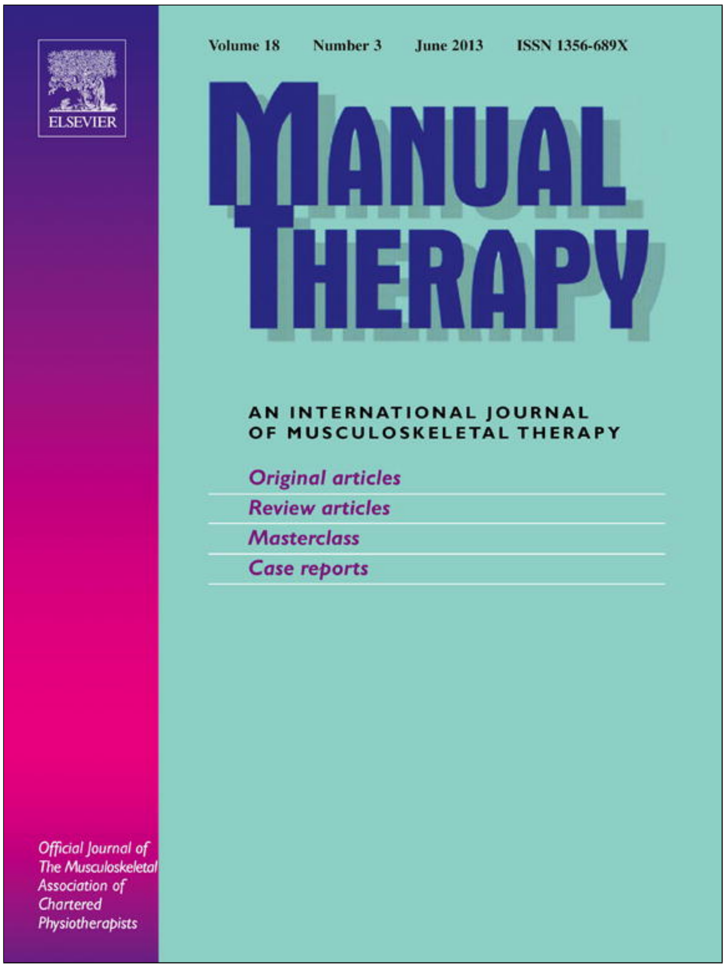
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# Left/right neck rotation judgments are affected by age, gender, handedness and image rotation

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ABSTRACT

Understanding motor imagery of the hands and feet has led to promising new treatments for neurological and chronic pain disorders. We aimed to extend this line of research to the neck with a view to developing the definitive platform study upon which clinical and experimental studies can be based. In a cross-sectional experiment with a convenience sample, volunteers were shown 40 photographs of a model with their head turned to the left or right. Images were presented in random order and orientation. Participants judged the direction of neck rotation. They also completed a left/right hand judgment task. 1361 pain-free participants volunteered. Mean ± standard deviation response time (RT) for making left/right judgments of neck rotation was 1.621 ± 0.501 s. Median accuracy was 92.5%. RT was related to age, gender, and handedness ($p < 0.001$). That is, RT increased with age, was greater in females than in males and was greater in left-handers than in right-handers. Accuracy reduced with age ($p < 0.001$), but was unaffected by gender or handedness. Judgments were more accurate when images showed a neck rotated to the right than when they showed a neck rotated to the left ($p < 0.001$). The magnitude of image rotation affected both response time and accuracy ($p < 0.001$). In general, the performance parameters established for left/right limb judgments also apply for left/right neck rotation judgments. The current work establishes the definitive normative values against which clinical and experimental groups can be compared and reveals unpredicted effects of the direction neck rotation and the orientation of the image.



## 1. Introduction

There is a growing literature on the use of motor imagery in rehabilitation of neurological (Jackson et al., 2001) and chronic pain (Moseley, 2004a) conditions. ‘Motor imagery’ in this instance refers to the mental movement of a body part using the models, or maps, of the specific body part that are held within the brain. Thus, motor imagery can be explicit, whereby one voluntarily makes the mental movement – also called imagined movements – or implicit, whereby one is not necessarily aware that they are making a mental movement. Assessment of implicit motor imagery ability, using a left/right hand judgment task, provides valuable information about information processing performance and cortical proprioceptive representation of the body (Moseley, 2004b; Hudson et al., 2006; McCormick et al., 2007). The neurological mechanisms that underpin left/right hand or foot judgments are well understood (see (Parsons, 2001)), but little work has been done on equivalent tasks for other body parts. Left/right hand judgments have been used to investigate clinical groups, for example amputees with phantom sensations (Nico et al., 2004), and people with complex regional pain syndrome (Schwoebel et al., 2001; Schwoebel et al., 2002; Moseley, 2004b). These studies have led to new and promising treatments for these disorders, for example graded motor imagery, which involves sequenced periods of left/right judgment training, imagined movements and mirror movements (Moseley et al., 2012a) and is supported

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by clinical trials and systematic reviews (Moseley, 2004a, 2006; Daly and Bialocerkowski, 2009).

The present study extends this work to the neck. Neck pain is a common health problem worldwide (Fejer et al., 2006), and currently, the evidence for the efficacy of treatments of neck pain is underwhelming (Hoving et al., 2001; Leaver et al., 2010). We contend that learning more about motor imagery of the neck may lead to new treatment options for neck problems, just as learning about motor imagery of the limbs has led to new treatment options for limb problems. The first aim of the present study was to develop a comprehensive and definitive database of normative responses to a left/right neck rotation judgment task, and therein determine the relations between response time (RT) or accuracy, and age, gender and handedness of the participants, the direction of neck rotation shown in the image, and the effect of image orientation (rotated 0°, 90°, 180°, and 270°). Specifically, to determine if the performance parameters and limitations that have been established for limb judgment also apply to neck rotation judgments. By doing so we aimed to establish the platform upon which clinical and experimental studies can be pursued. To be consistent with the established limb judgment tasks, the neck motor imagery task was a visual task undertaken from a third person perspective. Images showed people in a static position of neck rotation, that is, the people in the images were already in the rotated position and were not moving. The second aim was to verify the utility of an on-line recruitment and data collection protocol as a means to increase statistical power and widen the scope of questions that can be investigated with this approach (Nosek et al., 2002).

## 2. Methods

### 2.1. Participants

A convenience sample of people who were alerted to the study via social media, and who have access to a broadband internet connection. The study was advertised on-line and via social media. Ethical approval was granted by the institutional ethics committee.

### 2.2. Questionnaire

After giving consent, participants completed a questionnaire that included demographic characteristics, physical activity and occupation-related variables (see Supplementary file S2).

### 2.3. The left/right neck rotation images

The task: Portrait photographs including the head, neck, and shoulders were taken from the front, back, and side of one female and one male model. Models were aged in their 20's, wore plain black clothing, and had neutral facial expressions. Each photograph had a plain green background. Hue and saturation were similar for all photographs. In each photograph, the model had their head turned to the left or to the right. There were equal numbers of head turned left and head turned right, relative to the shoulders, and equal numbers of male and female photographs. Equal numbers of photographs were randomly rotated to 0°, 90°, 180°, and 270°. Screen size, refresh rate, color spectrum, and resolution were dependent on the participant's computer. No attempt was made to record this information.

### 2.4. The left/right neck rotation judgment task performance

Data were collected via Recognise™ (NOI, Adelaide, Australia). An experimental block constituted 40 images. Participants responded to each image by indicating whether the model in the image had their head turned to the left or right, relative to their shoulders. Participants were instructed to make a response as quickly as possible, without guessing. Participants were advised to wait for one minute between batches. Data from the first block were discarded. Data from the second block were analyzed.

Participants also undertook a routine left/right hand judgment task so that we could verify the utility of the approach by comparing it to established data for this test (Moseley, 2004b). For all tests, responses were made using the 'a' key for a 'left' response and the 'd' key for a 'right' response. If no response was made in five seconds, the next photograph was shown and a time of 5000 ms was recorded for that image. Participants were advised not to guess.

### 2.5. Reliability and validity

The reliability of the Recognise Software™ has been previously established in people with and without pain (Bray and Moseley, 2011; Dey et al., 2012). Internal and external validity of the Recognise Software™ was established before the link went 'live' (see Supplementary file S2).

### 2.6. Data processing

Data were included if participants completed the questionnaire and all experimental blocks. Individual image responses were excluded if there were eight or more ($\geq$20% of a block) responses of 5000 ms in a row, or if RT was less than 500 ms, which we considered to be too short to reflect a true judgment response (Kunde, 2001). Participants who reported current neck pain or reported being ambidextrous were excluded, which is consistent with previous studies (Nico et al., 2004; Moseley, 2004b).

### 2.7. Statistical analysis

The relationship of age, gender and handedness to RT and accuracy were analyzed using two multivariate linear regressions; one for RT, the other for accuracy. A Cohen's $f^2$ regression accommodated the large sample size. Univariate ANOVAs compared responses to images of left-turning necks to images of right-turning necks in left and right-handed participants: 2 (factor = Image: left or right) $\times$ 2 (factor = Handedness: left or right). A one-way multiple comparison Bonferroni ANOVA was used to establish if the magnitude of image rotation had an effect on participant RTs or accuracies. A one way ANOVA regression was used to determine whether there was an RT-accuracy trade-off, which means that increased speed of responses are accompanied by increased error rate, an observation that would suggest participants are not prioritizing accuracy of their response. Data were analyzed using PASW version 18.0 (IBM/SPSS Inc.). A correction was made for multiple measures such that significance was set at $\alpha = 0.01$.

## 3. Results

### 3.1. Participants

1737 people from 40 countries participated. 324 reported neck pain at the time of testing. 52 had incomplete questionnaire data so they were removed (see Table 1 for demographic details).

### 3.2. Response time and accuracy for left/right neck rotation judgments

Mean $\pm$ SD RT and accuracy for left/right neck rotation judgments in healthy people without current neck pain was

**Table 1**
Demographic details.

| Number of participants | 1737 |
|---|---|
| Left handers | 181 |
| Right handers | 1466 |
| Ambidextrous | 53 |
| No response on handedness | 37 |
| Males | 520 |
| Females | 1130 |
| No response on gender | 87 |
| Age (mean, range) in years | 40 (10–90) |
| Neck pain at time | 324 |
| No response on neck pain | 52 |
| Number of datasets analyzed | 1361 |

1.62 ± 0.50 s (89.75% ± 11.25%). Because accuracy data were negatively skewed (skewness = −3.148, kurtosis = 15.688), we also determined median accuracy, which was 92.50%.

### 3.3. Relationship between response time and accuracy of left/right neck rotation judgments

Participants who responded faster were also more accurate ($p < 0.001$, $r^2 = 0.107$). That is, there was no RT-accuracy trade-off (see Fig. 1).

### 3.4. Effect of age, gender and handedness

RT was related to age, gender and handedness ($F(3,1197) = 35.74$, $p < 0.001$; $r^2 = 0.082$; $f^2 = 0.0893$). RT increased with age ($t = -8.807$, $p < 0.001$); males were faster than females ($t = 4.222$, $p < 0.001$) (see Fig. 2) and right-handers were faster than left-handers ($t = 2.687$, $p = 0.007$). Accuracy was also related to age, gender and handedness ($F(3,1197) = 6.291$, $p < 0.001$; $r^2 = 0.016$; $f^2 = 0.0163$). However, this relationship was dominated by a strong relationship with only age such that accuracy decreased with age ($t = 4.045$, $p < 0.001$), but was not related to gender ($t = -1.188$, $p = 0.235$) or handedness ($t = -0.686$, $p = 0.493$).

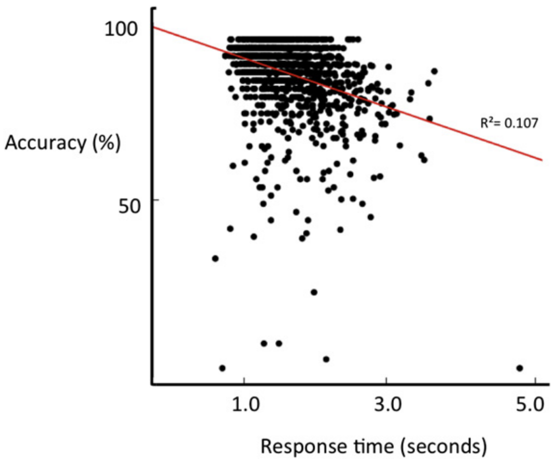


**Fig. 1.** Mean response time (horizontal axis) and accuracy (vertical axis) for left/right neck rotation judgments. Note that more accurate participants were also quicker ($r^2 = 0.107$, $p < 0.05$), indicating that there was no speed-accuracy trade off.

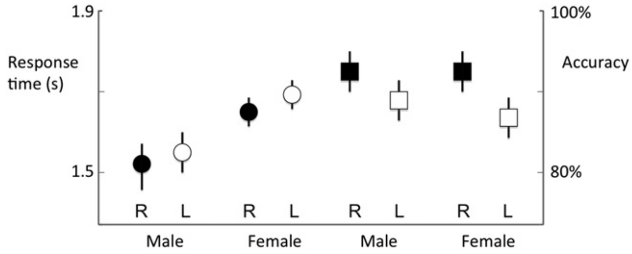


**Fig. 2.** Response time (RT) (circles) and accuracy (squares) for males and females when making left/right judgments of neck rotation for images showing right rotation (filled shapes) and left rotation (open shapes). Error bars denote standard error.

### 3.5. Effect of the direction of neck rotation on response time and accuracy

The direction in which the model's head was turned did not affect RT, regardless of handedness (no main effects of Image or Handedness and no Image × Handedness interaction; $p > 0.269$ for all). However, participants were more accurate for images of right neck rotation than they were for images of left neck rotation ($F(1,2496) = 14.9$ $p < 0.001$), regardless of participant handedness (no Handedness × Image interaction, $p > 0.28$) (see Fig. 2).

### 3.6. Effect of image rotation on response time and accuracy

The magnitude of image rotation affected both participant response time ($F(3,51901) = 1140.07$ $p < 0.001$) and accuracy ($F(3,51133) = 382.16$ $p < 0.001$). Participants were fastest and most accurate at responding to images that were of upright orientation, followed by 90° clockwise rotation, 270° rotation, and were slowest and least accurate to images that were presented upside-down (see Fig. 3 and Fig. 4).

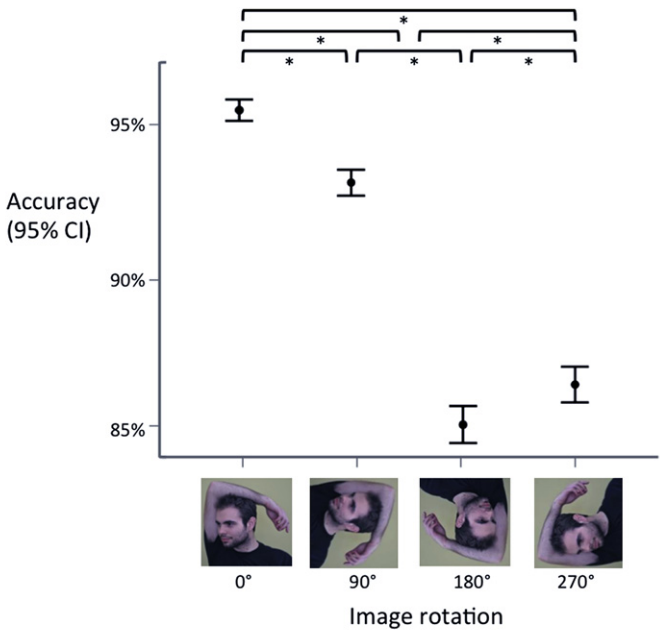


**Fig. 3.** Mean (circles) and 95% confidence interval (error bars) for response time in the four image orientations. Asterisk denotes significant difference at $p < 0.05$.

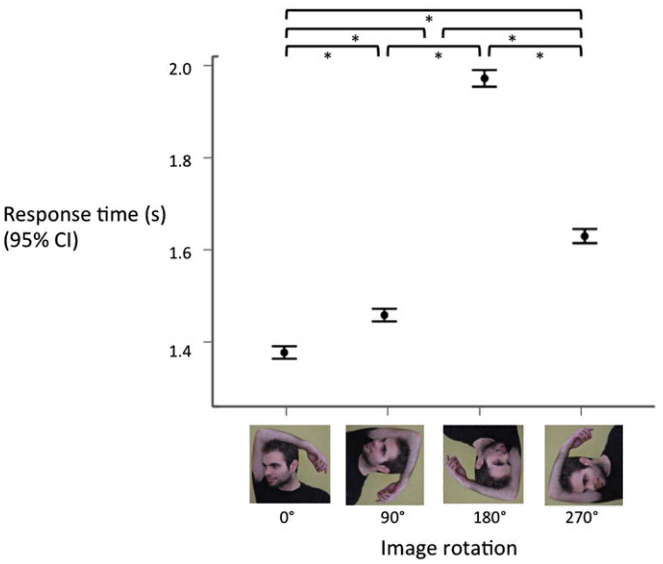


**Fig. 4.** Mean (circles) and 95% confidence interval (error bars) for accuracy in the four image orientations. Asterisk denotes significant difference at $p < 0.05$.

### 3.7. Left/right hand judgments

The mean (± SD) RT and accuracy for left/right hand judgments in healthy people ($n$ = 1622) was 1.983 s ± .557 s and 87.74 ± 10.63%, respectively.

## 4. Discussion

We aimed to develop a comprehensive database of normative responses to a left/right neck rotation judgment task, via an on-line recruitment and data collection protocol. The success of our approach is evidenced by the sample: 1361 pain-free healthy participants from 40 countries, age range 10–90 years (previous normative motor imagery studies have included between 8 and 32 participants (Parsons, 1987, 1990; Parsons and Fox, 1998; Parsons et al., 1998; Schwoebel et al., 2001; Moseley, 2004b; McCormick et al., 2007)).

### 4.1. Validity of the on-line protocol

The results for left/right hand judgments of the present study are similar to established data (see Table 2), which underpins the validity of our approach.

### 4.2. Relationships between age, gender, and handedness, and response time and accuracy of left/right judgments of neck rotation

That people get slower and less accurate as they age would be predicted on the basis of established data for simple and choice reaction time tasks (Luchies et al., 2002) and on implicit motor imagery using a left/right hand judgment task (Saimpont et al., 2009). Planning, structuring, and executing of a movement, after the stimulus has been analyzed and an appropriate response has been determined, takes longer with increasing age, and the age-dependent effect increases with task complexity (Light and Spirduso, 1990).

Males are faster than females at making accurate left/right neck rotation judgments. There is some evidence that males outperform females in mental rotation performance and several explanations have been proposed. For example, Jordan et al (Jordan et al., 2002) reported differences in functional brain activation during mental rotation despite equivalent performance, suggesting men and women adopt different strategies to solve mental rotation problems. Notably however, where performance differences do exist, they seem to be getting smaller over time (Richardson, 1994). This is important, because it implies that the differences reflect functional exposure to movement-dependent tasks, rather than a genetically determined differentiation.

That right-handers are better than left-handers would not be predicted on the basis of the existing literature on perceptual and motor skills. That performance is better when one makes a judgment on an image that corresponds to their own dominant side has been reported previously (Nico et al., 2004), but this would only yield an RT advantage for right-handers if there were more images of right hands than there were images of left hands, which there was not. That such a fundamental finding might emerge for the first time here could be because our study is much more highly powered than previous investigations into perceptuomotor performance. Further large-sample studies that interrogate this possibility seem warranted.

### 4.3. The effect of neck rotation direction on response time and accuracy, and its relationship to handedness

That response time was not affected by the direction of head rotation suggests against an information processing bias toward one rotation or the other (Hudson et al., 2006). That accuracy was higher when the pictured head was turned to the right, regardless of handedness, is difficult to interpret, but it is not the first evidence of left/right asymmetry in perceptuo-motor performance. In fact, a preference for right neck rotation over left neck rotation has been reported from preterm infants (Konishi et al., 1987; Ververs et al., 1994) and kissing adults (Gunturkun, 2003). That we found an effect consistent with this in accuracy but not in RT is intriguing and may suggest that cortical representation of right neck rotation may be more precise than that of left neck rotation (Hudson et al., 2006) (see also (Moseley et al., 2012a)).

### 4.4. The effect of image orientation on response time and accuracy

The established relation between magnitude of image rotation and left/right limb judgments (Parsons, 2001) held true for left/right neck rotation judgments. That is, people take longer to make a judgment for pictures rotated 180° than for pictures rotated 90° or 270°. According to limb judgment data, our result implies that left/right neck rotation judgments involve mental rotation of our head in space to match the rotated image. Shorter reaction times, and better accuracy, at 90° than at 270° was not predicted because they involve identical excursions from the resting upright position, but it is not overly surprising – we have preferences in a range of motor behaviors, for example foot and hand dominance (Hammond, 1995), eye dominance (Porac and Cohen, 1976), ear and head tilt preferences (Putnam, 1996) (also reflected in telephone headset preferences (Jackson et al., 2001)), whole body

**Table 2**
Comparison of left/right judgment to off-line protocols.

| Study | Mean response time (seconds) | Mean accuracy (%) |
|---|---|---|
| Moseley, 2004b | 2.31 ± 0.68 | 94 ± 4.5 |
| Hudson et al., 2006 | 1.74 ± 0.73 (first epoch)<br>1.78 ± 0.59 (second epoch) | Not reported |
| **CURRENT study** | **1.983 ± 0.557** | **87.74 ± 10.63** |

turning bias (Mead and Hampson, 1996), and even a side preference when it comes to holding babies (Harris and Fitzgerald, 1985).

### 4.5. Study limitations

Interpretation of the current results should consider several limitations. First, the ratio of female to male participants (1130:520) means that there was a strong female bias. That male RT was significantly faster than female RT suggests that perhaps the population mean is slightly lower than our results suggest. Another limitation of the current work relates to our second aim – to determine the utility of an on-line protocol. Although factors such as computer malfunctions, screen refresh-rates, screen size, colors and image resolution would increase the variance in our data, they should not impart a systematic bias within it. This method of data collection will be used in subsequent large-scale studies, which will also be exposed to similar experimental conditions, so the normative data are appropriate for future comparisons. A third limitation of the current work relates to the response apparatus, where both the 'a' and 'd' keys are located in the left side of visual space. This was a requirement of the software, but it has the potential to introduce a response bias related to the allocation of attentional resources according to a spatially-defined coordinate system (Moseley et al., 2012b). This may be of more importance to left/right limb judgments than neck rotation judgments (Moseley et al., 2009), but the recent discovery of a spatially-defined disruption in sensory processing around the trunk in people with back pain (Moseley et al., 2012) suggests that future work should allow for response keys to be located on either side of the body midline. A final limitation is that participants were asked to adopt a specific position during the test, but, due to the on-line nature of the task, compliance could not be monitored. This is important because RT on left/right hand judgment tasks is highly dependent on the resting posture of the hands (Parsons, 1987) (see also (Moseley and Brugger, 2009) for measurable changes in response times due to subtle changes in resting posture). We would expect that people would generally perform an on-line test like this while sitting upright, but we can't exclude the possibility that they did not.

## 5. Conclusion

We have established a normative database for left/right neck rotation judgments and verified that the performance parameters that apply to left/right hand judgments generalize to left/right neck rotation judgments. Our data provide a very comprehensive normative dataset for a motor imagery task and provide the platform for further studies in experimental situations and in clinical groups.

## Ethics approval

University of South Australia.

## Statement of financial interest

DB is the Director of the Neuro Orthopaedic Institute (NOI), which owns and sells the Recognise™ programme.

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## Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.math.2012.10.006.

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