Body Schema as Assessed by Upper Limb Left/Right Judgment Tasks Is Altered in Stroke: Implications for Motor Imagery Training

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Background and Purpose: Individuals with stroke often experience significant impairment of the upper limb. Rehabilitation interventions targeting the upper limb are typically associated with only small to moderate gains. The knowledge that body schema can be altered in other upper limb conditions has contributed to the development of tailored rehabilitation approaches. This study investigated whether individuals with stroke experienced alterations in body schema of the upper limb. If so, this knowledge may have implications for rehabilitation approaches such as motor imagery.

Methods: An observational study performed online consisting of left/right judgment tasks assessed by response time and accuracy of: (i) left/right direction recognition; (ii) left/right shoulder laterality recognition; (iii) left/right hand laterality recognition; (iv) mental rotation of nonembodied objects. Comparisons were made between individuals with and without stroke. Secondary comparisons were made in the stroke population according to side of stroke and side of pain if experienced.

Results: A total of 895 individuals (445 with stroke) participated. Individuals with stroke took longer for all tasks compared to those without stroke, and were less accurate in correctly identifying the laterality of shoulder ($P < 0.001$) and hand ($P < 0.001$) images, and the orientation of nonembodied objects ($P < 0.001$). Moreover, the differences observed in the hand and shoulder tasks were greater than what was observed for the control tasks of directional recognition and nonembodied mental rotation. No significant differences were found between left/right judgments of individuals with stroke according to stroke-affected side or side of pain.

Discussion and Conclusions: Left/right judgments of upper limb are frequently impaired after stroke, providing evidence of alterations in body schema. The knowledge that body schemas are altered in individuals with longstanding stroke may assist in the development of optimal, well-accepted motor imagery programs for the upper limb.

Video Abstract available for more insights from the authors (see the Video, Supplemental Digital Content 1, available at: http://links.lww.com/JNPT/A394).

Key words: *left/right judgment, mental practice, motor imagery, stroke, upper limb*

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INTRODUCTION

Stroke is a common cause of death and a leading cause of disability.[1,2] Individuals with stroke commonly experience persistent impairments of the upper limb including paresis, abnormal muscle tone, pain, and changes in somatosensation,[3,4] leading to reductions in functional arm use.[3] Poor recovery of upper limb function following stroke has been associated with poorer perceived quality of life.[5] Stroke survivors also experience more difficulties participating in work and leisure activities than those without,[6] and have a higher utilization of health care services to manage problems that arise as a result of their stroke than those without.[7]

It has been proposed that stroke survivors may also experience alterations in body schema.[8] Body schema is viewed as the individuals' internal representation of their body shape and postures.[9] Working body schema continuously tracks an individual's movements and positions of one's body parts in space.[10] The construction and ongoing maintenance of how one's body feels to its owner is considered to be malleable, formed by tactile, proprioceptive, and visual inputs, and modulated by memories, beliefs, attitudes and perceptions.[11] Modifications to how individuals perceive their body may occur when the coping strategies of individuals related to body reality are overwhelmed by factors such as injury, disease, disability, or social stigma.[12]

Alterations in body schema have been observed in chronic conditions other than stroke such as neck, back, and upper limb pain.[13-16] It has also been observed with a range of complex chronic conditions that involved chronic pain.[17,18] It has been proposed that these alterations in body schema may be associated with changes in cognitive and somatosensory functions,[14] and may involve disruptions in the cortical proprioceptive representation of the body.[13,19] Changes in body schema and associated functions may therefore influence the planning and execution of movements,[13,19] and negatively impact upper limb recovery.

An established method to assess an individual's working body schema is to assess implicit motor imagery ability.[20] The most common approach to the assessment of implicit motor imagery is the left/right judgment task (LRJT).[21] The LRJT involves presentation of images of body parts to the individual, who is then asked to determine whether these images belong to the left or right side of the body.[22] In determining the handedness of a presented hand image, individuals unconsciously imagine moving their own hand into the orientation of the stimulus image.[20,22] Left-handed and right-handed individuals mentally orientate their own hand to match that of the stimulus presented in similar fashion.[23] The task is associated with activation of sensorimotor cortical areas responsible for control of the contralateral hand and other areas that are commonly activated during motor behavior, as observed in functional neuroimaging studies.[19]

Individuals with stroke are known to be more likely to develop chronic pain than those without stroke.[24-28] Shoulder pain and complex regional pain syndrome (CRPS) of the hand are common post-stroke.[29,30] Arm pain further influences the abilities of individuals with stroke to perform personal care, household, and leisure activities beyond the impact of the initial stroke.[29] Given people with stroke often experience sensory disturbances (eg, of tactile perception and proprioception) and are more likely to live with chronic pain than nonstroke individuals, it is reasonable to expect that stroke survivors may experience altered body schema. However, it is currently unknown whether altered body schema is associated with stroke and whether the presence of chronic upper limb pain influences this.

Current stroke guidelines identify a need for improved rehabilitation of upper limb function, and a lack of evidence for effective treatment of chronic upper limb pain following stroke.[31,32] The use of mental practice of motor tasks (motor imagery) is an established and well-utilized intervention in upper limb rehabilitation following stroke,[33,34] and has recently been utilized in the treatment of chronic pain in nonstroke populations.[35] Mental practice of motor tasks is often referred to as explicit motor imagery.[36] This term is used to define that individuals are aware that they are imagining moving, and distinguishes itself from implicit motor imagery, where individuals are considered to be unaware that they are imagining their orientation of one's body part, in response to presentation of an image of a body part.[19] Neuroimaging studies have shown that explicit motor imagery involves activation of similar overlapping brain areas as actual physical movement.[37,38] However, use of motor imagery is currently listed as a weak recommendation in the most recent clinical guidelines,[31] due to evidence showing only small to moderate benefit. Compliance of motor imagery intervention programs has also been raised as an issue for both therapists and patients,[39] with some individuals with stroke experiencing difficulty in the learning and performance of motor imagery tasks.[40]

In explicit motor imagery, the representation of one's body is transformed to match the action of the proposed task. An individual's body schema serves a critical function in the spatial orientation of the body necessary for movement perception and action production.[20] It is therefore possible that alterations or disorders of working body schema, as measured by implicit motor imagery ability, may influence individuals' ability to learn and perform explicit motor imagery in an efficient manner that is satisfying and salient to individuals in their ongoing rehabilitation.

The primary aim of the current study was to identify whether pain-free individuals with stroke (>3 months) displayed a disorder of body schema compared with those without stroke, as measured by LRJTs consisting of images of body positions of the shoulder/hand.[19] Measures of control for directional recognition and mental rotation of nonembodied objects were included.

The secondary aims were to: (i) identify whether a difference in left/right judgments of shoulder/hand images exists in individuals according to side of stroke (ie, "affected" limb and "nonaffected" limb); and (ii) identify whether a difference in left/right judgments exists in individuals with stroke who experience chronic pain of either the shoulder or hand according to side of body affected.

METHODS

An online research platform including a questionnaire and LRJTs was designed for individuals with and without stroke. Recruitment was through flyers, newsletters, website listings, social media links, and a research register for stroke survivors. Potential participants were presented with a project information sheet online and asked whether they wished to proceed. Participants chose the environment, time of testing, and use of either a tablet device or desktop computer. Use of tablet devices for similar judgment tasks has good to excellent concurrent validity with desktop computers.[41] Pilot trials were performed by individuals with and without stroke, and testing took 15 to 20 minutes. Data were collected between October 2015 and October 2018.

The study protocol (Ethics ID 1340670) was approved by the Human Research Ethics Committee of the University of Melbourne, the University Human Ethics Committee of La Trobe University, and the Institutional Review Board of the University of California, San Francisco.

This article conforms to STROBE (Strengthening the Reporting of Observational Studies in Epidemiology) guidelines.[42]

Participants

Individuals were eligible to participate in the survey if they were older than 18 years and able to provide consent. Potential participants with stroke were excluded if they had been diagnosed with a neurological condition other than stroke, or their stroke was less than 3 months prior to participating. Nonstroke individuals who participated in the study who reported chronic pain were also excluded. Participants were allocated into stroke and nonstroke groups for analysis purposes.

Questionnaire

The online questionnaire sought age, gender and, if experienced, details of stroke. Participants with stroke were asked to indicate through the use of drop-down boxes: number of strokes, dates of first and most recent strokes (if applicable), type of stroke (bleed/clot/both/not sure), and side of brain affected by stroke/s (left/right/both/unknown). Participants were also asked whether they experienced persistent pain (>3 months), and if so, to indicate the body region of their pain experience. As the study was performed anonymously online, physical assessments of the upper limb (eg, strength, somatosensation, and motor control) were not able to be performed.

Left/Right Judgment Tasks

Participants were guided through 4 separate judgment tasks using the Recognise research platform (NOI, Adelaide, Australia; www.noigroup.com). Instructional pages with sample images were provided prior to each task (see Appendix 1, Supplemental Digital Content 2, available at: http://links.lww.com/JNPT/A397). Participants were asked to indicate a left-sided judgment, using a finger(s) of choice, by depressing the "V" key (on central left of keyboard) and a right-sided judgment by depressing the "N" key (on central right of keyboard). They were advised that they would have a maximum of 15 seconds (for tasks 1-3) or 30 seconds (for task 4) to respond before the next image was automatically shown. Participants were asked to provide a response as soon as they had made a judgment decision. Maximal display time was increased for task 4 (nonembodied mental rotation task) due to the observed difficulties in pilot testing by individuals with and without stroke, consistent with findings that object recognition with abstract stimuli is more difficult than with embodied stimuli.[43] Measurements of response time and accuracy were taken for each image.

The first judgment task (directional recognition task) displayed 40 images of arrows of different size and boldness that were either pointing left or right (20 of each). This task was included as a control measure for response time in a choice reaction task that was relevant to the embodied LRJTs (ie, directional recognition with a left/right scenario), rather than a measure of simple response time. The second (shoulder LRJT) and third judgment tasks (hand LRJT) displayed images of the shoulder and hand, respectively. Each task utilized 5 different images, presented in original and reflected form, at rotations of 0°, 90°, 180°, and 270°, thereby also including a mental rotation element. This equated to 40 images (20 left and 20 right) for each task. Participants were asked to indicate whether the image was a left or right body part. The fourth judgment task (nonembodied mental rotation task) utilized 4 different Shepard Metzler images[44] displayed as rotated pairs that were either the same or reversed (mirrored), representing a left/right scenario at rotations of 0°, 90°, 180°, and 270°. Participants were asked to indicate whether the pairs were the same or different. Order of presentation of images in each task was randomized, and each participant received all the images. This task was designed as a control for mental rotation ability, as it is considered that the processes involved in laterality judgments of body parts that are presented visually are sculpted in a somatic or biomechanical space rather than a visual space, compared with the mental rotation of shapes where conversions are carried out in a viewer-based or scene-based visual space.[19,45] See Figure 1 for sample images for each task.

Data Processing and Analysis

Left/right judgment performance was analyzed for each task. Participants' data were excluded if the task was not

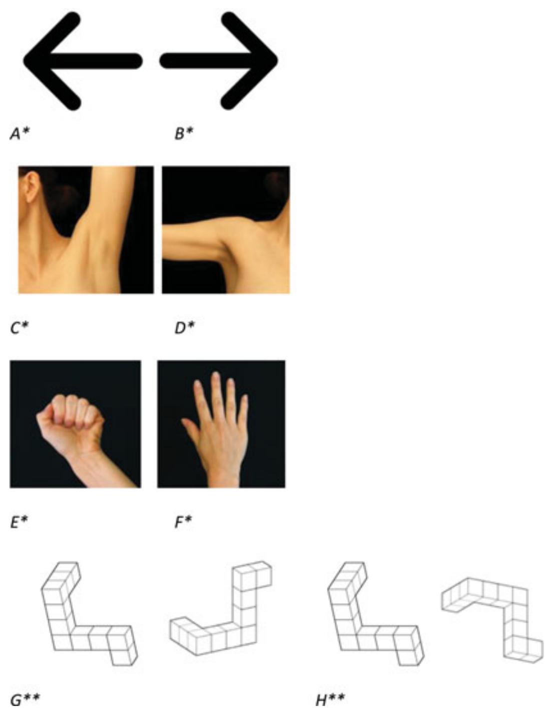

Figure 1. Sample images used in the judgment tasks. *A = left arrow; B = right arrow; C = left shoulder; D = right shoulder; E = left hand; F = right hand; G = paired images (same); H = paired images (different).* *Body images used with permission of NOIgroup Publications. **Shepard Metzler images from the mental rotation stimulus library.[46] This figure is available in color online (www.jnpt.org).

Table 1. Age and Gender Reported Within Samples

	Stroke (n = 445)	No Stroke (n = 450)	*P* Value
Age, mean (SD), y	58 (12)	41 (13)	<0.001[a]
Gender, female	230 (52%)	314 (70%)	<0.001[b]

[a]Student *t* test.
[b]χ^2.

completed in its entirety, and if the response time was less than 500 ms as this time frame more likely represents a guess.[13] If the response time for 8 consecutive images reached the maximal time limit, then the data were excluded, assuming the internet/computer had failed, or that the participant was either distracted or unable to complete the task.

Participants were grouped for analysis purposes to address each aim, based on: (i) presence of stroke (≥3 months) in individuals who did not experience chronic pain (analysis 1); (ii) affected or unaffected side of stroke in pain-free individuals with stroke (analysis 2); (iii) affected or unaffected side of pain in individuals with stroke and chronic pain relevant to the body image displayed (ie, shoulder pain/hand pain) (analysis 3).

Due to an established relationship between chronic upper limb pain and left/right judgment abilities in other nonstroke conditions,[46-48] participants with chronic pain (with and without stroke) were therefore not included in the primary analysis (analysis 1). For the secondary analyses, participants were excluded if there was insufficient information to determine group allocation (eg, indicated "unknown" or unable to indicate side of stroke). Individuals were also excluded if they reported multiple strokes with both sides being affected (for analysis 2), or if they experienced chronic pain bilaterally (for analysis 3).

Statistical analyses were performed using IBM SPSS Statistics, Version 25. Baseline characteristics were summarized using descriptive statistics. Means and standard deviations (SDs) were calculated for response time and compared using the Student *t* test. Accuracy scores, as measured by percentage of correct responses, were compared using χ^2.

RESULTS

Participants

A total of 895 people from 36 countries (445 with stroke and 450 without) who met the inclusion criteria participated. Stroke participants were older, while nonstroke participants were more likely to identify as being female. A summary of age and gender of participants is reported for individuals with and without stroke in Table 1. Chronic pain was reported by 271 of the stroke participants (106 shoulder pain and 81 hand pain). All 4 tasks were completed by 834 participants (413 with stroke and 421 without). The successful completion rates by participants for each task are represented in Table 2. The groups of participants used for each analysis of the respective tasks are represented in Figure 2. Those individuals with chronic pain that did not include the region of the body image presented in the task were excluded from the analysis of the respective task.

Statistical power was calculated post hoc based on participation rates in the nonembodied mental rotation task (task 4), given that it represented the smallest participation numbers. Power was calculated using G power for small to medium effect size (0.3) as 0.88.

Individuals with stroke demonstrated a longer response time than nonstroke individuals in the directional recognition task (mean difference = 0.45 seconds), beyond what can be accounted for by the age difference of the groups.[49] Both groups performed the task well (accuracy >98%).

Primary Aim: Differences in Mental Rotation and Left/Right Judgments Between Pain-Free Groups With and Without Stroke

Stroke participants were less accurate and took longer to respond for all mental rotation judgment tasks: shoulder recognition, hand recognition, and Shepard Metzler image pairs, compared with those without stroke. Response time differences were greater than in the initial directional recognition task. Means and standard deviations for all tasks comparing pain-free individuals with and without stroke are listed in Table 3. The number of participants included for each analysis is indicated relevant to the primary aim once the relevant inclusion and exclusion criteria were applied.

Secondary Aims: Between-Group Comparisons in Left/Right Judgments of Body Positions of Stroke Survivors According to Side of Stroke and Side of Pain

No significant differences were detected in either response time or performance accuracy of the LRJTs for the shoulder and hand images, when comparisons were made by side of stroke (affected vs nonaffected) or by side of pain

Table 2. Numbers of Participants (by Group) Completing Each Task[a]

Participant Group	Task 1	Task 2	Task 3	Task 4
Nonstroke: Pain-free	450	434	422	421
Stroke: Pain-free	174	156	154	151
Stroke: Chronic pain (any region)	(283)	(269)	(276)	(262)
Stroke: Pain-free (affected side)		128	122	
Stroke: Pain-free (nonaffected side)		128	122	
Stroke: Pain (image region, painful side)		88	81	
Stroke: Pain (image region, nonpainful side)		88	81	

[a]Task 1 = directional recognition task; task 2 = shoulder recognition task; task 3 = hand recognition task; task 4 = nonembodied mental rotation task.

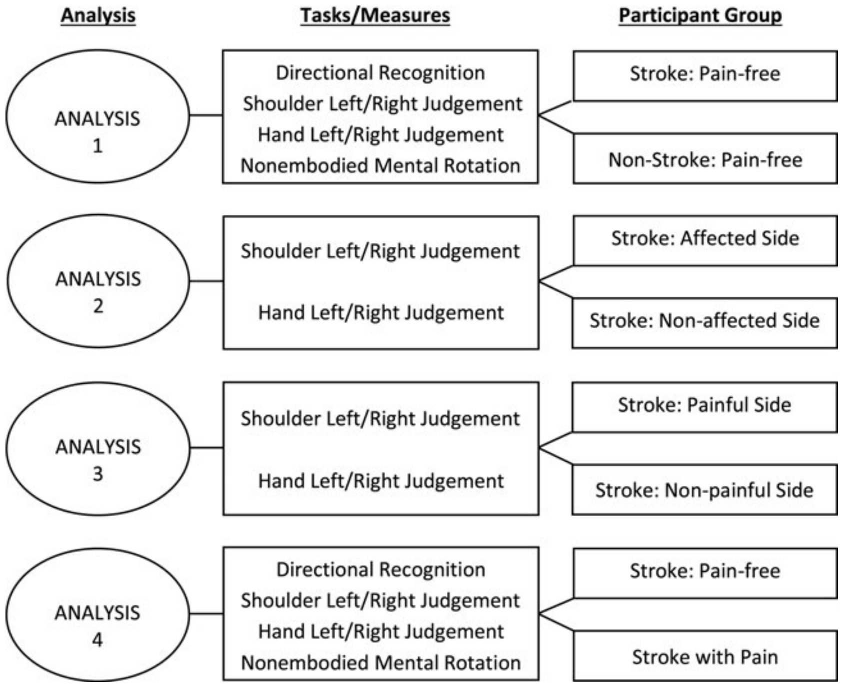

Figure 2. Diagram showing participant groups and tasks/measures utilized for each analysis.

(affected vs nonaffected). Means and standard deviations for comparisons by affected side of stroke are listed in Table 4, and for comparisons by affected side of limb pain in Table 5.

DISCUSSION

Differences in Mental Rotation and Left/Right Judgments Between Pain-Free Groups With and Without Stroke

We found that individuals with chronic stroke (mean 7 years post-stroke) were less accurate in identifying the laterality of shoulder and hand images and took longer to respond, than individuals without stroke. This could not be explained by difficulties in directional recognition, given the high accuracy rate for both groups and magnitude of observed differences in task 1 response time. Left/right processing is an important part of body perception, and the LRJT is considered an assessment of working body schema.[50] Poor accuracy in left/right judgment performance has been described as a reflection of disrupted cortical proprioceptive representations of body schema,[15] while response times are considered to be indicative of the individuals' processing of bodily spatial representations.[15] Our finding of impaired implicit motor imagery ability is indicative of the presence of working body schema disorder post-stroke.

Between-Group Comparisons in Left/Right Judgments of Body Positions of Pain-Free Stroke Survivors According to Side of Stroke

Our findings of reduced overall accuracy and increased response time in chronic stroke are consistent with some studies in acute and subacute stroke.[51,52] These studies reported

Table 3. Task Comparisons for Pain-Free Individuals With and Without Stroke

	Stroke n = 174	No Stroke n = 450	*P* Value
Directional recognition task			
• Response time, s	1.29 (1.19)	0.84 (0.64)	<0.001[a]
Shoulder task			
• Response time, s	3.73 (2.75)	2.28 (1.73)	<0.001[a]
• Accuracy	81.7%	91.7%	<0.001[b]
Hand task			
• Response time, s	3.58 (2.59)	2.55 (2.03)	<0.001[a]
• Accuracy	81.9%	91.4%	<0.001[b]
Nonembodied mental rotation task			
• Response time, s	5.40 (3.54)	4.60 (3.29)	<0.001[a]
• Accuracy	60.3%	70.9%	<0.001[b]

[a]Student *t* test.
[b]χ^2.

Table 4. Task Comparisons for Pain-Free Individuals With Stroke by Affected Side

	Affected	Nonaffected	*P* Value
Shoulder task (n = 128)			
• Response time, s	3.74 (2.95)	3.60 (2.65)	0.071[a]
• Accuracy	81.0%	81.9%	0.397[b]
Hand task, n = 122			
• Response time, s	3.42 (2.45)	3.57 (2.59)	0.051[a]
• Accuracy	82.3%	80.8%	0.172[b]

[a]Student *t* test.
[b]χ^2.

differences in accuracy and response time. In comparison, Lundquist and Nielsen[53] did not find a significant difference in accuracy in a small stroke sample (n = 31), but failed to assess response time. However, unlike the results reported for acute stroke by Kemlin et al,[52] we did not find that the side of stroke influenced results in our chronic stroke population. We believe results of this current study add to the growing knowledge of altered body schema in survivors of stroke.

Between-Group Comparisons in Left/Right Judgments of Body Positions of Stroke Survivors According to Side of Chronic Pain (If Experienced)

We did not find a significant difference in laterality recognition of shoulder and hand images between images representing the affected side and the nonaffected side in those individuals with stroke experiencing chronic pain in that region. This contrasts with previous findings of other chronic neuropathic and musculoskeletal pain populations involving the limbs.[21,48] To our knowledge, this is the first time that this phenomenon has been studied in stroke, a population where chronic pain is commonly experienced.[25,54]

Studies of LRJT in other complex conditions such as chronic pain have found that laterality of body part recognition is affected in recognition of images representing the symptomatic side.[15] While individuals with stroke had reduced ability to identify the laterality of the body images compared with those without stroke, our secondary analyses did not reveal significant differences in individuals with stroke between images of the affected and non-affected sides (as grouped by nominated side of stroke) for either response time or accuracy. This nondifferentiated impairment is suggestive of alterations in body schema that are not unique to the affected body side.

The effects of stroke, such as alterations in body schema, might be expected to be unilateral in nature due to the acute focal lesion typically being in a single hemisphere, and evidence that the left temporal cortex is considered to be associated with knowledge of body representation.[55] The unilateral nature of impairment has been observed in impairment of laterality recognition of images of the affected side in acute left hemisphere strokes.[52] However, alterations in neural connections also occur over time in the contralesional hemisphere following unilateral cortical damage,[56-58] and alterations in brain activation are evident in both hemispheres in relation to changes in both motor performance[59] and somatosensory stimulation.[60] Further, the presence of somatosensory loss following stroke is often observed on both the ipsilateral and contralateral sides,[61,62] and unilateral tactile stimulation of the hand has also been associated with bilateral activation of somatosensory regions.[63] It may be that disruption of the broader network impacted our findings of nondifferentiated effect on LRJT in individuals with long-term stroke. These findings would benefit from further prospective interrogation for possible relationships relative to site of lesion and duration post-stroke through the use of functional neuroimaging studies.

It has been proposed that, by utilizing images of body parts, the LRJT is a measure of implicit motor imagery ability,[15] and is therefore a recommended measure of working body schema.[19,21] Enhanced ability in mental rotation of body images may contribute to improved effectiveness in the ability to perform mental practice of skilled movements.[64] Upper limb LRJTs have been shown to be enhanced in individuals with enhanced motor skills,[65] and reduced in the recognition of images representing the affected side in many painful chronic upper limb conditions associated with impaired use of

Table 5. Task Comparisons for Individuals With Stroke by Side of Chronic Pain

	Pain Side	No Pain Side	*P* Value
Shoulder task (n = 88)			
• Response time, s	3.74 (2.73)	3.76 (2.70)	0.813[a]
• Accuracy	79.4%	78.6%	0.502[b]
Hand task (n = 81)			
• Response time, s	3.58 (2.64)	3.62 (2.73)	0.717[a]
• Accuracy	84.6%	83.4%	0.360[b]

[a]Student *t* test.
[b]χ^2.

the limb such as CRPS,[47] frozen shoulder,[46] and carpal tunnel syndrome.[48]

Improvements in left/right judgment have been achieved through practice of the LRJT itself,[66] while training of the LRJT prior to mental practice of motor tasks has been associated with enhanced outcomes when utilized as part of a graded motor imagery program[67] in the treatment of CRPS, further supported by observations of changes in activation in somatosensory regions.[68] This program combined, in order, left/right judgment training, mental practice of motor tasks, and mirror therapy.[67] Improvements in left/right judgment ability have also been associated with rehabilitation gains following total knee replacement surgery,[50] further supporting the proposal that the LRJT is an indirect assessment of working body schema.[50]

Stroke rehabilitation has long utilized motor imagery in the functional rehabilitation of the upper limb.[69-71] In a recent systematic review,[72] motor imagery was associated with significant improvements in performance of daily life tasks that involved use of the upper limb when combined with conventional rehabilitation, such as training of manipulation activities. This systematic review also highlighted that there was currently no consistent treatment protocol for use of motor imagery in stroke, despite most studies finding significant, but modest improvements.

The inclusion of training embodied left/right judgments within a motor imagery program may lead to an increased working body schema skill set for the individual to be able to perform explicit motor imagery of upper limb tasks and improve rehabilitation results. Training of LRJTs prior to mental practice of motor tasks as part of a graded motor imagery program has shown promising signs of improved function in individuals early post-stroke,[73] and reductions in pain in nonstroke individuals with complex chronic pain conditions such as CRPS[74] and phantom limb pain.[75]

The fourth task, the nonembodied mental rotation task[44] has also been associated with activation of motor areas,[76] but less than observed with embodied images.[19] The nonembodied mental rotation task utilized pairs of rotated block stimuli (Shepard Metzler images)[44] and was the most difficult task for both groups (reflected by accuracy scores and response times), but again the individuals with stroke experienced greater difficulty than those without stroke. The additional response time taken by the participants with stroke for the embodied and nonembodied mental rotation tasks was beyond what was observed in the directional recognition task.

Strengths and Limitations

To our knowledge, this study is the first to investigate left/right limb judgments in chronic stroke and on this scale in any stroke population (n = 445). The design included additional control measures compared with previous studies investigating left/right judgments. Previous studies have utilized the "A" and "D" keys,[13,21,51,77,78] which are both located in the left side of a standard QWERTY keyboard. In this study, the response keys to indicate left ("V") or right ("N") were allocated centrally based positions, in an attempt to control for hemispheric biases and conditions involving inattention. Care was also taken to present the same combination of images, compared to a previous stroke study,[51] which had generated random presentation of images through the online program, *Recognise*. Given the nature of stroke and potential effects on response time and mental rotation ability compared with a nonstroke population, tasks were included that measured response time and accuracy for: (i) a directional recognition task (task 1), and (ii) a disembodied mental rotation task (task 4) to act as controls for directional recognition and mental rotation ability. In including these tasks, it can be determined that differences found in performance of the LRJTs were unlikely due to difficulties in directional recognition due to the high accuracy of both groups in performing this task. However, it is difficult to determine whether the differences found in performance of the LRJT were due to difficulties in mental rotation alone. Both stroke and nonstroke populations experienced increased additional difficulty in their performance of the nonembodied mental rotation task compared with the embodied limb mental rotation tasks. This finding may have clinical implications in supporting the use of embodied images as a more suitable training tool as part of a motor imagery intervention that is well tolerated by the individual.

All 4 tasks were completed by 834 of the 895 participants, representing a noncompletion rate of 7%. This rate is consistent with reported rates of noncompletion for nonincentive online studies,[79] suggesting that the parameters defined for all 4 of the tasks were appropriate to enable completion by stroke and nonstroke participants.

A weakness of this study involves the availability of data to determine the side of stroke, and the inability to capture details regarding the location of lesion. Twenty-one stroke participants could not indicate the side of their stroke. This knowledge of hemispherical side and location would provide valuable information in more detailed analysis, given the existing evidence that the left temporal cortex is considered to be associated with knowledge of body representation.[55] Also, given the nature of comparisons of affected and nonaffected sides for the limb judgment tasks, participants who experienced multiple strokes affecting both sides of the brain (n = 9) were excluded for the analysis by side of stroke as were individuals who experienced bilateral limb pain (n = 15) for side of pain analysis. In being an online study, physical assessment of each individual was not able to be performed, and therefore it is not possible to determine the degree of impairment experienced by the stroke survivors, or the cause of the impairment with certainty.

There were also differences between the stroke and nonstroke participants, with the nonstroke participants being younger and more likely to identify as being female. Previous studies utilizing similar shoulder and hand LRJTs have reported that gender did not account for a significant effect for accuracy or response time,[21,80] while there has been conflicting evidence regarding the potential effect of increasing age.[36,81]

Despite wide promotion, the study will have been inaccessible to many, as internet access, computer skills, and English language competency were requirements. Individuals with stroke who experienced aphasia were also considered unlikely to have participated due to the written nature of the study, and aphasia being known to contribute negatively to internet use.[82]

This study has further implications for clinical research of interventions targeting body schema in stroke survivors such as motor imagery programs to enhance compliance and effectiveness. It also provides support for the use of left/right discrimination training to be used as part of an interventional study to test whether these deficits are amenable to training in individuals with stroke. If so, training of left/right discrimination may be beneficial as part of a rehabilitation program for stroke that utilizes motor imagery.

CONCLUSIONS

Individuals with long-term stroke display alterations in working body schema of the upper limb compared with nonstroke individuals, as measured by the LRJT for the shoulder and hand. This knowledge may assist in optimizing stroke outcomes through the development of novel strategies targeting body schema and improvements in the implementation of established interventions such as motor imagery as part of their rehabilitation.

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