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Do trunk-based left/right judgment tasks elicit motor imagery?

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Introduction

Over the past decade, left/right judgment tasks (LRJTs) have been introduced to the management of various clinical conditions, especially those involving chronic pain. Typically requiring patients to make speeded judgments as to the laterality of images depicting a single limb segment (e.g. is it a *left* hand or a *right* hand that is being presented?), these tasks exploit the finding that they can implicitly elicit motor imagery (Parsons, 2001).

Evidence that these tasks elicit motor imagery is established with multiple studies dating back over 40 years confirming the finding (Cooper and Shepard, 1975, Sekiyama, 1982). Perhaps most notably, studies conducted by Parsons (1987b, 1994) show that the laterality of an image depicting a hand is judged by mentally rotating (imagining) one's own corresponding limb moving into the precise position of the one depicted and then comparing the two. Images requiring more awkward movements and longer trajectories to reach have been found to take longer to recognise than those requiring more natural movements and shorter trajectories. This observation gave rise to what Parsons described as "*exact match confirmation"* (Parsons, 1994; pp. 730), a component of the left/right judgment process that is critical to our understanding of the task as one that elicits motor imagery.

Importantly, for those interested in the clinical application of LRJTs, there are a number of studies reporting that patients with chronic pain affecting a limb are selectively slower to recognise images corresponding with the same limb (Schwoebel et al., 2001, Schwoebel et al., 2002, Moseley, 2004). These studies and others investigating LRJT performance in patients with an impaired limb (Reinersmann et al., 2010, Schmid and Coppieters, 2012, Fiorio et al., 2006) have served to highlight the clinical utility of LRJTs with them being included as part of imagery-related interventions in rehabilitation programmes (Moseley, 2006, Johnson et al., 2012). The implementation of LRJTs into clinical practice has been strengthened further by a publication focusing on the practicalities of using the tasks in practice together with commercially-available tools to aid implementation (Moseley et al., 2012).

Lately, the use of LRJTs in patient groups has been expanded with the development of *neck* and *trunk-based* LRJTs aimed at those with spinal pain (Bray and Moseley, 2011, Bowering et al., 2014, Linder et al., 2016, Pedler et al., 2013). Typically, images presented to participants in these studies depict a whole body or part of a body which is then manipulated in two ways. Firstly, the trunk or neck of each of these figures is deviated in some way (e.g. lateral flexion, rotation) and it is the direction of this deviation that the participant is required to detect (i.e. is it *left* or *right*?). In addition to this, the whole body in the images presented is systematically oriented around one of the body’s anatomical planes.

Reports to date suggest studies have been conducted based on the assumption that participants perform motor imagery of trunk (or neck) movements (i.e. rotation, side flexion) in order to make their judgments, in much the same way as the process described above for the hand-based LRJT. For example, Bray and Moseley (2011) refer to how they “modified the left/right limb judgment task to interrogate the working body schema of the trunk” (pp. 168) and the requirement of participants to make a “mental movement to match the posture” (pp. 168) presented. Similarly, Bowering et al. (2014) state, “left/right judgments require a mental movement to match the posture shown in an image” (pp. 1070) consistent with the exact match hypothesis referred to above.

Although the approach to developing images for the intended purpose may appear logical, previous research examining spatial transformation of the whole body suggest that the critical element of imagining trunk movements may be unnecessary. Parsons (1987a) showed that when asked to identify an asymmetrical characteristic (e.g. one outstretched arm) on a whole body figure that has been oriented away from an upright or neutral position, it is typical to imagine one's whole body moving around different axes (also see related work by Zacks and Tversky, 2005). However, there is no suggestion or evidence that once this mental transformation of one's whole body has been performed that there is any need to imagine the laterally deviated part of the body (e.g. an outstretched left arm) moving to the position depicted in order to solve the task. Rather, in this previous research, it is concluded that once one imagines the whole body in the position of the one shown, the subsequent laterality judgment (i.e. is the left or right arm outstretched?) becomes automatic. That is, this component of the task does not require motor imagery.

It is possible that the process of undertaking trunk and neck LRJTs may follow a very similar process. Accordingly, people may imagine their whole body moving to the position of the one depicted, but once this is completed, the judgment as to whether the back or neck is deviated to the left or right becomes automatic. This is critical because the potential clinical utility of these tasks is based on their ability to elicit motor imagery of lateral trunk or neck movements, rather than motor imagery of the whole body in space. At the very least, trunk-based LRJTs presented in studies to date appear to confound the relative contribution of the requirement to perform a mental transformation of the whole body with the requirement to make a judgment regarding the lateralised trunk posture presented (Punt, 2017).

It is interesting that some studies investigating trunk and neck-based LRJTs in patients with chronic back and neck pain have failed to show any difficulties in completing the task in comparison with control participants, as would be predicted if motor imagery of lateralised movements was involved (Pedler et al., 2013, Linder et al., 2016). If the task required participants with back pain to simulate lateral movements of the trunk, then one might expect slower response times (RTs) consistent with the relative difficulty in executing the corresponding movements. While some studies have suggested difficulties (Bray and Moseley, 2011, Bowering et al., 2014), the general deterioration in accuracy reported for the trunk-based images (with no difference in response time) do not appear as persuasive of a deficit in motor imagery as the selectively disrupted performance that has been reported for patients with chronic limb pain on limb-based LRJTs (Schwoebel et al., 2001, Schwoebel et al., 2002, Moseley, 2004).

The aim of the present study was to investigate whether data from a trunk-based LRJT typical of those being used in clinical studies, were consistent with the principle of *exact match confirmation* and therefore indicative of motor imagery being elicited. Accordingly, we asked unimpaired and pain-free participants to make speeded judgments to images depicting whole body figures in positions of trunk lateral flexion or rotation. Critically, in addition to manipulating the degree of whole body rotation, we manipulated the extent or amplitude of the trunk movements depicted. As with limb-based LRJTs, if the important principle of *exact match confirmation* was adhered to, then images depicting deviations of the trunk that are further away from neutral (i.e. large amplitudes) should take longer to recognise (i.e. have slower RTs) than images depicting deviations of the trunk that are closer to neutral (i.e. these should require faster RTs).

Methods

Participants

Twenty nine young (mean age = 24.4 (3.5) years), unimpaired individuals (10 males) participated in the experiment. A formal sample size calculation was not undertaken but our sample was either similar or larger than other studies investigating LRJT performance with multiple factors (e.g. Parsons, 1987a, Zacks et al., 2002, Lenggenhager et al., 2008). All participants were unimpaired students at the [redacted] and were screened to ensure they were free from pain. The study was approved by the [redacted]

[redacted] Ethical Review Committee. Participants provided written informed consent prior to taking part.

Stimuli

Digitised images were created of complete three-dimensional human figures using *Poser 10* software (my.smithmicro.com). These figures aimed to be similar to those used in recent studies exploring trunk-based LRJTs in patients with low back pain (Bowering et al., 2014, Bray and Moseley, 2011, Linder et al., 2016). Once the initial image had been created (a standing figure viewed from behind), this entire figure was then systematically rotated in 45^0 'steps' around either the body's sagittal (X), axial (Y) or coronal (Z) planes. This resulted in 22 different whole body orientations. In addition, for each image showing a whole body orientation, images were created using twelve different trunk postures. These images presented the trunk bent sideways (lateral flexion) or twisted (rotated) to the left or right side.

Additionally, the extent (amplitude) of each of these postures was also systematically varied, the figure's posture deviating to either a small, medium or large degree. In total, there were therefore 264 different images. Representative images presented in the experiment are shown in Figure 1.

Figure 1

Procedure

The experiment was conducted in a quiet room within a university laboratory. Participants stood in a relaxed and symmetrical posture with their arms held loosely by their sides. They faced a computer monitor placed in their mid-sagittal plane, approximately 80cm away on a height adjustable table. For each participant, table height was varied to ensure that the centre of the monitor was horizontally in line with their eyes. On the edge of the table, between the monitor and the participant, though not obscuring vision, a microphone was mounted in order to collect verbal responses.

The experiment was controlled using customised software (*E-Prime* 2.0, www.pstnet.com). Stimuli (see above) were presented one at a time in the middle of a monitor. A centrally placed fixation cross preceded each stimulus and appeared on the screen for a random period between 950msec and 1450msec. Participants were required to make speeded judgments as to whether the trunk of each figure viewed was bent/twisted to the left or right; a two-alternative forced choice decision, typical in LRJTs. Participants responded by saying “left” or “right”, and the software logged each RT via the microphone. The experimenter subsequently logged the direction of the response (i.e. left or right) by pressing one of two keys on a keyboard; this input triggered the following trial. Verbal responses are common in LRJT studies (e.g. Nico et al., 2004, Ionta et al., 2007) and research suggests that this response mode avoids small biases that can be introduced with manual responses (Cocksworth and Punt, 2013).

Every participant completed two experimental blocks, each block containing all 264 images (528 images in total). Images within each block were presented in a randomised order. There was a short break between the two experimental blocks. Prior to completing the two experimental blocks, participants completed a practice block containing 12 randomly selected images from the bank of 264 to familiarise themselves with the protocol, and to allow any misunderstandings to be eliminated..

Data analysis

The experiment generated accuracy and RT data and these were analysed independently. Accuracy was logged for each trial (correct = 1, incorrect = 0) with mean accuracy calculated within each individual for each condition. Mean accuracy was expressed as a figure between zero and one. Response time was the latency in milliseconds (msec) between stimulus onset and verbal response. Mean RT was calculated for each individual and for each factor of interest. However, only accurate responses were included in the RT analysis and RTs were filtered, removing those that fell outside 500-3500msec (Ionta et al., 2012, Cocksworth and Punt, 2013).

Where data displayed signs of skew and kurtosis, they were log transformed prior to analysis. Accuracy and RT data were subsequently analysed via two separate analyses of variance (ANOVA) with repeated measures. We were interested in the effect of whole body orientation on performance as well as the axis of this orientation. Accordingly, *Orientation* (0° vs. 45° vs. 90° vs. 135° vs 180°) and *Axis* (X vs. Y vs. Z) were entered as factors in the analyses.

Importantly, we were also interested in whether the extent or amplitude of the lateral trunk movement had an effect on these data, consistent with the *exact match confirmation* hypothesis. Accordingly, *Amplitude* was entered for analysis with three levels (small vs. medium vs. large). This resulted in two separate 5x3x3 ANOVAs being conducted.

Results

Accuracy

Accuracy for two participants was below 75% and their data were excluded from analysis. The ANOVA revealed a significant main effect of Orientation (*F*(4,104)=24.54, $p<0.001$). Accuracy was highest for images presented at 0^0 (mean = 0.98, SD = 0.02) and became progressively less accurate as images were orientated away from this position with the lowest accuracy occurring at 180^0 (mean = 0.83, SD = 0.13). There was a significant main effect of Axis ($F(2,52)=8.41$, $p<0.005$). Accuracy was significantly lower for images orientated in the X axis (mean = 0.89, SD = 0.08) than the other two axes (Y: mean = 0.94, SD = 0.05; Z: mean = 0.93, SD = 0.05, $p<0.05$ for both). The different amplitudes of trunk movement shown in the images also led to significant differences in accuracy ($F(2,52)=7.17$, $p<0.005$). Accuracy was lowest for images depicting a small amplitude (mean = 0.90, SD = 0.05) than the other two amplitudes (medium: mean = 0.92, SD = 0.05; large: mean = 0.92, SD = 0.05; $p=0.96$ for both). There was no difference in the accuracy of responses for images depicting medium or large amplitudes; see Figure 2 (left panel). There was also an Axis x Orientation interaction ($F(8,208)=6.77$, $p<0.001$). As can be seen in Figure 3 (left panel), the reduced accuracy associated with images as they deviated away from 0^0 was not uniform for the different axes. At 45^0, accuracy was comparable for all axes, but at 90^0, differences began to emerge with accuracy for each axis different from the other ($p<0.05$); whereas at 135^0, accuracy for the Y and Z axes were comparable and responses were more accurate than for the X axis ($p<0.05$). At 180^0, accuracy was significantly reduced for images showing whole body orientations around the X and Z axes compared with those around the Y axis ($p<0.05$).

Figure 2

Response times

The removal of responses from the analysis faster than 500msec or slower than 3500msec resulted in the loss of 2.3% of the total number of accurate trials. Responses were fastest for images presented at 0^0 (mean = 832msec, SD = 207msec) and became progressively slower as images were rotated with the slowest responses at 180^0 (mean = 1328msec, SD = 375msec). This led to a significant main effect for Orientation

($F(4,104)=94.66$, $p<0.001$). There was also a main effect of Axis ($F(2,52)=21.80$, $p<0.001$), with responses slower for images presented in the X axis (mean = 1094msec, SD = 279msec) than the other two axes (Y: mean = 1000msec, SD = 274msec; Z: mean = 1024, SD = 263msec; $p<0.001$ for both). There was no significant difference in RTs for images presented in the Y and Z axes ($p=0.07$).

The different amplitudes of movement presented also differed reliably leading to a significant main effect for Amplitude ($F(2,52)=15.1$, $p<0.001$). Importantly, responses were faster for images showing medium (mean = 1024msec, SD = 268msec) and large (mean = 1019msec, SD = 269msec) amplitudes than for images showing small amplitudes (mean = 1075msec, SD = 276msec; $p<0.005$ for both); see Figure 2 (right panel). Responses to images showing medium and large amplitudes were statistically comparable ($p=0.58$). There was an Axis x Orientation interaction ($F(8,208)=15.86$, $p<0.001$). As can be seen in Figure 3 (right panel), as whole body orientation became more rotated and deviated away from 0^0, responses were not uniformly slower for the different axes. While RTs were comparable across axes at 45^0 ($P=0.8$), at 90^0 and 135^0 they were significantly slower for the X axis than the other two axes ($p<0.01$ for both). At 180^0, RTs were comparable for the different axes ($p=0.07$). There were no other interactions for RT data.

Figure 3

Discussion

It has been suggested that trunk-based LRJTs elicit motor imagery of lateralised trunk movements (e.g. side flexion, rotation) offering potential value as an assessment and intervention in clinical practice for patients with back pain (Bray and Moseley, 2011, Bowering et al., 2014). Although the ability of *limb-based* LRJTs to elicit motor imagery of limb movements is established (Cooper and Shepard, 1975, Sekiyama, 1982, Parsons, 1987b), the introduction of trunk-based LRJTs into clinical practice has been based on an assumption that they elicit motor imagery of lateralised trunk movements (Bray and Moseley, 2011). To date, this assumption has not been tested using methods previously used to demonstrate the ability of limb-based LRJTs to elicit motor imagery (Sekiyama, 1982, Parsons, 1987b, Parsons, 1994). For the first time, this study aimed to investigate whether data (accuracy and RT) from a trunk-based LRJT are indicative of motor imagery in unimpaired and pain-free participants.

In order to address this issue, participants were asked to make speeded left/right judgments of images depicting whole bodies, each with the trunk bent or turned to the left or right, typical of images used in trunk-based LRJT images used in clinical studies to date. If the task required individuals to imagine moving into the various positions presented (i.e. using motor imagery), then images depicting larger amplitudes of movement should have resulted in longer RTs than those depicting smaller amplitudes of movement. Such a finding would be entirely consistent with a key principle of motor imagery; that of temporal regularity between the physical and mental performance of an action (Decety et al., 1989). This principle has been central to the argument that limb-based LRJTs elicit motor imagery and is the basis for the *exact match confirmation* hypothesis (Parsons, 1994).

However, our data do not support such a process. Rather, images depicting larger amplitudes of movement resulted in markedly faster RTs than those depicting smaller amplitudes, a situation that is entirely inconsistent with participants imagining themselves moving into the positions shown. Further, accuracy for images showing larger amplitudes of trunk movement was greater than for images depicting smaller amplitudes of movement, demonstrating that the results could not have arisen due to a speed-accuracy trade-off. Accordingly, the *amplitude* effects are inconsistent with the *exact match confirmation* hypothesis and suggest participants did not imagine moving their trunk into the positions presented.

Given this finding, it is important to consider how individuals do solve the task. Data presented here are in line with a previous study relating to left/right judgments involving images where the whole body is rotated around different axes (Parsons, 1987a). For example, RTs for images increased incrementally as they depicted the whole body deviating away from a neutral standing position, leading to the orientation effects reported. It was also clear that orientation around different axes presented variable levels of difficulty for participants. For example, orientation around the X axis presented the greatest challenge.

In the Parsons (1987a) study, images of whole bodies were presented with a single outstretched arm and the left/right judgment that participants were asked to make was to identify which arm was outstretched. Other studies exploring the spatial transformation of the whole body take a similar approach; figures in the images used having either an outstretched arm or simply have one limb presented in a different colour (Lenggenhager et al., 2008, van Elk and Blanke, 2014). These studies report similar findings and are broadly supportive of individuals imagining their whole body moving to the orientation depicted. However, there is no suggestion that participants imagine their own limb moving to the position depicted in these studies. Rather, it is understood that once participants have imagined their whole body moving to the orientation depicted, the subsequent left/right judgment (i.e. which arm is raised or which hand is a different colour?) is a relatively straightforward and automatic decision. As Parsons (1987a) explains, when viewing the body in an upright position, “it was obvious which arm was outstretched” (pp. 175).

Similarly, data presented in this study suggest a comparable process; i.e. once participants had imagined their whole body oriented to the position shown, the decision as to whether the trunk was turned or bent to the left or right was a relatively simple and automatic process, not requiring any motor simulation. Indeed, the finding of faster RTs (and greater accuracy) for images depicting large amplitudes suggests it was the salience of visual cues depicting asymmetry that was the critical factor for this component of the task.

Although this study suggests that trunk-based LRJTs do not elicit motor imagery of trunk movements, it must be remembered that some previous studies have indicated that individuals with back pain can demonstrate difficulties with the task. For example, poorer performance (decreased accuracy) on trunk-based LRJTs was reported by Bray and Moseley (2011) and Bowering et al. (2014). However, unimpaired performance on the task in individuals with back pain on the same task has also been reported (Linder et al., 2016) . Nevertheless, findings of difficulties remain interesting and it is important that future research aims to identify the underlying reasons for any performance deficits reported. Findings in this study suggest it is unlikely that poorer performance is mediated by an inability to perform motor imagery of lateralised trunk movements, even though this may be impaired in chronic back pain sufferers. However, as this study only included pain-free participants, it is not possible to shed further light on this issue.

The study reported here was conducted in a laboratory setting with young, unimpaired participants. Procedure allowed for millisecond precision of timing and carefully controlled conditions ensured participant understanding and consistent engagement with the task. While there are obvious strengths with this approach, there are limitations in maintaining such conditions in more *real world* settings. In contrast, the emergence of online tools for LRJTs (Moseley et al., 2012) has been a significant innovation and has facilitated the much wider use of the tasks in practice and research, and should be welcomed. However, online tools can suffer from timing inaccuracies (Schmidt, 2001). Additionally, one has to balance the advantages that online tools can bring such as the ability to reach large groups of participants with the reduced control of important factors (e.g. understanding, engagement, environment) that one often must accept with such studies.

The introduction of trunk-based LRJTs into clinical practice was based on the assumption that the task elicits motor imagery of lateralised trunk movements. For individuals with back pain who may have chronic difficulties in making lateralised movements of the trunk with related cortical reorganisation (Flor et al., 1997, Tsao et al., 2008), the possibility of implicitly eliciting the simulation of such movements and associated neural activity is clearly attractive and would presumably have therapeutic value. However, findings presented here strongly suggest that the task does not elicit such motor imagery. The ability of the task to elicit whole body transformations (motor imagery) should not be confused with its apparent failure to elicit motor imagery of lateralised trunk movements; it is the latter that would have therapeutic value in individuals with chronic back pain.

Figure legends

Figure 1. The *top row* shows representative images of how the whole body was oriented; whole bodies were rotated around either: a. the *sagittal* (*X*) plane, b. the *axial* (*Y*) plane or c. the *coronal* (Z) plane. The *middle* and *bottom rows* shows how for any given whole body orientation, images could show either lateral flexion (middle row) or rotation (bottom row) with any given posture reflecting either a small (*d* and *g*) , medium (*e* and *h*) or large (*f* and *i*) amplitude.

Figure 2. Mean accuracy (left) and RTs (right) for the different amplitudes of trunk movement presented. Error bars denote 95% confidence intervals. Asterisks denote statistical significance.

Figure 3. Mean accuracy (left) and RTs (right) for the different whole body orientations across the different axes. Error bars denote 95% confidence intervals.

References

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

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

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

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

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

FIORIO, M., TINAZZI, M. & AGLIOTI, S. M. 2006. Selective impairment of hand mental rotation in patients with focal hand dystonia. *Brain,* 129**,** 47-54.

FLOR, H., BRAUN, C., ELBERT, T. & BIRBAUMER, N. 1997. Extensive reorganization of primary somatosensory cortex in chronic back pain patients. *Neuroscience Letters,* 224**,** 5-8.

IONTA, S., FOURKAS, A. D., FIORIO, M. & AGLIOTI, S. M. 2007. The influence of hands posture on mental rotation of hands and feet. *Experimental Brain Research,* 183**,** 1-7.

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

JOHNSON, S., HALL, J., BARNETT, S., DRAPER, M., DERBYSHIRE, G., HAYNES, L., ROONEY, C., CAMERON, H., MOSELEY, G. L., DE, C. W. A. C., MCCABE, C. & GOEBEL, A. 2012. Using graded motor imagery for complex regional pain syndrome in clinical practice: failure to improve pain. *European Journal of Pain,* 16**,** 550-61.

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

LINDER, M., MICHAELSON, P. & RÖIJEZON, U. 2016. Laterality judgments in people with low back pain - A cross-sectional observational and test-retest reliability study. *Manual Therapy,* 21**,** 128-133.

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

MOSELEY, G. L. 2006. Graded motor imagery for pathologic pain - A randomized controlled trial. *Neurology,* 67**,** 2129-2134.

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

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

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

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

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

PARSONS, L. M. 2001. Integrating cognitive psychology, neurology and neuroimaging. *Acta Psychologica,* 107**,** 155-181.

PEDLER, A., MOTLAGH, H. & STERLING, M. 2013. Laterality judgments are not impaired in patients with chronic whiplash associated disorders. *Manual Therapy,* 18**,** 72-6.

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

REINERSMANN, A., HAARMEYER, G. S., BLANKENBURG, M., FRETTLOH, J., KRUMOVA, E. K., OCKLENBURG, S. & MAIER, C. 2010. Left is where the L is right. Significantly delayed reaction time in limb laterality recognition in both CRPS and phantom limb pain patients. *Neuroscience Letters,* 486**,** 240-245.

SCHMID, A. B. & COPPIETERS, M. W. 2012. Left/right judgment of body parts is selectively impaired in patients with unilateral carpal tunnel syndrome. *Clinical Journal of Pain,* 28**,** 615-22.

SCHMIDT, W. C. 2001. Presentation accuracy of Web animation methods. *Behavior Research Methods, Instruments, and Computers,* 33**,** 187-200.

SCHWOEBEL, J., COSLETT, H. B., BRADT, J., FRIEDMAN, R. & DILEO, C. 2002. Pain and the body schema: effects of pain severity on mental representations of movement. *Neurology,* 59**,** 775-777.

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

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

TSAO, H., GALEA, M. P. & HODGES, P. W. 2008. Reorganization of the motor cortex is associated with postural control deficits in recurrent low back pain. *Brain,* 131**,** 2161-2171.

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

ZACKS, J. M., OLLINGER, J. M., SHERIDAN, M. A. & TVERSKY, B. 2002. A Parametric Study of Mental Spatial Transformations of Bodies. *NeuroImage,* 16**,** 857-872.

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