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Original article

Spatially defined disruption of motor imagery performance in people with osteoarthritis

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Abstract

Objectives. To determine whether motor imagery performance is disrupted in patients with painful knee OA and if this disruption is specific to the location of the pain.

Methods. Twenty patients with painful knee OA, 20 patients with arm pain and 20 healthy pain-free controls undertook a motor imagery task in which they made left/right judgements of pictured hands and feet. Accuracy and reaction time of judgements were compared between groups and pain locations (side: left *vs* right; site: upper *vs* lower).

Results. Patients with knee pain were less accurate ($P < 0.01$) than healthy controls, but not different from people with arm pain (all $P > 0.11$). There were no differences in reaction time between groups ($P = 0.64$). Further, there was no effect of side or site of pain on reaction time ($P = 0.43$, 0.54, respectively) and no effect of site of pain on accuracy of left/right judgements ($P = 0.12$). However, there was an interaction effect of side of pain on accuracy of left *vs* right images ($P = 0.03$). If left-sided pain was present, accuracy was lower when images showed left hands/feet than when images showed right hands/feet.

Conclusion. Motor imagery performance is disrupted in patients with knee OA, but is also disrupted in patients with arm pain. Accuracy of left/right judgements is disrupted in a spatially defined manner, raising the important possibility that brain-grounded maps of peripersonal space contribute to the cortical proprioceptive representation.

Key words: left/right judgement, proprioception, motor imagery, OA, accuracy, reaction time, spatial representation.

Introduction

Symptomatic knee OA is associated with disrupted movement and proprioception. These disruptions have primarily been attributed to impairment in the periphery (for example, in the joint capsule) or the spinal cord [1, 2]. Recently, however, the brain has been identified as a potential source of disrupted proprioception [3–5].

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The fact that the brain holds maps of the body is well established [6]. The most studied body map is that in the primary somatosensory cortex (S1), which holds a map of the surfaces of the body [6]. Neuroimaging has confirmed the presence of a somatotopic body map in S1 [7–9] and has uncovered similar body maps in other areas, for example the insula [10, 11] and secondary somatosensory cortex [12]. Together, the brain-grounded body maps that allow accurate planning, coordination and execution of movements are known as the working body schema. It follows then that disruption of working body schema results in motor and proprioceptive deficits. In contrast to somatotopic maps held in S1, the neural correlate for working body schema has not been elucidated, which means that the neuroimaging approaches that underpin our understanding of somatotopic maps cannot be applied to the investigation of working body schema. An established alternative is to use a behavioural approach

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that removes the contribution of peripheral and spinal proprioceptive factors, for example, motor imagery.

Evaluation of motor imagery performance commonly involves a left/right judgement task, in which one identifies a picture of a body part (in various positions) as belonging to either the left side of the body or the right. This task requires one to make an initial judgement and to then confirm that judgement by mentally moving one's own body part to match the posturing of the body part shown in the picture [13]. This task requires an intact working body schema [14]. Most importantly, as no actual movement occurs in left/right judgements, sensory feedback is removed as a potential source of disrupted performance.

Left/right judgements yield two outcomes: accuracy and reaction time. Accuracy is thought to inform us about the acuity of the working body schema (i.e. how well one can mentally manoeuvre a body part; a pre-requisite for planning movement) [15] or, possibly, the representation of peripersonal space (i.e. the space surrounding the body; see [24] for a review). Conversely, reaction time reflects the total time it takes to select sidedness, mentally manoeuvre a body part and make the final decision [14]. Reaction time is also thought to generally inform us about the brain's capacity to process incoming information (i.e. which may be reduced when pain is present) as well as the brain's capacity to give priority or attentional bias towards a body part or an area of space [13, 16–18]. Accuracy and reaction time are differentially affected in pathological states such as chronic pain [15, 18, 19].

The first aim of the current work was to determine whether knee OA is associated with impaired left/right judgement performance. We hypothesized that people with knee OA would be slower and less accurate than healthy controls in left/right judgements. Participants with upper limb pain were included as controls to determine whether any disruptions were specific to lower limb pain. We anticipated that people with knee OA would have impaired performance for pictures of the leg, but not for pictures of the arm. Thus the second aim of the current work was to determine whether impairment in left/right judgement performance is specific to the location of pain [i.e. specific to both side and site (upper *vs* lower) of pain]. We hypothesized that an interaction would exist, such that left/right judgement performance would be worse when the image of the body part corresponds to the area of pain.

Methods

Study

Cross-sectional study design.

Participants

Three groups of participants were recruited. The first group was composed of 20 consecutive patients with confirmed knee OA [20]. The second group was 20 age-matched patient controls with upper limb pain. The patient controls had pain in a variety of locations ranging from hand/wrist pain (i.e. post-fracture) to elbow pain (i.e. epicondylalgia) to shoulder pain (i.e. impingement, rotator cuff tear, post-dislocation). The third group was 20 healthy pain-free controls. See Table 1 for participant eligibility criteria, source of participants and method of recruitment.

Data collection in knee OA patients and patient controls was approved by the Northern Sydney Central Coast Area Health Service Human Research Ethics Committee. For recruitment of healthy controls, approval was received from the University of Sydney Human Research Ethics Committee and written consent was obtained. The study conformed to the Declaration of Helsinki and the National Statement on Ethical Conduct in Research Involving Humans by the National Health and Medical Research Council of Australia.

Procedure

Participants completed a questionnaire that collected demographic information (age, height, weight and dominant hand/foot) and other condition-specific information. For dominant hand/foot, participants were asked which hand they write with and which foot they would kick a ball with. The following knee-specific scales were completed: knee pain (current knee pain and average knee pain >last 48 h; 100-mm visual analogue scale with 0 = no pain and 100 = worst pain imaginable); Oxford knee score [21] (0–48, with higher scores representing lesser disability); and Neglect scale for the knee [22] (0–36, with higher scores representing more neglect). Visual and motor imageries were also assessed by asking subjects to visualize performing a squat and returning to standing. Subjects rated how easy it was for them to see (visual) and feel (motor) themselves do the movement on a seven-point scale, where seven represents very easy and one represents very hard. This forms part of the Movement Imagery Questionnaire [23].

The left/right judgement task

Left/right judgements were performed using Recognise, a commercially available online software program (http://recognise.noigroup.com/recognise). We used a series of 10 photographs of left/right hands in a variety of postures. The hands were of a variety of sizes and also skin tones. These photographs are taken from a pool of 20 photographs and were presented in random order. Participants were instructed to perform the task as quickly and as accurately as possible. Participants were also instructed not to move their hands to match the position of the image. Using the index fingers of both hands, participants responded by pressing one of two keys on the computer keyboard to indicate whether they thought it to be a right hand (d key; right index finger) or a left hand (a key; left index finger). Pictures were displayed for a maximum of 5 s or until the subject pressed a key. If no key was pressed, the picture was automatically advanced. Participants were given one practice trial of 10 images in order to orient themselves to the left/right judgement task and to the computer set-up. These data were not analysed. Participants then undertook a second trial of 10 images for which data were analysed.

TABLE 1 Eligibility criteria, participant recruitment source/method and flow of participant recruitment

Study information	Knee OA	Patient controls (arm pain)	Healthy pain-free controls
Eligibility criteria	Fulfils ACR radiographical + clinical criteria Knee pain + osteophytes on radiographs + at least one of the following: age >50 years; stiffness <30 minutes; and crepitus. If recent radiographs not present, patient fulfils ACR clinical criteria Knee pain + at least three of the following: age >50 years; stiffness <30 minutes; crepitus; body tenderness; body enlargement; and no palpable warmth.	Presents with upper limb pain Does not have: knee OA; low back pain; or leg pain.	Does not have: knee OA; low back pain; and upper/lower limb pain.
Source of participants	The Royal North Shore Hospital Physiotherapy Outpatient Department in Sydney, Australia.	The Royal North Shore Hospital Physiotherapy Outpatient Department or from the hospital's fracture clinic.	Staff/students recruited from the University of Sydney/ Royal North Shore Hospital or volunteers recruited from the community.
Method of recruitment	Consecutive cases.	Convenience sample.	Convenience sample.
Flow of participant recruitment	Twenty-seven patients with knee OA initially satisfied the inclusion criteria for this group. Four patients did not consent and three were excluded due to technical errors in the left/right judgement task.	Forty-two potential patient controls were screened to be included in the study with 19 excluded for presence of knee OA/current LBP/lower limb pain and three excluded due to technical errors in the left/right judgement task.	Twenty-five healthy controls satisfied inclusion criteria with five excluded due to technical errors in the left/right judgement task.

Accuracy (percentage correct) and reaction time (seconds) were the primary outcome variables. An otherwise identical process was followed to obtain left/right judgements of feet. The order in which these two tasks (hand or feet) were undertaken was randomized.

In order to make left/right foot judgements, one mentally manoeuvres the lower limb in order to position the foot to match that shown in the image [13]. As the pictures of feet commonly included the ankle/lower limb, it was anticipated that when mentally manoeuvring one's own foot/lower limb to match the posturing in the pictures, this mental rotation would likely include the knee. Because knee proprioception plays an important role in placing the foot, we suggest that it is not unreasonable to expect foot and leg proprioceptive maps to be involved concurrently. Lastly, using pictures featuring only the knee is not feasible because it is very difficult to determine knee sidedness without further context.

Statistical analysis

All statistics were performed using SPSS 19.0 (SPSS, Chicago, IL, USA). The accuracy data were not normally distributed (i.e. visual inspection and significant Shapiro–Wilk statistics), therefore non-parametric statistics were used for analyses involving these data. However, when data from healthy controls were excluded from analysis, accuracy data were normally distributed (Shapiro–Wilk statistic 0.08–0.91), so parametric statistics were used for those analyses. Normality was verified for all reaction time data.

A Kruskall–Wallis test was used to detect an effect of group (knee OA, patient control and healthy control) on image accuracy (left foot, right foot, left hand and right hand). *Post hoc* Mann–Whitney tests were used to determine specific differences between each group. A Bonferroni correction for multiple measures was applied such that $\alpha = 0.016$. For reaction time data, a four (image: left foot, right foot, left hand and right hand) $\times$ three (group: knee OA, upper limb pain and healthy controls) repeated measures analysis of variance (ANOVA) was used to detect an effect of group. Age was entered as a covariate. Due to differences in age between groups, a sensitivity analysis, using a three (group: OA, arm pain and healthy controls) $\times$ four (image: left foot, left hand, right foot and right hand) repeated measures ANOVA was completed including only people over the age of 50 years in the healthy control group ($n = 5$) for both accuracy and reaction time. Lastly, in light of differences in participant numbers between groups in the sensitivity analysis, a *post hoc* analysis was performed using previously collected left/right judgement data from a separate pain-free cohort (age and gender matched to knee OA patients; see supplementary File S1, available as supplementary data at *Rheumatology* Online). This *post hoc* analysis was a three (group: OA, arm pain and healthy controls) $\times$ two (image: feet and hands) repeated measure ANOVA to evaluate group differences for both accuracy and reaction time outcomes.

To determine the effect of the side of pain (left *vs* right), only participants with unilateral pain were selected ($n = 30$; missing left/right judgement data for one patient control). A two (image: left or right) $\times$ two (pain location: left or right) repeated measures ANOVA was used to detect an effect of left/right pain location on the accuracy of left/right judgements for left *vs* right images. To determine the effect of site of pain (upper *vs* lower body), only participants with pain were selected ($n = 36$; missing left/right judgement data for one patient control). A two [image: upper (hands) or lower (feet)] $\times$ two (pain location: upper or lower limb) repeated measures ANOVA was used to detect an effect of upper/lower pain location on the accuracy of left/right judgements for hand *vs* foot images. Both analyses were repeated for reaction time. Left- *vs* right-sided pain and upper *vs* lower pain were chosen for these analyses, as recent sensory processing data suggest that there is a spatially based reference system that differentiates between left and right stimuli but not cephalad–caudad (upper *vs* lower body) stimuli [24]. To ensure that the results of the above analyses were not influenced by the use of different subsets of participants, we completed a three (pain side: left *vs* right *vs* bilateral) $\times$ two (pain site: upper *vs* lower) $\times$ four (image: left hand, right hand, left foot and right foot) analysis for both accuracy and reaction time outcomes using the entire available sample ($n = 36$; three people with missing data for pain location, one person with missing left/right judgement data).

Finally, to determine whether randomization resulted in any differences in the proportion of left *vs* right images between groups, or between those with left-sided pain *vs* those with right-sided pain, we undertook Fisher's exact tests without correcting for multiple measures so as to maximize our chance of detecting a difference.

Results

Of the recruited participants, 4 had bilateral symptomatic knee OA and 16 had unilateral symptomatic knee OA. Of the 16 participants with unilateral OA, 9 had no previous history of pain in the unaffected knee. The remaining seven had a previous history of pain in the unaffected knee, but no current pain. In the patient control group, 15 had unilateral upper limb pain and 2 had bilateral pain (missing data for 3 participants). See Table 2 for further participant demographic information.

Accuracy of left/right judgements

People with knee OA were less accurate (median accuracy of 60%) than healthy controls (median accuracy of 100%) on left/right judgements for all images except those of the right hand (Fig. 1A). People with knee OA were no more or less accurate than people with upper limb pain (median accuracy of 75%). That is, there was a significant difference between groups for left foot images ($\chi^2 = 17.26$, $P < 0.001$), right foot images ($\chi^2 = 10.21$, $P = 0.006$) and left-hand images ($\chi^2 = 9.72$, $P = 0.008$), but no difference for right-hand images ($\chi^2 = 4.79$, $P = 0.09$). See supplementary Table S2, available as supplementary data at *Rheumatology* Online, for

TABLE 2 Subject demographics

Variable	Knee OA	Patient control	Healthy control
Age, years	68.0 (9.0)	64.9 (7.8)	37.3 (15.5)
Female, %	70	45	60
Hand dominance			
Right hand dominant, *n*	18	18	20
Left hand dominant, *n*	0	1	
Missing data	2	1	
Leg dominance			
Right leg dominant, *n*	18	19	20
Left leg dominant, *n*	0	0	
Missing data	2	1	
Body mass index, kg/m^2	29.4 (5.0)	26.1 (3.7)	23.4 (3.0)
Pain location, *n*			
Left side	7	5	
Right side	9	10	NA
Bilateral	4	2	
Missing	0	3	
Knee pain intensity (100 mm)			
Current pain	21.9 (25.5)	1.5 (6.5)[a]	0.95 (2.3)[b]
Pain >last 48 h	51.9 (21.6)	2.2 (7.1)[a]	1.2 (3.0)[b]
History of knee pain, years			
Right	7.3 (14.1)	0	0.1 (0.3)
Left	4.9 (9.0)	0.1 (0.3)	0.1 (0.3)
Affected	8.3 (7.4)	NA	NA
Non-affected	2.6 (16.2)	NA	NA
Bilateral	6.0 (3.2)	NA	NA
Oxford knee score (/48)	22 (8.3)	47 (2.1)	48 (1.4)
Neglect scale (/36)	11 (6.5)	2.4 (4.7)	0.3 (0.8)
Visual imagery scale (1–7)	3.3 (2.7)	5.0 (2.0)	6.2 (1.2)
Motor imagery scale (1–7)	2.8 (2.5)	4.7 (2.2)	5.6 (1.7)

All values are mean (S.D.) unless otherwise specified. NA = not applicable. [a]Mild levels of pain reported by two patient controls due to muscle soreness in the upper calf. [b]Mild levels of pain reported by seven healthy controls; three reported muscle soreness in the upper calf, four reported pain on the skin of the knee due to sunburn.

condition × image *post hoc* results. Age was not related to accuracy of left/right judgements ($P = 0.84$). Results were unchanged with the addition of age as a covariate.

The sensitivity analysis (i.e. only including healthy control participants over the age of 50 years; $n = 5$) and the *post hoc* analysis (i.e. using age- and gender-matched healthy controls) both found similar results. People with knee OA were less accurate than healthy controls ($P = 0.005$, $P < 0.001$, respectively), but were no more or less accurate than those with arm pain ($P = 0.20$, $P = 0.17$). People with arm pain were also less accurate than healthy controls ($P = 0.04$, $P = 0.007$).

Reaction time for left/right judgements

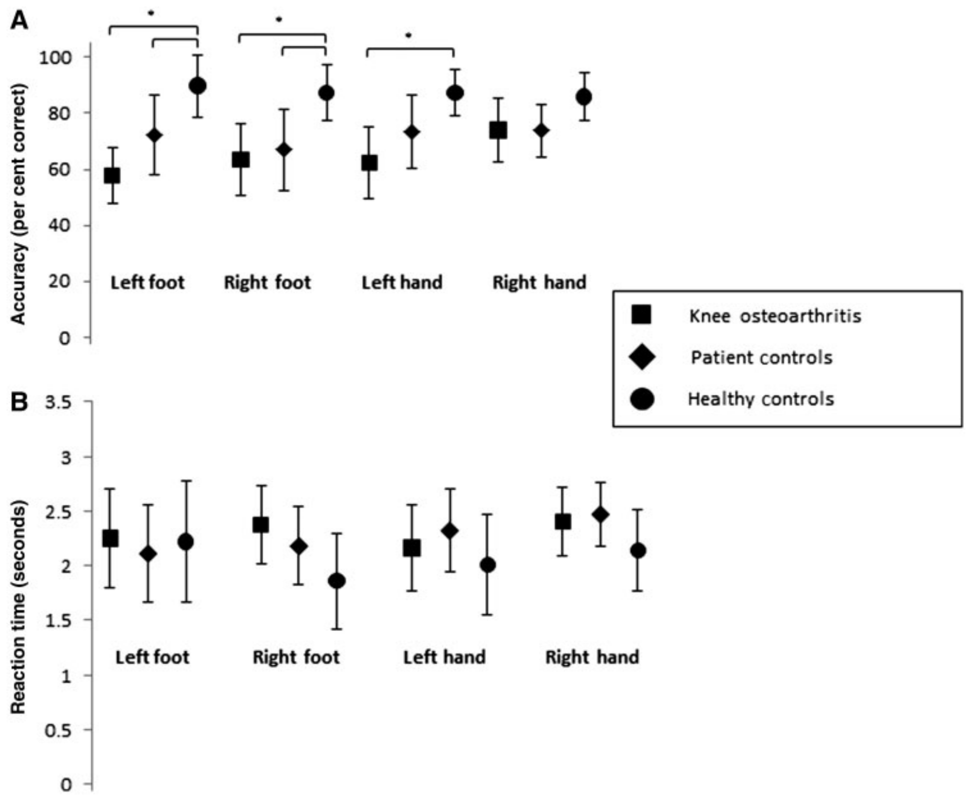
After controlling for age, there were no statistically significant differences in reaction time between groups ($F_{2,54} = 0.46$, $P = 0.64$; Fig. 1B). There was also no effect of image ($F_{3,54} = 0.52$, $P = 0.67$) and no group × image interaction ($F_{6,54} = 0.77$, $P = 0.60$). This finding was confirmed by the sensitivity analysis that demonstrated no main effect of group ($F_{2,40} = 1.23$, $P = 0.30$) and by the *post hoc* analysis using age- and gender-matched pain-free controls ($F_{2,55} = 0.38$, $P = 0.69$).

Spearman's rho correlations between accuracy and reaction time of left/right judgements were negative (all $P < 0.01$; see supplementary File S3, available as supplementary data at *Rheumatology* Online), suggesting that participants who were less accurate were also slower at responding (i.e. they were not less accurate merely because they were responding very quickly). Further, the proportion of left and right images was similar across groups (Fisher's exact $P > 0.32$ for all).

Effect of pain location on left/right judgements

The location of pain was found to influence the accuracy of left/right judgements in a spatial manner—the side of pain was important, but the site of the pain (upper *vs* lower limb pain) was not important. When comparing the influence of side of pain (left *vs* right-sided) on the ability to correctly identify left *vs* right images, there were main effects of image ($F_{1,28} = 5.3$, $P = 0.03$) and side of pain ($F_{1,28} = 9.1$, $P < 0.01$). This was driven by a significant interaction ($F_{1,28} = 5.4$, $P = 0.03$) whereby if left-sided pain was present, accuracy was lower for left images than for right images (Fig. 2A). When only the knee OA data were included in the analysis, the significant interaction

FIG. 1 Mean left/right judgement performance values for each group. (**A**) Mean accuracy of left/right judgements (per cent correct) for each condition (95% CIs). (**B**) Mean reaction time of left/right judgements (seconds) for each condition (95% CIs). *$P < 0.01$.



remained ($F_{1,14} = 6.1$, $P = 0.03$; Fig. 2B). The proportion of left and right images was similar between those with left-sided pain and those with right-sided pain (Fisher's exact $P = 0.76$). Conversely, when comparing the ability to correctly identify upper or lower images between those with upper or lower limb pain, there was no main effect of image ($F_{1,34} = 3.4$, $P = 0.07$) nor site of pain (upper *vs* lower; $F_{1,34} = 2.7$, $P = 0.11$), and there was no image × pain location interaction ($F_{1,34} = 0.03$, $P = 0.87$) (Fig. 2C).

With regard to reaction time, location of pain did not affect the time it took to recognize any of the tested body parts in left/right judgements. For left *vs* right images, there were no main effects of image ($F_{1,28} = 0.64$, $P = 0.43$) or side of pain (left *vs* right; $F_{1,28} = 3.91$, $P = 0.06$) and no image × pain location interaction ($F_{1,28} = 0.002$, $P = 0.95$) (please refer to Fig. 3A). The same was found for upper *vs* lower body images (Fig. 3B), with no main effect of image ($F_{1,34} = 0.38$, $P = 0.54$) or site of pain (upper *vs* lower; $F_{1,34} = 0.01$, $P = 0.92$) and a non-significant interaction effect ($F_{1,34} = 0.87$, $P = 0.36$).

The *post hoc* analyses that were completed to ensure spatial effects were not due to differences in the patient subsets used supported both our accuracy and reaction time findings (see supplementary File S4, available as supplementary data at *Rheumatology* Online).

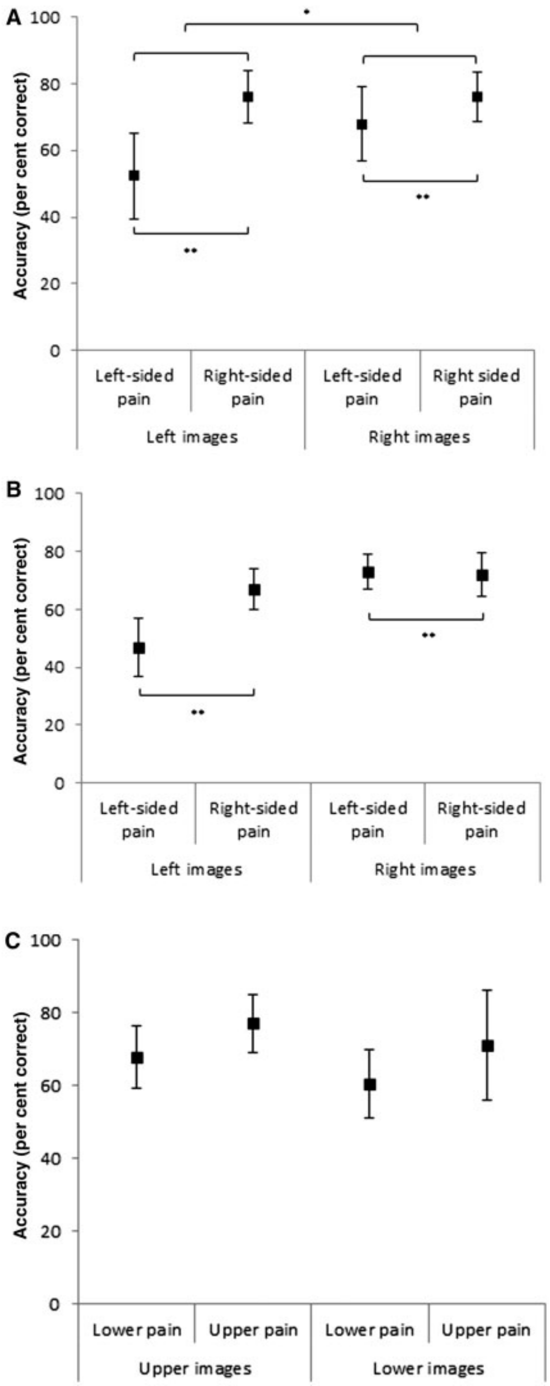
Discussion

We hypothesized that left/right judgement performance would be worse in people with knee OA than in healthy controls. The results partially support this hypothesis: knee OA patients were less accurate than healthy controls but there were no differences between groups for reaction time outcomes. Further, we hypothesized that there would be an interaction between location of pain and performance. This was also partially supported; we found that the side of pain (left *vs* right-sided pain), but not the site of pain (upper *vs* lower), influenced the accuracy of left/right judgements. However, there was no effect of pain location on reaction time. Also, disruptions to accuracy performance in people with knee OA were not limited to images of the lower body as hypothesized; decreased accuracy was present for images of both feet and hands.

Overall disruptions in accuracy and reaction time in knee OA relative to healthy controls

That the patients with knee OA perform worse than healthy controls in left/right judgements is a new finding, although previous research has revealed decreased performance in other painful conditions. For example, upper limb amputees are slower and less accurate on a left/right judgement task as compared with healthy controls [25].

Fig. 2 Effect of the location of pain on mean accuracy values for left/right judgements. (**A**) Effect of side of pain (left *vs* right) on mean accuracy (95% CIs) for left and right images. Significant interaction effect ($P = 0.03$) not demonstrated on the graph. (**B**) Knee OA participants only: effect of side of pain (left *vs* right) on mean accuracy (95% CIs) for left and right images. Significant interaction effect ($P = 0.03$) not demonstrated on the graph. (**C**) Effect of site of pain (upper *vs* lower) on mean accuracy (95% CIs) for upper and lower images. Main effect of side of image, $^{*}P < 0.05$; Main effect of side of pain, $^{**}P < 0.01$.



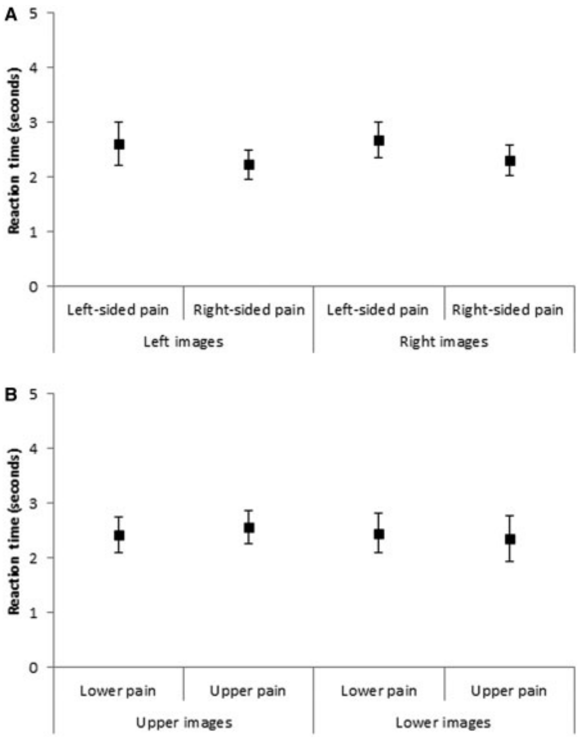
In patients with complex regional pain syndrome, reaction time is greater for images corresponding to the affected limb than for images of the unaffected limb [18, 26]. Interestingly, the present findings compare most closely to left/right judgement performance in patients with chronic low back pain where accuracy of judging left/right trunk rotation was significantly worse than it was in healthy controls [15].

One might postulate that having a chronic pain condition leads to decreased accuracy but unaffected reaction time outcomes based on the present evidence. However, recent studies evaluating left/right judgements in people with chronic upper limb pain (hand images) [19] and chronic lower limb pain (foot images) [27] have found conflicting results to the present study. In brief, people with leg pain were both slower and less accurate than normal and pain control subjects in response to drawings of a painful extremity [27]. In contrast, people with arm pain were slower than both pain controls and normal controls, but accuracy was not affected [19]. The differences between the current results and those of previous studies may be attributed to differences in the left/right judgement task used in each. In the latter two studies [19, 27], line drawings of a hand/foot were used, presenting the body parts in a variety of rotations but always in a standardized posture. The current work used hand/foot photographs with the body parts in a variety of rotations and a variety of postures. Perhaps the added complexity of the images used here contributes to the different results. This idea is supported by similar findings between the present study and the chronic low back pain study [15], which both used photographs of actual body parts.

That only accuracy of left/right judgements is affected in patients with knee OA suggests disruption of the working body schema or its integration with motor processes [15]. That is, even when the brain confirms image sidedness via motor imagery, an incorrect judgement is made. Further, this decreased accuracy in knee OA patients was not specific to lower limb images—it was present for upper limb images as well. This suggests that the presence of pain itself may impede the mental rotation process. As mentioned previously, left/right judgements involve different stages: initial automatic selection, integration of the body schema with motor processes (i.e. mentally manoeuvring of body part to match picture) and the response [13]. Since reaction time was not affected in people with knee OA, this suggests that there is no evidence to support the presence of a bias in making the initial judgement (i.e. as there was no side- or image-specific slowing of responses [13]) nor evidence to support a general slowing of CNS processing.

In patients with knee OA, decreased accuracy of left/right judgements (as compared with healthy controls) was not present for images of all body parts. Indeed, the accuracy of left/right judgements was not different for pictures of the right hand between patients with knee OA and healthy controls (or those with arm pain). One might suggest that the ability to recognize the right hand is improved through its constant use. That all but one participant in the

Fig. 3 Effect of the location of pain on mean reaction times for left/right judgements. (**A**) Effect of side of pain (left *vs* right) on mean reaction time (95% CIs) for left and right images. (**B**) Effect of site of pain (upper *vs* lower) on mean reaction time (95% CIs) for upper and lower images. No significant differences.



present study were right-handed seems consistent with this suggestion.

That there were no significant effects of age on the accuracy of left/right judgements is interesting, as it is known that older age often results in a reduction in left/right judgement performance [28]. This is pertinent, as the healthy normal participants were younger than those with knee OA or arm pain. We postulate that because the present left/right judgement task was relatively easy (e.g. involved 10 judgements compared with 56–96 judgements in other studies) [15, 18, 25], it is possible that the ease of the test may have eliminated some of the age difference in performance that we would expect. However, that age extinguished the group differences in reaction time makes sense. There is good evidence to suggest that reaction time tends to slow as we age [28, 29].

The role of pain in left/right judgement performance

While participants with knee OA had disruptions to the accuracy of left/right judgements, these disruptions appear more likely to be related to the presence of pain than to the specific condition. This is supported by the result that patients with knee OA were no more or less accurate than patients with upper limb pain, but both were less accurate than healthy controls. Further, specific investigation into the role of pain location on left/right judgement performance suggests that disruption of performance is not specific to the location of pain, particularly for the reaction time data. If reaction time disruptions were specific to the location of pain (i.e. side and site), we would expect to see a bias in information processing away from the painful side (that is, a slower reaction time for the painful side) [16–18, 30, 31] and delayed response specific to images of the painful body part. However, we did not find this—reaction time was unaffected by the location of pain (left *vs* right and upper *vs* lower). That expected pain (i.e. experimental) [32] can delay reaction time tasks has been shown previously; however, this does not appear to hold for the present sample recruiting people with chronic painful knee OA.

Reduced accuracy was not specific to the location of pain (i.e. to both side and site of pain). We did find, however, a side-to-side effect, that is, a spatially defined disruption of accuracy. It is known that in addition to anatomical maps in the brain (anatomically based frame of reference), there are also spatial maps (spatially based frame of reference) where something occurs in relation to the body's midline. These spatial maps are thought to code for peripersonal space (that is, the space surrounding your body) [33] and events that occur within that space. That accuracy disruption was only dependent on left/right pain location and not upper/lower pain location raises the possibility that disruption of the spatially based frame of reference contributes to reduced accuracy of left/right limb judgements. These data add to a growing body of literature suggesting disruption of spatial representation in pain conditions [34] (see [24] for a review). The strongest support for the spatially based frame of reference is given by studies investigating the effect of crossing the arms, such that anatomical maps are placed in conflict with spatial maps. In patients with complex regional pain syndrome, it was demonstrated that tactile stimuli presented on the side of space that usually corresponds to the anatomical position of the unaffected arm is prioritized over identical stimuli presented to the affected side of space, regardless of which arm is where [34]. Further, in healthy volunteers, crossing the arms results in paradoxical responses when doing speeded temporal order judgements (judging which tactile stimuli came first) [35].

That differences exist between left/right judgement accuracy based on the presence of left *vs* right pain may also reflect an interaction between use, as determined by dominance, and pain such that those with right-sided pain are compensated by their use of the right limb. This idea is particularly relevant for our finding of a primarily left-sided effect on accuracy (i.e. if left-sided pain is present, accuracy of identifying images of left hands/feet is much worse than all other images). Further, that hand function is more complex than foot function may explain why the interaction between pain and dominance might be less when leg pain is present than when arm pain is present. Indeed, our results seem to support this possibility—visual inspection of Fig. 2B (i.e. data from only knee OA participants) shows less of a right-sided compensation as compared with Fig. 2A (i.e. data from knee OA and arm pain participants). Notably, our study is underpowered to statistically assess this result and while our design does not allow us to investigate this possibility further, another study appears warranted. Alternatively, differences in left/right judgement accuracy based on the presence of left *vs* right pain may be due to lateralization of spatial information in the brain. This is particularly pertinent to the significant interaction effect seen where if left-sided pain was present, accuracy was worse for left images than for right, but if right-sided pain was present, the difference in accuracy between left and right images was not as large. It is well established that with tactile stimuli, spatial tactile tasks are lateralized to the right hemisphere. The right hemisphere has been demonstrated to be more active in a spatial tactile pattern discrimination task (but not in temporal discrimination) [36] and in evaluation of distances on the body surface (but not in evaluation of stimulus intensity) [37]. Further, spatial representations (in addition to anatomical representations) are integrated in multimodal brain areas that also receive noxious input (in addition to touch, auditory and visual input) [38]. Thus it seems possible that if left-sided pain was present, then accuracy judgements would be worse. This speculative although not outrageous possibility requires further work.

Limitations

The healthy controls recruited in the present study were significantly younger than those participants with either arm pain or knee OA. However, all findings of the present study were supported by the sensitivity analysis and confirmed using an independent sample of age- and gender-matched pain-free controls. Therefore we are confident in the results.

Images of feet, rather than knees, were used to assess lower limb cortical proprioceptive representation. There is a large body of work that provides a comprehensive understanding of the neurological processes involved in making left/right foot judgements [13], but relatively little is known about making knee judgements. Also, placing the foot and grounding the body is a primary function of lower limb movements. For these reasons, we chose to use images of feet. It is unclear whether people with knee OA would have a more specific response to pictures of full lower limbs (e.g. including the knee, lower leg and foot). As mentioned, the use of knee images alone is not ideal because determining left *vs* right is very difficult due to the lack of identifying characteristics as present on other body parts such as feet.

Conclusions

Patients with knee OA were less accurate than healthy controls at a left/right judgement task but no slower. Further, the disruptions to accuracy were not specific to knee OA—they were also present in people with upper limb pain. However, disruption of accuracy of left/right judgements was not dependent on the painful body part. Rather, accuracy was disrupted in a spatially defined manner that raises the important possibility that disruption of spatial maps of peripersonal space contribute to the disruption of cortical proprioceptive representation, or working body schema, seen in people with pain.

Rheumatology key messages

- People with knee OA are less accurate at left/right judgements than healthy controls.
- People with knee OA are no slower than healthy controls at left/right judgements.
- In knee OA or arm pain, left/right judgement accuracy disruptions are spatially defined (dependent on which side hurts).

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Supplementary data

Supplementary data are available at *Rheumatology* Online.

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