentations about this research**.**

You will be asked to allow the lead researcher to access your medical records. This is in order to identify the type of stroke you had.

Any information containing personal details will be securely disposed of 1 year following completion of the study.

Members of the research team will have access to your details and data from the study may be accessed by regulatory authorities.

What will happen to the results of the Study?

The results of the study will be reported in the lead researcher’s doctoral study. Reports of the study may be used in academic journal articles or conference presentations.

You will receive a summary of the findings from the study.

What do I do if I have a complaint?

Any complaints in the first instance should be directed to:

The Director of Research and Head of Graduate School, Research Office ,xxxxxxxx

If you have any questions about taking part in this research then please contact xxxxxx,.
Email xxxxxx
Tel: xxxxxx

Participant Information Sheet Three : Experiment three

What is the Effect of Hand Laterality Judgement practice in Stroke Patients?
A Student Study

Who is the researcher?
My name is xxxxxxx a MSc physiotherapy student,
My email is xxxxxx
You are free to contact me if you wish any more information.
I aim to respond to emails within 24 hours of receiving them.

What is the research about?

I am doing research on the effect of practicing exercises on the computer where you decide if a picture is of a right or left hand.

There is research suggesting that doing a hand laterality judgement task activates similar parts of the brain compared to actual movement.

I am investigating how practicing these exercises effects performance on a hand laterality judgement test.

I am also investigating if there may be any improvement in the affected upper limb after practicing with the computer programme.

What will I have to do?

I will arrange a time that is convenient for you to come.
You will be asked to come to the University xxxxxx campus.
You will be met at the main reception.

You will be asked a series of questions to see if you are suitable for the study. You will then be asked to complete a questionnaire about how the stroke has affected you.

Next you will be asked to do the hand laterality judgement task.
This will involve looking at various pictures of hands that are rotated at different angles. You will be asked to indicate which hand you think it is.
The whole test will take approximately 1 hour to complete.

After this the strength of your affected limb will be measured. This process will take about 10 minutes. The measures will be taken by my supervisor who is a qualified neurological physiotherapist.

We will then help you to access the Recognise™ app and download it to your mobile device. You will be shown how to use the Recognise and have the chance to practice.

You will be given a plan to practice using the app for 30 minutes for 5 days a week. You will need to practice for 3 weeks. Each week you will be asked to send your results to the researcher with an Email.

You will be given an appointment to return to the university after 3 weeks.

You will repeat the hand laterality judgement test and the range of movement tests to see if practicing with the app has made any difference.

You will be able to keep the app after the study if you wish.

Do I have to do this study? What happens if I don't want to do it anymore?

You are free to say no to the study.You can say that you don't want to participate at any point. You do not have to give a reason why you don't want to participate.

How is my data going to be stored?

All the data collected will be stored securely on the university computer system and will only be accessed by the researcher and suoervisors. You are free to do see the data about you if you wish.

How will the research be reported?

The research will be reported as a dissertation for the University of xxxxxx and the results will also be reported in my supervisors doctoral thesis.

The results may be reported in professional journal or a conference.

Throughout the entire write up no names will be written or any information that could potentially lead to someone identifying you.

What are the risks of doing this study?

The research that you are involved in has been reviewed by the university ethics board to see if there any significant risks to you.

This research project carries very low risk to yourself. You may find some of the questions at the first assessment distressing.

I cannot say if there will be any changes in your arm as a result of taking part.

This research will inform future researchers about the effects of practicing the hand laterality judgement task.

Who do I contact if I want to make a complaint?

If you wish to make a complaint about the research, you can contact my supervisor xxxxxx email xxxxxx tel xxxxxx

If you are not satisfied or wish to make a more formal complaint you should contact xxxxxx Director of Research Office, University of xxxxxx

Recruitment Information One : Experiment one

How well can you tell Right hands from Left hands?

Right Handed Volunteers Aged 60+ Required to Take Part in a Research Project.

Why am I doing this research ?

This research project will form part of my doctoral studies.

Deciding whether a picture is of the right or left hand is thought to involve brain process related to hand function. I want to find out whether these processes are affected by ageing.

I will be comparing the results from a group of healthy older adults with the results from a group of younger adults.

I will then compare the older adults results with those of similarly aged stroke survivors. Ultimately I want to find out if stroke survivors can benefit from doing exercises aimed at telling right hands from left hands. Previous research, with people with chronic pain , has shown that doing these types of exercises can help improve their condition. I want to find out if the same type of exercises can benefit stroke patients.

What will you need to do?

I need healthy people aged 60+ to volunteer to take a simple computer based test. In this test you will be asked to decide whether the pictures you will see are either of the right or left hand. For each picture, I will record how long it takes you to decide and whether you have chosen correctly. Although this sounds quite easy, previous research has found that some pictures are harder to identify than others and this relates to how difficult it would be to make the movement physically. See pictures below.

a) Easy  b) difficult. 

To take part you will need to be in good general health, right handed and not have any pain or condition affecting your hands. The computer test will take about 1 hour to complete and testing will take place at the University of xxxxxx Campus.

If you are interested in taking part and would like more information please contact: xxxxxx:

Email : xxxxxxx

Telephone: xxxxxx

Recruitment Information two : Experiment one

How well can you tell Right hands from Left hands?

Right Handed Volunteers Aged 18 – 30 Required to Take Part in a Research Project at the University xxxxxxx.

Investigators:

xxxxxx,

xxxxxx.

Why am I doing this research?

This research project will form part of my doctoral studies.

Deciding whether a picture is of the right or left hand is thought to involve brain process related to hand function. I want to find out whether these processes are affected by ageing.

Firstly, I will be comparing the results from a group of healthy older adults with the results from a group of younger adults.

I will then compare the older adults' results with those of similarly aged stroke survivors. Ultimately I want to find out if stroke survivors can benefit from doing exercises aimed at telling right hands from left hands. Previous research, with people with chronic pain, has shown that doing these types of exercises can help improve their condition. I want to find out if the same type of exercises can benefit stroke patients.

What will you need to do?

I need healthy people aged 18 -30 to volunteer to take a simple computer based test. In this test you will be asked to decide whether the pictures you will see are either of the right or left hand. For each picture, I will record how long it takes you to decide and whether you have chosen correctly. Although this sounds quite easy, previous research has found that some pictures are harder to identify than others and this relates to how difficult it would be to make the movement physically. See pictures below.

a) Easy  b) difficult. 

To take part you will need to be in good general health; **right handed** and not have any pain or condition affecting your hands. The computer test will take about 30 minutes to complete and testing will take place at the University xxxxxx

If you are interested in taking part and would like more information please contact: xxxxxxx

Email : xxxxxxx Telephone: xxxxxx

Recruitment Flyer : Experiment two

[redacted]

Hand Recognition after Stroke

Researchers.

[redacted]

Have you had a Stroke ?

Are you aged 60 or over?

Are you Right Handed?

We would like to invite you to take part in a research study to see how well you can tell right hands from left hands.

When we decide whether a picture is of a right or left hand, brain processes to do with hand function are triggered.

We want to find out how these processes are affected by having a stroke .

[redacted]

What is involved .

You will need to attend one session lasting 2 hours. In this session you will complete a hand recognition test on the computer. Some measurements of your arm will also be taken.

Who can take part ?

You may be able to take part if:

You are aged 60 or over.

You had a stroke at least 3 months ago.

You are right handed.

We would need more details from you about your stroke to confirm whether or not you can take part.

If you are interested and would like more information please contact:

[redacted]

Email : [redacted]

Telephone: [redacted]

Appendix 2 Data Collection Forms

Experiment One : Participant Data Collection Form

Office Use only Id Number

The Effects of Age on Hand Laterality Judgement.

Participant Information Form.
Please fill in your details below and either email or send the completed for to the address below.

Name: D.O.B

Address :

Telephone No:

Email:

Contact In case of emergency :

Have you had a stroke in the past Y/ N
If Yes please contact Frances Sapsford (see contact details below)

Do you have any conditions that affect either of your hands? Y/N
If Yes please contact Frances Sapsford (see contact details below)

Please list any other medical conditions you have ?

Please list any medications you currently take.

Do you do any exercise? Y/N
If yes, approximately how many times a week do you exercise.

Are you right Handed ? Y /N
If No please contact XXXXXX (see contact details below)

Do you wear glasses for reading? Y /N
If yes please bring them with you for the Appointment.

Please return the completed form to xxxxxxx
Email
Address:

Hand Recognition after Stroke

Participant Information Questionnaire.

Version 2: October 2016

Participant identification Number: ______________

Chief Investigator: **Frances Sapsford**

Address: **xxxxxxxxxx**

xxxxxxxxxx

xxxxxxxxx

Telephone: **XXXXXXXXX**

Email: xxxxxxxxxxx

CONTACT DETAILS

Visit Date: ________________________

Assessor: ________________________

Participant Details

Name: ____ D o B: __________/________/ _______

Address: ____

____

Tel No: ____

NHS Number: ____________________________

Date of stroke: ______/_______/_______.

General Practitioner Details

Name: _____________________________________ Tel No: _________________________

Address: ____

____

Hospital Details

Stroke/Rehabilitation Consultant: ____

Address: ____

___________________________________ Tel No: ____________________________

Informed Consent

Has the particpant given written informed consent before undergoing any study related procedure?

Yes ☐ Date of consent: ______________________________

No ☐ The participant **MUST NOT** be included in the study

Sex: ☐ Male

☐ Female

Handedness: ☐ Right

☐ Left (ineligible to participate in study)

☐ Ambidextrous

Current residence:

☐ Own house/flat

☐ Living with family/friends

☐ Sheltered housing

☐ Residential care/nursing home

☐ Other

Arm affected by stroke ☐ Right

: ☐ Left

☐ Both (ineligible to take part in study)

Eligibility Questionnaire

1. Are you aged 60 or over? Y / N
2. Are you Right handed? Y / N
3. Has at least 3 months passed since you had a stroke? Y / N
4. Is this your first ever stroke? Y / N
5. Do you have reduced arm movement on the stroke affected side? Y / N
6. Are you able to clearly see a computer screen with or without glasses? Y / N

Participants must satisfy all of the above criteria before they participate in the study. If the answer is no to <u>any</u> of the above questions, the participant is <u>ineligible</u> and must NOT enter the study. Therefore do not continue with this eligibility questionnaire.

7. Do you have any other arm or hand problems?
   e.g. severe pain / injury that affects you using your arms/hand Y / N
8. Is your affected arm extremely stiff meaning that you cannot move it even with help from someone else? Y / N
9. Have you used Hand Recognition exercises before? (also called laterality recognition). Y / N
10. Do you have any other neurological disorders eg . MS; Dementia; Parkinson's Disease? Y / N
11. Do you have any difficulties with speech or thinking that make it difficult for you to follow instructions? Y / N
12. Are you currently having therapy for your affected upper limb? Y /N

Participants must NOT meet any of the above criteria (7 – 12) to participate in the study. If the answer is YES to <u>any</u> of the above questions, the participant is <u>ineligible</u> and must NOT continue with. the study. Therefore do not continue with this questionnaire.

Details of Stroke from Participant and medical records.

Initial neurological impairment

(from the Participant and Medical notes)

	No	**Yes**	**R or L**
Unilateral weakness affecting face			
Unilateral weakness affecting arm/hand			
Unilateral weakness affecting leg/ foot			
Sensory deficit affecting face			
Sensory deficit affecting arm/hand			
Sensory deficit affecting leg/foot			
Homonymous hemianopia			
Visuospatial disorder e.g. sensory inattention			
Brainstem/cerebellar signs			
Other deficit If yes please explain below:			
Dysphasia			

Please tick as appropriate and note side if "Yes"

Current neurological impairment

	No	**Yes**	**R or L**
Unilateral weakness affecting face			

Unilateral weakness affecting arm/hand			
Unilateral weakness affecting leg/ foot			
Sensory deficit affecting face			
Sensory deficit affecting arm/hand			
Sensory deficit affecting leg/foot			
Homonymous hemianopia (test)			
Visuospatial disorder e.g. sensory inattention (test)			
Brainstem/cerebellar signs			
Other deficit If yes please explain below:			
Dysphasia			

Please tick as appropriate and note side if "Yes"

Stroke type (of most recent stroke)

Assumed infarct (no clinically relevant infarct on CT) ☐

Clinically relevant infarct on CT/MRI ☐

Intracerebral haemorrhage ☐

Subarachnoid haemorrhage ☐

No CT/MRI undertaken ☐

CT/MRI head scan report (from Medical Records)

____
____
____
____
____

Stroke subtype

TACS ☐

PACS ☐

LACS ☐

POCS ☐

Uncertain ☐

Was this a first ever stroke? Yes No

(Circle as appropriate)

if this is not the first ever stroke then the participant must be excluded from the study

Do you have/ any other medical conditions that you are currently having treatment or investigations for?

Condition	Date of Diagnosis	Treatment / investigation

Participants who disclose any other neurological condition or other conditions affecting the upper limb and/or hand function must be excluded from the study.

Have you had in the past any other medical conditions or operations?

Diagnosis/Disease/Abnormality	**Year of Diagnosis/Surgery (DD/MM/YYYY)**	**Currently Active? (Yes/No)**

About symptoms in your arm today.

a) Pain

If 0 (zero) is no pain at all, and the number 10 (ten) means as painful as it could be then how much pain do you have now?

☐

How would you describe the pain?

- Excruciating (very severe)
- Severe
- Moderate
- Mild
- None

(Participants with severe/ excruciating pain should not proceed with the study)

b) Sensation

If 0 is no feeling and 10 is full feeling how well can you feel your arm today ? Choose a number between 1 and 10.

c) Movement

If 0 is full movement and 10 is no movement how well can you move your arm today?

Choose a number between 0 and 10

Experiment 3 Participant Data Collection Form

This is just a brief questionnaire to see what type of stroke you have had and what current therapies you are currently using. If you don't know the answer to a question don't worry, just answer no.

Feel free to email this back to me or bring it with you when you come in for repeat testing.

I'd like to thank you again for taking part in this imagery research and your valuable contribution to the current body of knowledge of imagery programmes in stroke.

How old are you? …………………………………………………..

What was your Occupation/Job? …………………………………………………..

What is you dominant hand? (Before and after the stroke?)

…………………………………………………....

How long ago was your Stroke? …………………………………………………..

What Kind of Stroke was it? …………………………………………………..

What Side is the stroke? …………………………………………………..

Do you know which artery was involved? Yes/No

If Yes please state which artery it was

………………………………………………….

Do you know which part of the Brain was involved? Yes/ No

If yes Please state which part of the brain is affected?

What current therapy(s) are you using? Physiotherapy/

Exercise/ robotics/ muscle relaxants

Other(s) …………………………………………………

Edinburgh Handedness Scale (Short form) Veale et al (2012)

Edinburgh Handedness Inventory - Short Form

Please indicate your preferences in the use of hands in the following activities or objects:

	Always right	Usually right	Both equally	Usually left	Always left
Writing					
Throwing					
Toothbrush					
Spoon					

Scoring:

For each item: Always right = 100; Usually right = 50; Both equally = 0; Usually left = -50; Always
left = -100

To calculate the Laterality Quotient add the scores for the four items in the scale and divide this by four:

Writing score	
Throwing score	
Toothbrush score	
Spoon score	
Total	
Total ÷ 4 (Laterality Quotient)	

Scores Right handed 61 -100 ; Left handed -100 –61 mixed handed -60 -60

Range of Movement Measurement Protocol

Starting Position all Seated	Movement	Stabilisation	goniometer axis	Proximal Arm	Distal arm	
Wrist extension . Elbow flexed to 90° Forearm in Pronation : hand over the edge of the table	Participant actively extends wrist keeping fingers in flexion	. Forearm stabilised to prevent pronation / supination	Over anterior radio carpel joint.	Anterior mid line of forearm	Anterior mid line touching 3rd metacarpal head.	Figure has been removed due to copyright restrictions
Active Wrist Flexion. Elbow flexed to 90° Forearm in Pronation : hand over the edge of the table	Participant actively flexes wrist allowing fingers to relax.	Forearm stabilised to prevent pronation / supination	Over Posterior radio carpel joint	Posterior mid line of forearm	Posterior mid line touching 3rd metacarpal head.	Figure has been removed due to copyright restrictions
Active Radial Deviation Elbow flexed to 90° forearm in pronation. Hand supported on table	participant actively moves hand into radial deviation.	Forearm stabilised to prevent pronation / supination	Over posterior l Capitate	Posterior mid line of forearm	Parallel to the long axis of the 3rd metacarpal	Figure has been removed due to copyright restrictions
Active Ulnar Deviation. Elbow flexed to 90° forearm in pronation. Hand supported on table	Participant actively moves hand into Ulnar Deviation	Forearm stabilised to prevent pronation / supination	Over posterior l Capitate	Posterior mid line of forearm	Parallel to the long axis of the 3rd metacarpal	Figure has been removed due to copyright restrictions

Starting Position all Seated	Movement	Stabilisation	goniometer axis	Proximal Arm	Distal arm	
Active Forearm pronation Shoulder adducted into side. Elbow flexed to 90° Forearm in mid position	Participant actively turns hand over into pronation.	Stabilise humerus to prevent abduction / adduction	Lateral and posterior to the ulnar styloid process.	Longitudinal axis of the humerus	Parallel to the dorsal forearm	Figure has been removed due to copyright restrictions
Active forearm Supination Shoulder adducted into side. Elbow flexed to 90° Forearm in mid position	Participant actively turns hand over into supination	Stabilise humerus to prevent abduction / adduction	Medial and posterior to the Ulnar styloid.	Longitudinal axis of the humerus	Parallel to the Volar surface of the forearm	Figure has been removed due to copyright restrictions
Active Elbow flexion . Shoulder and Forearm resting in mid position. Elbow Straight	Participant actively flexes the elbow	Upper arm stabilised to prevent rotation	over lateral epicondyle of the Humerus	longitudinal axis of the Humerus . pointing towards the tip of the acromion	Longitudinal axis of Radius pointing toward the radial styloid	Figure has been removed due to copyright restrictions
Active Elbow Extension. Shoulder and Forearm resting in mid position. Elbow fully flexed	Participant actively straightens the arm to extend the elbow.	Upper arm stabilised to prevent rotation	over lateral epicondyle of the humerus	longitudinal axis of the Humerus . pointing towards the tip of the acromion	Longitudinal axis of Radius pointing toward the radial styloid	Figure has been removed due to copyright restrictions
Active Shoulder medial rotation Sitting Shoulder in mid position and elbow flexed to 90°. Forearm in mid position resting on table	Participant actively moves forearm in towards body	Distal end of humerus stabilised. Scapular and thorax stabilised	Over olecranon process aligned with the humeral shaft pointing towards the head of humerus.	Parallel to the supporting surface	Longitudinal axis of the ulna pointing towards ulnar styloid	

Starting Position all Seated	Movemen t	Stabilisatio n	goniometer axis	Proximal Arm	Distal arm	
Active Shoulder Lateral rotation Sitting Shoulder abducted and elbow flexed to 90°.Upper arm resting on table. Forearm in mid position	**Participant** actively moves forearm away from the body	Distal end of humerus stabilised. Scapular and thorax stabilised	Over olecranon process aligned with the humeral shaft pointing towards the head of humerus.	Parallel to the supporting surface	Longitudinal axis of the ulna pointing towards ulnar styloid	

Procedure for Motricity Index. (Colin and Wade 1990)

Participant is positioned sitting in front a table with both arms resting on the table.

1. **Pinch grip** : a 2.5 cm cube is placed on the table in front.

   The participant is instructed to grip the cube between the thumb and forefinger.

   If the participant is unable to reach the cube on the table, the examinor may place the cube between the participants thumb and index finger.

   Score for pinch grip.

0	No movement
11	Beginnings of prehension (any movement of finger or thumb)
19	Grips cube, but unable to hold against gravity
22	Grips cube, held against gravity, but not against weak pull
26	Grips cube against pull, but weaker than other side
33	Normal pinch grip

2. **Elbow flexion:** The elbow is tested with the elbow flexed to 90°, forearm horizontal and upper arm vertical. The Participant is instructed to bend the elbow so that the hand touches the shoulder. The examiner resists with a hand on the wrist, and monitors the biceps. If there is no movement, the examiner may support the elbow in extension, and give a score of 14 if movement is then seen.

3. **Shoulder abduction**: The elbow is fully flexed and against the chest .The participant is asked to abduct the arm. The examiner monitors contraction of the deltoid (movement of shoulder girdle does not count-there must be movement of humerus in relation to scapula). A score of 19 is given when the shoulder is abducted to more than 90˚ beyond

the horizontal against gravity but not against resistance.

Score for Elbow and Shoulder

0	No movement
9	Palpable contraction in muscle, but no movement
14	Movement seen, but not full range/not against gravity
19	Movement; full range against gravity, not against resistance
25	Movement against resistance, but weaker than other side
33	Normal power

Motricity Index Recording Sheet

Participant ID Number______________________________

Arm (in sitting position)

A. Pinch grip; 2.5cm cube between thumb and forefinger

B. Elbow flexion; from 90 degrees, voluntary contraction/movement

C. Shoulder abduction; from against chest

A. Pinch grip

0	No movement
11	Beginnings of prehension (any movement of finger or thumb)
19	Grips cube, but unable to hold against gravity
22	Grips cube, held against gravity, but not against weak pull
26	Grips cube against pull, but weaker than other side
33	Normal pinch grip

Score R arm ☐ Score L arm ☐

B. Elbow flexion

0	No movement
9	Palpable contraction in muscle, but no movement
14	Movement seen, but not full range/not against gravity
19	Movement; full range against gravity, not against resistance
25	Movement against resistance, but weaker than other side
33	Normal power

Score R arm ☐ Score L arm ☐

C. Shoulder abduction

0	No movement
9	Palpable contraction in muscle, but no movement
14	Movement seen, but not full range/not against gravity
19	Movement; full range against gravity, not against resistance
25	Movement against resistance, but weaker than other side
33	Normal power

Score R arm ☐ Score L arm ☐

Arm score = scores (1) + (2) + (3) + 1 (to make 100)

TOTAL RIGHT ARM ☐ **TOTAL LEFT ARM** ☐

Line bisection test_(Wilson, Cockburn, & Halligan, 1987)

Particpant ID

Instructions : Draw a Cross in the centre of each line.

Double Letter cancellation test (Diller et al 1974)

Participant ID

Instructions : Cross Out Every E and R

AEIKNRUNPOEFBDHRSCOXRPGEAEIKNRUNPB

BDHEUWSTRFHEAFRTOLRJEMOEBDHEUWSTRT

NOSRVXTPEBDHPTSIJFLRFENOONOSRVXTPE

GLPTYTRIBEDMRGKEDLPQFZRXGLPTYTRIBS

HMEBGRDEINRSVLERFGOSEHCBRHMEBGRDEI

E & R