Motor Imagery in People With a History of Back Pain, Current Back Pain, Both, or Neither

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Introduction: There is mounting evidence that cortical maps are disrupted in chronic limb pain and that these disruptions may contribute to the problem and be a viable target for treatment. Little is known as to whether this is also the case for the most common and costly chronic pain—back pain.

Objectives: To investigate the effects of back pain characteristics on the performance of left/right trunk judgment tasks, a method of testing the integrity of cortical maps.

Methods: A total of 1008 volunteers completed an online left/right trunk judgment task in which they judged whether a model was rotated or laterally flexed to the left or right in a series of images.

Results: Participants who had back pain at the time of testing were less accurate than pain-free controls ($P = 0.027$), as were participants who were pain free but had a history of back pain ($P < 0.01$). However, these results were driven by an interaction such that those with current back pain and a history of back pain were less accurate (mean [95% CI] = 76% [74%-78%]) than all other groups (> 84% [83%-85%]).

Discussion: Trunk motor imagery performance is reduced in people with a history of back pain when they are in a current episode. This is consistent with disruption of cortical proprioceptive representation of the trunk in this group. On the basis of this result, we propose a conceptual model speculating a role of this measure in understanding the development of chronic back pain, a model that can be tested in future studies.

Key Words: motor imagery, back pain, left/right judgments

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There is mounting evidence to indicate that proprioceptive deficits exist in people with back pain.[1–6] One possible explanation is that as nociceptive input clearly disrupts motor output, it so too disrupts the transmission of peripheral proprioceptive information.[7] Alternatively, proprioceptive deficits in pain may reflect disruptions to the body part's cortical proprioceptive representation—the brain-grounded representation or "map" that is used for the precise planning and execution of movements.[8] Physiological changes in back-relevant zones of the primary somatosensory cortex[9] and motor cortex,[10] collectively called "cortical reorganization," afford a possible explanation for tactile and motor deficits that occur with back pain (see Flor and colleagues[9,11] for reviews). However, a neural substrate of the proprioceptive maps has not been uncovered, which means we must rely on behavioral tasks, rather than neuroimaging, to investigate cortical proprioceptive representation.

One common method of interrogating cortical proprioceptive maps is timed motor imagery tasks; for example, left/right judgments: the process of judging whether a body part depicted in an image belongs to the left or right side of the body. There is a large amount of literature on these tasks as they relate to limb movements (see Parsons[12] for review), and that work has been extended to clinical populations.[13–19] Because the back acts as a single, inseparable, functioning unit, it is not as easily categorized as belonging to the left or right side of the body. Therefore, left/right trunk judgment tasks have been modified so that the posture is described as a deviation from neutral. That is, participants judge whether the posture shown in the picture is rotated or laterally flexed toward the left or the right. On the basis that left/right judgments require a mental movement to match the posture shown in an image, they are thought to provide a quantified estimate of the coherence of the body part–specific cortical proprioceptive map.[12,20]

Preliminary investigation demonstrated the utility of extending this paradigm to the trunk and raised the possibility that those with chronic back pain are less accurate on left/right trunk judgments than their healthy counterparts.[13] However, several critical questions remain unanswered. For example, a clear and definitive impression of how healthy participants perform on left/right trunk judgments and the effect of age, sex, and leggedness has not been determined as it has for limb judgments. Whether left/right trunk judgments follow the same biomechanical restraints that limb judgments do is also unknown. In addition, we do not know whether those with current back pain perform differently from those who are currently pain free but have a history of back pain, or whether people perform differently during their first episode of back pain than they might during subsequent episodes.

We aimed to fill these gaps in the knowledge and compile the definitive data set against which future studies could be compared. We report the performance findings from a series of left/right trunk judgment tasks from a large, diverse cohort. We include a group of healthy, pain-free controls to provide normative data, and 2 pain categories: current back pain and a history of back pain. On the basis of previous work in people with limb pain,[21,22] we hypothesized that participants with current back pain would perform no

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differently than control participants, but participants with a history of back pain would perform worse than both those with current back pain and healthy controls.

MATERIALS AND METHODS

Participants

The participants were recruited by convenience. Advertisement for the study was included in a newsletter emailed to the database of the Neuro Orthopaedic Institute, Adelaide, Australia (http://www.noigroup.com), and placed on the Body in Mind research group Web site (http://www.bodyinmind.org), which has regular readers in 100 countries. Because of the online nature of the study, all participants required Internet access and had to be able to read and understand English instructions. Informed consent was obtained from all participants. The study had ethics approval from the University of South Australia Human Research Ethics Committee.

Task

The study was run entirely online using Recognise (Noigroup, Adelaide, Australia). The utility, validity, and repeatability of this online approach have been established.[17–19,23] All images were loaded completely before the tasks ran to ensure download speed did not affect performance. Participants completed a questionnaire concerning demographics, physical activity level, general health, and current and previous back pain. This questionnaire included the questions “Are you experiencing low back pain as you now fill in this questionnaire?” and “Have you had low back pain in the past which made you seek a treatment from a health professional?” to categorize participants into groups—healthy, current back pain, a history of back pain, and both. Participants were instructed to sit on a comfortable chair in front of the computer and complete a left/right hand judgment task to gain familiarization with the protocol. For this task, participants were instructed to press the “a” key when they saw a left hand or the “d” key when they saw a right hand. The task was terminated by the correct response.

After familiarization with the task, the study consisted of 2 blocks. The 2 blocks were identical and participants took a 2-minute break between each block. Each block consisted of 40 trials. A trial involved an image being presented on the monitor. The 40 trials were presented 1 at a time, until participants made a response or 8000 ms had lapsed. There were 2 image types: images of the back and control images, which contained the back with other body parts. All images in the task were neutral—they contained models with plain clothing against a plain-colored background with a neutral expression that was consistent across images. Half of the images showed a model bent or rotated to the left and half showed the model bent or rotated to the right. To ensure that participants did not change the strategy by which they did the task, for example, by using a cue related to the left or right border of the image, the images were also randomly dispersed into 1 of the 4 rotational categories: 0, + 90 (clockwise), −90 (anticlockwise), or 180 degrees. The images were presented in a random order.

For each trial, participants were required to indicate whether the model in the image had their trunk laterally flexed or rotated to the left or right, using the “a” and “d” keys to represent left and right, respectively; this was consistent with the familiarization hand task. Each image was shown until the participant had made a response, or until 8 s had lapsed. Performance on the task was analyzed using accuracy and reaction time (RT) data. No feedback regarding accuracy or RT was provided to the participants during the task.

Data Analysis

Accuracy and RTs were recorded for each task. Only data from the second block were included in data processing and statistical analysis, as the first block were also considered a practice. Because cognitive judgment responses require a longer time than simple reaction responses,[24] single responses were excluded if they occurred within 500 ms to avoid guessed responses. Individual responses were also excluded if over 20% of responses (8 responses) in a row were > 8000 ms, which we considered, a priori, to identify participants who had failed to engage in, or did not understand, the task. Incorrect responses were also excluded from the RT analysis. Data analysis was completed using IBM PASW version 18 software.

The relation between performance and age, sex, and leggedness was analyzed using 2 multivariate regressions: 1 for RT and 1 for accuracy, and only using data from pain-free participants. To determine the relation between performance and image rotation, the mean for each image orientation was calculated for every participant. These means were then analyzed using 2 separate 1 (RT or accuracy) × 4 (orientation) analyses of variance (ANOVAs).

To test the central hypothesis, participants were categorized according to their back pain status: current—those reporting back pain at the time of testing; history—those reporting previous back pain; and healthy—those reporting no back pain at any time. In some cases, participants were labeled as having both current and a history of back pain, indicating those in an episode of back pain, with previous episodes. Other participants reported only current back pain, indicating they were in their first episode, or only a history of back pain, indicating they had experienced previous episode/s of back pain, but were currently pain-free. The RT and accuracy data of each group were then compared between image type (back or control) using a conservative multifactorial ANOVA. Accuracy data from left/right judgments are usually not normally distributed, so they are log transformed before analysis. For each ANOVA, the within-subject (repeated measures) factor was image type, with 2 levels: back and control. The first between-subject factor was current back pain, with 2 levels: yes or no. The second between-subject factor was history of back pain, with 2 levels: yes or no.

RESULTS

Participants

Data were collected from 1189 participants. A total of 181 data sets were excluded from analysis because of incomplete questionnaires or because ≥ 8 consecutive responses were > 8000 ms. Full data from 1008 (324 male, 684 female; mean ± SD age = 37 ± 13 y) participants were used in the final analyses. Of these, 117 participants reported having a current episode of back pain, 462 reported a history of back pain, and 429 reported no history and no current back pain (herein termed “healthy” participants).

Age, Sex, and Leggedness

All analyses on accuracy used log-transformed data to satisfy the assumptions of parametric statistics. In healthy

TABLE 1. The Mean (SD) Response Time and Accuracy Results of Healthy Participants to Images Orientated at 0, + 90, − 90, and 180 Degrees

				
Image Orientation	**0 Degrees**	**+ 90 Degrees**	**− 90 Degrees**	**180 Degrees**
Response time				
Mean ± SD (ms)	1313 ± 631	1391 ± 547	1545 ± 649	2626 ± 1229
95% CI (ms)	1258-1367	1344-1438	1489-1601	2520-2732
Accuracy				
Mean ± SD (%)	99.1 ± 4.8	99.2 ± 3.4	99.0 ± 4.0	93.8 ± 11.6
95% CI (%)	98.7-99.5	99.0-99.6	98.7-99.4	92.8-94.8

pain-free participants, neither RT nor accuracy were affected by age, sex, or leggedness ($P > 0.290$ for all).

Image Rotation

To demonstrate that our task was consistent with previous limb left/right judgments, only data from healthy participants were analyzed with regard to image rotation. The magnitude of rotation of images was negatively related with RT ($F_{3,15} = 592.7$, $P < 0.001$). Participants were fastest at responding to images with no rotation (0 degrees), next fastest to those rotated to + 90 degrees, then those at − 90 degrees, and slowest to those at 180 degrees ($P < 0.001$ for all) (Table 1).

Similarly, the magnitude of rotation of images was negatively related with accuracy ($F_{3,15} = 90.4$, $P < 0.001$). The accuracy of participant responses at 0, + 90, and − 90 degrees were all statistically similar ($P = 1.000$), but participants were less accurate at responding to images orientated to 180 degrees than they were to images at any other orientation ($P < 0.001$) (Table 1).

Effect of Current Back Pain and a History of Back Pain

RT was not affected by back pain status (Fig. 1)—participants with current back pain were no slower or faster than those without current back pain ($P = 0.958$). Participants with a history of back pain were no slower or faster than those without a history of back pain ($P = 0.149$). Neither was there an interaction between current back pain and history of back pain on RT ($P = 0.908$).

Accuracy was affected by back pain status (Fig. 1). Participants with current back pain were less accurate than those without current back pain (main effect of current: $F_{1,1003} = 4.905$, $P = 0.027$). Participants with a history of back pain were less accurate than those without a history of back pain (main effect of history: $F_{1,1003} = 9.966$, $P = 0.002$). There was an interaction between current back pain and history of back pain on accuracy ($F_{1,1003} = 6.165$, $P = 0.013$), such that those with both current back pain and a history of back pain were less accurate (mean [95% CI] accuracy = 76% [74%-78%]) than all other groups (mean [95% CI] accuracy = > 84% [83%-85%]) (Fig. 1).

The frequency distribution of participants at each accuracy level revealed a similar spread of responses among each group except the current back pain group (Fig. 2). The healthy, history of back pain, and combination (current and history of back pain) groups all followed a unimodal

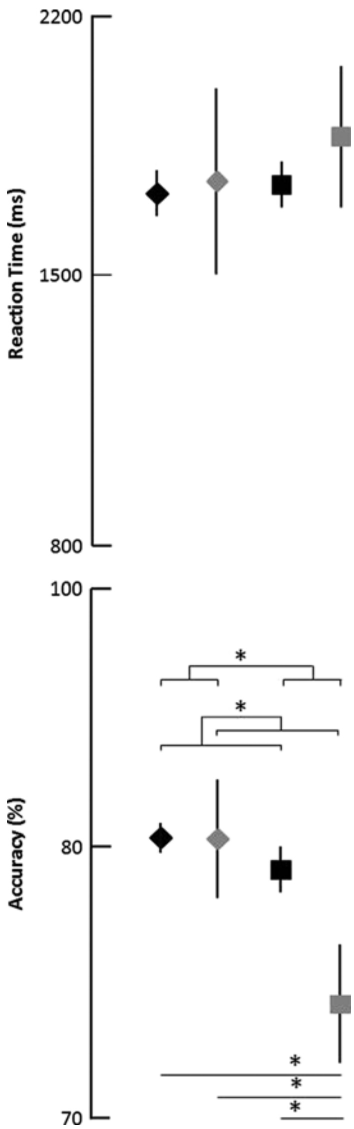

FIGURE 1. Mean (squares/diamonds) and SD (error bars) response time and accuracy of left/right judgments for healthy (black diamond), current back pain (gray diamond), and history of back pain (black square) participants, and participants with both a history and current back pain (gray square). *indicates significant differences between groups.

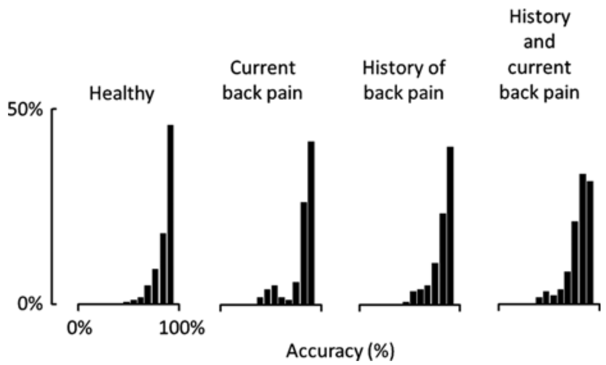

FIGURE 2. Frequency histogram showing the frequency of participants at each accuracy level as a percentage of the number of participants in that group. Note the distribution in the group experiencing their first episode of back pain, denoted "current back pain," with a bimodal distribution.

pattern, whereas the current back pain group followed a bimodal pattern.

DISCUSSION

Our results support the hypothesis that participants with a history of back pain would perform worse than those without, but were contrary to the hypothesis that there would be no effects of current back pain on performance. Notably, however, the 2 main effects may be misleading because they seem to be driven by an interaction, which is clearly observable in Figure 1—those who have current back pain and a history of back pain perform worse than the other groups do. This interaction between current back pain and a history of back pain implies that once someone has had an episode of back pain, a subsequent episode is more likely to be associated with motor imagery deficits. There is precedent for this kind of effect in association with back pain—a large body of work has shown that people who have recurrent episodes of back pain have predictable changes in the pattern of muscle activity during nonpainful tasks (see Hodges and colleaguses[7,25] for review). Those results, in conjunction with our own, would suggest that an initial episode of back pain may leave cortical body maps vulnerable to change should another episode occur, at least in some people. That is, back pain at the time of testing left/right trunk judgments does not dramatically affect performance, and a history of back pain does not disrupt performance during remission, but acute episodes on a history of back pain is associated with substantial disruption.

Interestingly, visual inspection of the performance of participants with current pain reveals a much larger spread in performance than that observed in the other groups. That is, some participants with current back pain performed much worse than the healthy participants; however, a similar portion performed much better than the healthy participants. This suggestion is supported by the frequency histogram shown in Figure 2. The distribution of the initial episode current back pain group clearly shows a bimodal pattern, with a large spread. Consistent with this idea, a recent study showed that those with pain after wrist fracture and an abnormal response on a left/right hand judgment task were substantially less likely to recover than otherwise identical people who performed normally on the same task.[26] This raises the intriguing possibility that responses to left/right trunk judgment tasks might provide an indicator of likelihood of recurrence. This is a speculative, but not outrageous, possibility. Our design does not allow us to test this possibility, but we contend that the current results infer a conceptual model that could be tested in future prospective studies.

Our conceptual model is thus (Fig. 3): the healthy group, with no history of back pain, reflect normal performance on the task (Fig. 3, Box i). The first episode group

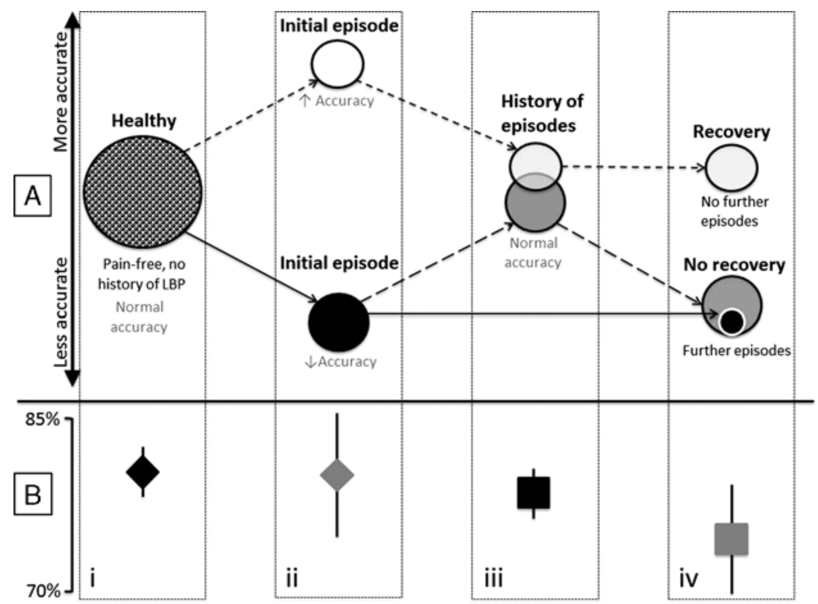

FIGURE 3. A, The conceptual model underpinning the accuracy results of the left/right judgment tasks of healthy, current back pain, history of back pain, and both (current and history) participants. B, The mean (squares/diamonds) and SD (error bars) of each group corresponding to those in (A).

(Box ii) is reflected in the 2 subsets: those who get better at the task, and those who get worse at the task. Although both groups perform normally once they have recovered from this initial episode (Box iii), those who performed worse go on to suffer further episodes of back pain (Box iv). There is a small portion of the current back pain group who will not recover from this initial episode, as indicated by the smaller black circle in Box iv. This model allows us to explain the larger variance in the current back pain group, and in the current with a history of back pain group, as well as the difference in mean values between all groups. Critically, this conceptual model aims to provide a hypothetical framework for further research, rather than a putative integration of experimental results. The model is speculative but could be easily tested in a prospective study. We contend that, if it is supported, this model would have clear implications for our understanding of the problem of chronic back pain, and also for its management.

That performance was worse when the images were rotated 180 degrees than if they were rotated 90 degrees, and worse than if they were not rotated at all, is consistent with previous studies investigating left/right neck rotation judgments (eg, Wallwork and colleagues[17–19]) and left/right limb judgments (eg, Coslett and colleagues[27–29]). These results are also supported by the Parson confirmation theory, which states that we make an initial judgment and then mentally move our body to match the posture shown so as to confirm it.[12,30] Accordingly, these findings seem consistent with, although they do not prove, the idea that we use similar processes to perform left/right judgments of body parts regardless of the body part involved. Our study did not have a sufficient spectrum of posture "awkwardness"[21] to fully confirm this observation.

Our results corroborate and extend the work of Bray and Moseley[13]—that back pain produces motor imagery deficits. Interestingly, hand and foot pain produces motor imagery deficits that manifest as alterations in RT (eg, Coslett and colleagues[27,31]); conversely, back pain produces motor imagery deficits that manifest as altered accuracy. The difference in both outcomes might reflect different disruptions in stimulus processing. For example, longer RTs are thought to reflect an information-processing bias. This is believed to result from an interpretive bias[32] toward one limb over the other, with the correction of the wrong initial judgment incurring a delay. However, altered accuracy is more likely to reflect problems with the cortical proprioceptive maps, or their integration with motor processes.[33]

That people with complex regional pain syndrome show marked delays in left/right judgments when the picture corresponds to their affected limb,[21] and also show clear neglect-like characteristics[34–37] strongly support the idea of ipsilateral information processing deficits underlying RT increases. However, people with back pain also show spatial neglect-like responses to tactile stimuli,[38] but our current results show no RT deficit in left/right trunk judgments. Perhaps this is because the back is a single functional unit as compared with the limbs. Perhaps it is because our test involves judgment of a posture rather than an anatomic region. Future research is clearly required to untangle these issues.

Cortical proprioceptive maps are maintained by tactile, proprioceptive, and visual input.[39] However, unlike the hands or face, where visual, tactile, and even auditory stimuli feed into the cortical proprioceptive representation, these sensory inputs do not normally occur for the back. Perhaps then, the back would be more vulnerable to loss of accuracy in motor imagery tasks than the hands are because there are no other sensory modalities to augment the representation. That is, in everyday activities, our hands and feet are often visualized during use, and have almost constant tactile input. Indeed, visual input has been shown to improve tactile function[40] and vision improves the effects of tactile training in people with chronic hand pain,[41] a treatment that yields symptomatic and functional improvements in that group[42] (see Moseley et al[20] for review). Further to this, different body parts are known to be contained in different areas and with different representations within the primary somatosensory cortex,[43] and so it seems reasonable that different body parts are represented in different patterns within cortical proprioceptive maps. Brain imaging studies also show that different patterns of cortical reorganization can occur for different body parts with pain conditions (eg, Flor and colleagues[9,44]). We propose that the neural representations of different body parts play a role in the performance variation between back and limb left/right judgments; however, our study was unable to confirm this possibility.

Interpretation of the current study should consider first that our study does not show a causative link between back pain and poor performance on the left/right judgment task—even our speculative model does not make this claim. It is certainly possible that poor performance and recurrent or chronic back pain are simply epiphenomena—longitudinal research would be required to clarify this. There are also limitations of our study that should be noted. We used a large convenience and self-selected sample of participants with and without back pain, but we relied entirely on subjective report to include and exclude participants, and to gain information on their health status. It is possible that some people entered erroneous responses to some items to maximize their likelihood of participating. This study did not assess the effect of medication or demographic variables, such as education, on the results. We are also not able to verify the type of complaint, nor pinpoint anatomic structures that might be involved (although, critically, this is difficult even if the participant is fully examined in person). We also relied on the technical limitations and expertise of the end user. This means that computer processing speed and capacity, screen properties, and experimental environment could not be controlled. Although we aimed to minimize the impact of these problems, we cannot exclude them. Importantly, these issues reduce the precision and power of our study, rather than confound the main findings, and we would have overcome these problems to some extent with the large sample. Furthermore, large studies such as this are less vulnerable to false positives than small studies[45] and the reliability and validity of our approach has been established.[23] Notwithstanding, it is possible that there were other effects that we were not able to detect with our current design.

In summary, our results characterize performance at a trunk motor imagery task in people with and without back pain. We show that both current back pain and a history of back pain have some effect on motor imagery performance, but it is the interaction between the 2 that is associated with large deficits. A conceptual model, in which performance of left/right trunk judgments in a person experiencing their first episode of back pain may provide some insight into the likelihood of further episodes of back pain in the future, has been proposed and could be tested in future studies.

REFERENCES

1. Brumagne S, Cordo P, Lysens R, et al. The role of paraspinal muscle spindles in lumbosacral position sense in individuals with and without low back pain. *Spine*. 2000;25:989–994.
2. Brumagne S, Cordo P, Verschueren S. Proprioceptive weighting changes in persons with low back pain and elderly persons during upright standing. *Neurosci Lett*. 2004;366:63–66.
3. Brumagne S, Janssens L, Janssens E, et al. Altered postural control in anticipation of postural instability in persons with recurrent low back pain. *Gait Posture*. 2008;28:657–662.
4. Brumagne S, Janssens L, Knapen S, et al. Persons with recurrent low back pain exhibit a rigid postural control strategy. *Eur Spine J*. 2008;17:1177–1184.
5. Claeys K, Brumagne S, Dankaerts W, et al. Decreased variability in postural control strategies in young people with non-specific low back pain is associated with altered proprioceptive reweighting. *Eur J Appl Physiol*. 2011;111:115–123.
6. Moseley GL, Nicholas MK, Hodges PW. Does anticipation of back pain predispose to back trouble? *Brain*. 2004;127: 2339–2347.
7. Hodges PW, Moseley GL. Pain and motor control of the lumbopelvic region: effect and possible mechanisms. *J Electromyogr Kinesiol*. 2003;13:361–370.
8. Gandevia S. Kinesthesia: roles for afferent signals and motor commands. In: Rothwell L, Shepherd J, eds. *Handbook of Physiology, Section 12, Exercise: Regulation and Integration of Multiple Systems*. New York: Oxford University Press; 1996:128–172.
9. Flor H, Elbert T, Braun C, et al. Extensive cortical reorganization in chronic back pain patients. *Neurosci Lett*. 1997;224:5–8.
10. Tsao H, Galea MP, Hodges PW. Reorganization of the motor cortex is associated with postural control deficits in recurrent low back pain. *Brain*. 2008;131:2161–2171.
11. Wand BM, Parkitny L, O'Connell NE, et al. Cortical changes in chronic low back pain: current state of the art and implications for clinical practice. *Man Ther*. 2011;16:15–20.
12. Parsons LM. Integrating cognitive psychology, neurology and neuroimaging. *Acta Psychol*. 2001;107:155–181.
13. Bray H, Moseley GL. Disrupted working body schema of the trunk in people with back pain. *Br J Sports Med*. 2011;45:168–173.
14. Coslett HB, Medina J, Kliot D, et al. Mental motor imagery and chronic pain: the foot laterality task. *J Int Neuropsychol Soc*. 2010;16:603–612.
15. Schmid ABP, Coppieters MWP. Left/right judgment of body parts is selectively impaired in patients with unilateral carpal tunnel syndrome. *Clin J Pain*. 2012;28:615–622.
16. Stanton TR, Lin C-WC, Smeets RJEM, et al. Spatially defined disruption of motor imagery performance in people with osteoarthritis. *Rheumatology*. 2012;51:1455–1464.
17. Wallwork SB, Butler DS, Fulton I, et al. Left/right neck rotation judgments are affected by age, gender, handedness and image rotation. *Man Ther*. 2013;18:225–230.
18. Wallwork SB, Butler DS, Moseley GL. Dizzy people perform no worse at a motor imagery task requiring whole body mental rotation; a case-control comparison. *Front Hum Neurosci*. 2013;7:1–6.
19. Wallwork SB, Butler DS, Wilson DJ, et al. Are people who do yoga any better at a motor imagery task than those who do not? *Br J Sports Med*. 2012. [Epub ahead of print].
20. Moseley GL, Gallace A, Spence C. Bodily illusions in health and disease: physiological and clinical perspectives and the concept of a cortical 'body matrix'. *Neurosci Biobehav Rev*. 2012;36:34–46.
21. Moseley GL. Why do people with complex regional pain syndrome take longer to recognize their affected hand? *Neurology*. 2004;62:2182–2186.
22. Moseley GL, Sim DF, Henry ML, et al. Experimental hand pain delays recognition of the contralateral hand—evidence that acute and chronic pain have opposite effects on information processing? *Cognitive Brain Res*. 2005;25:188–194.
23. Wallwork SB. *Turning to the Left or Right? Normative Responses for a Left/Right Neck Rotation Judgment Task*. Adelaide, Australia: University of South Australia; 2010.
24. Sternberg S. Memory-scanning: mental processes revealed by reaction-time experiments. *Am Sci*. 1969;57:421–457.
25. MacDonald D, Moseley GL, Hodges PW. People with recurrent low back pain respond differently to trunk loading despite remission from symptoms. *Spine*. 2010;35:818–824.
26. Moseley G, Herbert RD, Parsons T, et al. Intense pain soon after wrist fracture strongly predicts who will develop complex regional pain syndrome: prospective cohort study. *J Pain*. (In press).
27. Coslett HB, Medina J, Kliot D, et al. Mental motor imagery indexes pain: the hand laterality task. *Eur J Pain*. 2010;14: 1007–1013.
28. Hudson ML, McCormick K, Zalucki N, et al. Expectation of pain replicates the effect of pain in a hand laterality recognition task: bias in information processing toward the painful side? *Eur J Pain*. 2006;10:219–224.
29. Moseley G. Graded motor imagery is effective for long-standing complex regional pain syndrome: a randomised controlled trial. *Pain*. 2004;108:192–198.
30. Parsons LM. Imagined spatial transformations of one's hands and feet. *Cognit Psychol*. 1987;19:178–241.
31. Coslett H, Medina J, Kliot D, et al. Mental motor imagery and chronic pain: the foot laterality task. *J Int Neuropsych Soc*. 2010;16:603–612.
32. Pincus T, Pearce S, McClelland A, et al. Interpretation bias in responses to ambiguous cues in pain patients. *J Psychosom Res*. 1994;38:347–353.
33. Moseley G, Butler DS, Beames TB, et al. *The Graded Motor Imagery Handbook*. Adelaide: Noigroup Publications; 2012.
34. Frettlöh J, Hüppe M, Maier C. Severity and specificity of neglect-like symptoms in patients with complex regional pain syndrome (CRPS) compared to chronic limb pain of other origins. *Pain*. 2006;124(1–2):184–189.
35. Kolb L, Lang C, Seifert F, et al. Cognitive correlates of "neglect-like syndrome" in patients with complex regional pain syndrome. *Pain*. 2012;153:1063–1073.
36. Moseley GL, Gallace A, Iannetti GD. Spatially defined modulation of skin temperature and hand ownership of both hands in patients with unilateral complex regional pain syndrome. *Brain*. 2012;135:3676–3686.
37. Moseley GL, Gallace A, Spence C. Space-based, but not arm-based, shift in tactile processing in complex regional pain syndrome and its relationship to cooling of the affected limb. *Brain*. 2009;132:3142–3151.
38. Bowering KJ, O'Connell NE, Tabor A, et al. The effects of graded motor imagery and its components on chronic pain: a systematic review and meta-analysis. *J Pain*. 2013;14:3–13.
39. Cole J, Paillard J. Living without touch and peripheral information about body position and movement: studies with deafferented subjects. In: Bermudez J, Marcel A, Eilan N, eds. *The Body and the Self*. Cambridge: MIT Press; 1995: 245–266.
40. Kennett S, Eimer M, Spence C, et al. Tactile-visual links in exogenous spatial attention under different postures: convergent evidence from psychophysics and ERPs. *J Cogn Neurosci*. 2001;13:462.
41. Moseley GL, Wiech K. The effect of tactile discrimination training is enhanced when patients watch the reflected image of their unaffected limb during training. *Pain*. 2009;144:314–319.
42. Moseley GL, Zalucki NM, Wiech K. Tactile discrimination, but not tactile stimulation alone, reduces chronic limb pain. *Pain*. 2008;137:600–608.
43. Nakamura A, Yamada T, Goto A, et al. Somatosensory homunculus as drawn by MEG. *NeuroImage*. 1998;7:377–386.
44. Maihofner C, Handwerker H, Neundorfer B, et al. Patterns of cortical reorganization in complex regional pain syndrome. *Neurology*. 2003;61:1707–1715.
45. Kahneman D, Tversky A. Subjective probability: a judgment of representativeness. *Cognit Psychol*. 1972;3:430–454.