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Sensorimotor performance and function in people with osteoarthritis of the hand: A case–control comparison

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ABSTRACT

Objectives: To determine whether hand left/right judgements, tactile acuity, and body perception are impaired in people with hand OA. To examine the relationships between left right judgements, tactile acuity and hand pain. To explore the relationships between sensorimotor measures (left/right judgements and tactile acuity) and measures of hand function in people with hand OA.
Methods: Twenty patients with symptomatic hand OA and 19 healthy pain-free controls undertook a hand left/right judgment task, a control left/right judgement task, two-point discrimination (TPD) threshold testing (assessing tactile acuity), a neglect-like symptoms questionnaire (assessing body perception) and several established measures of hand function.
Results: Neglect-like symptoms were experienced more frequently in the hand OA group ($P < 0.05$). People with hand OA were slower ($P < 0.05$) and less accurate ($P < 0.05$) in the hand left/right judgement task when compared to healthy controls, with no significant difference in the control task. Significant associations were found between hand left/right judgement reaction time and pain intensity ($P < 0.05$) and accuracy and pain intensity ($P < 0.05$). TPD was not different between groups, and no correlation was found between TPD and left/right judgement performance. No association was found between left/right judgement performance and measures of hand function (all $P > 0.05$). However, TPD (tactile acuity) was related to several measures of hand function (all $P < 0.05$).
Conclusion: People with hand OA had more frequent neglect-like symptoms and were slower and less accurate compared to healthy controls at hand left/right judgments, which was indicative of disrupted working body schema. Future studies may wish to examine whether interventions targeting sensorimotor dysfunction are effective at reducing pain and improving hand function and dexterity in people with hand OA.

Introduction

Osteoarthritis (OA) is a leading cause of disability globally [1]. The hand is commonly affected, with 20% of adults over 70 years old presenting with both symptoms and radiographic features of hand OA [2]. Symptomatic hand OA is characterised by chronic joint pain, stiffness and motor impairments, including reduced strength [3], dexterity and coordination [4]. Classically, treatment for hand OA has focused on the affected joint(s) and surrounding structures (e.g., muscles and ligaments) and pain has primarily been viewed as a symptom of joint degeneration and/or instability [5]. While joint-related factors are likely important for both pain and disability, there is now extensive evidence that, similar to other chronic pain conditions, OA is associated with a range of neuroplastic changes in the central nervous system that may contribute to both pain and motor impairments [6,7]. Notably, central sensorimotor deficits have been demonstrated in OA, with observations of widespread tactile hypoesthesia [8], reduced tactile acuity [9], body size distortions [10] and both disinhibition [11] and reorganisation [12] of the primary motor cortex. Together, these findings suggest that a substantial amount of the variance in both OA-related pain and disability may occur due to brain-related, rather than simply joint-related factors [9].

Clinically, brain-related sensorimotor dysfunction can be assessed using a variety of tests including questionnaires assessing body perceptual disturbances or neglect-like symptoms [13], left/right judgement tasks that assess implicit motor imagery

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Table 1
Eligibility criteria, recruitment method and flow of participants' recruitment

Study information	Hand OA	Healthy pain-free controls
Eligibility criteria	Fulfils ACR criteria: Hand pain, aching, or stiffness and 3 or 4 of the following:	Does not have: – Upper limb pain; – Cervical/thoracic pain pathologies
	– Hard tissue enlargement of 2 or more of 10 selected joints[a] – Hard tissue enlargement of 2 or more DIP joints – Fewer than 3 swollen MCP joints – Deformity of at least 1 of 10 selected joints[a]	No symptoms of upper limb radiculopathy
	Radiographic evidence (Kellgren Lawrence >1) No symptoms of upper limb radiculopathy No past or present Hx of neurological disease	No past or present Hx of neurological disease
Source of participants	Hand clinics in Auckland, hand surgeons	Staff recruited from the Auckland University of Technology and volunteers recruited from the community
Method of recruitment	Advertisement	Snowball sampling

[a] *Note*: Second and third distal interphalangeal (DIP), the second and third proximal interphalangeal, and the first carpometacarpal joints of both hands.

performance [14] and two-point discrimination (TPD) tests of tactile acuity [15]. There is evidence [9,16] that these elements of sensorimotor function are inter-related and are linked to the performance of an individual's working body schema. Working body schema is thought to be essential for the proper planning, coordination and execution of movement [32]. Given the extensive motor repertoire and fine motor control required at the hand during functional tasks [4,16,17], it seems likely that if people with hand OA demonstrate a disrupted working body schema and/or impaired tactile acuity, these measures would be related to measures of hand dexterity and functional performance. Additionally given that pain is a central feature in OA, and it has been shown to influence motor performance [18], it seems likely that greater nociceptive input to the brain has the potential to disrupt the working body schema. Despite its importance, to date there has been little research that has investigated these sensorimotor issues in individuals with hand OA.

Thus, the aims of this study were to examine whether brain-related sensorimotor impairments exist in people with hand OA and, if so, whether these are related to measures of hand function. Furthermore, in an attempt to better understand their underlying mechanisms and potential consequences we examined the correlation between different measures of sensorimotor impairment and, in turn, their association with pain intensity. Our main hypotheses were that: (1) people with hand OA would report more neglect-like symptoms; (2) people with hand OA would be slower and less accurate when performing a hand left/right judgement task but not a control left/right judgement task; (3) tactile acuity of the hand would be reduced in people with hand OA; (4) hand left/right judgement performance would be related to tactile acuity, pain intensity and pain duration; and (5) both hand left/right judgement performance and tactile acuity would be related to measures of hand function in people with hand OA.

Methods

Participants

Two groups of participants were recruited. The first group included 20 participants with symptomatic hand OA. Hand OA was confirmed through radiographic evidence and the American College of Rheumatology clinical criteria [19]. The second group was composed of 20 age- and gender-matched participants without hand OA. See Table 1 for participants' eligibility criteria. All participants provided written informed consent for the experimental procedure. Ethical approval for the study was attained from the Auckland University of Technology Committee, in accordance with the principles set out in the declaration of Helsinki.

Procedures

Demographic information (age, gender, height, and weight) was collected from all participants and pain location, duration and intensity were assessed. Participants were asked to rate their average pain intensity in the hand in the last week on an 11-points NRS scale with anchors of 0 = no pain and 10 = worst pain imaginable. The Edinburgh Handedness Inventory was used to assess handedness in all participants. Control participants were individually matched to hand OA participants according to age (±5 years), gender and hand (dominant vs non-dominant). All testing procedures took place in a single session of approximately 2 hours. To minimise any effects of fatigue, rest periods were given between tests and all tests were performed in a random order.

Neglect-like symptoms

Symptoms of a body perceptual disturbances were assessed using a neglect-like symptoms questionnaire (5–30, with greater scores representing more neglect-like symptoms) [20]. This questionnaire investigates symptoms of cognitive neglect (e.g., "my painful limb feels like it is not part of the rest of my body") and motor neglect (e.g., "I need to focus all my attention on my painful limb to make it move the way I want it to") [20,21]. The validity of the neglect-like questionnaire has been previously shown in participants with complex regional pain syndrome (CRPS), who showed increased signs of classic neglect as well as higher neglect-like questionnaire scores, indicative of a disrupted working body schema [21].

Hand left/right judgement and control left/right judgement tasks

Two left/right judgement tasks were examined, a hand/left right judgement task and control left/right judgement task. The hand left/right judgement task provided a measure of implicit motor imagery performance and relies on an intact working body schema [14]. The participants sat in a chair in front of a computer,

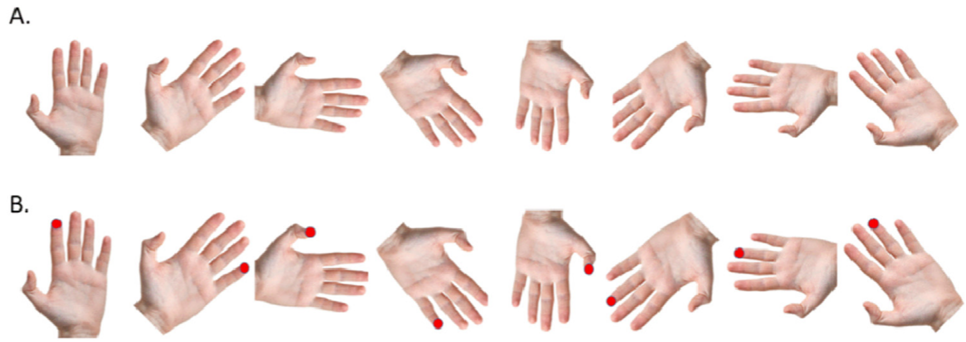

Fig. 1. (A) Hand left/right judgement (egocentric) pictures. (B) Control left/right judgement (allocentric) pictures.

approximately 60 cm from the screen. The palm of the participants' hands was comfortably placed on a table. A series of photographs of left and right hands were presented on the computer screen. These pictures showed either hand in differently rotated positions (Fig. 1).

Upon viewing the picture, participants were asked to indicate "as quickly and as accurately as possible" whether they were viewing the left or right hand. Upon making their decision, they were instructed to speak the word "left" or "right" into a microphone positioned in front of them. The signal from the microphone were transmitted to a custom-made LabVIEW software program (LabVIEW, Version: 2013, National Instruments), and the time from the presentation of the picture to the voice response was calculated. The accuracy of the response was also assessed. Each hand picture was shown for 5 seconds. Thereafter a blank screen with a black cross appeared on the screen for a 2-second interval before the next hand picture was shown. Based on previous experimental findings we examined four picture rotations (180°, 225°, 270°, and 315°), which have previously been shown to be most difficult to discern as being left or right hands [22]. The validity of left/right judgment tasks has been well established in both brain-imaging and clinical studies [23,33–38].

To control for a general decline in cognitive performance, or generally poorer performance of choice reaction time tasks (unrelated to working body schema), a control left/right judgement task was performed. In this task, a red dot was placed on the right or left side of the hand being presented on the screen [22]. During this task, participants decided if the red dot was positioned on the right or left side of the hand as it would be seen with the hand orientated with the fingers pointing upward (Fig. 1). This task, although contextually very similar, involves mental rotation around an object-centred frame of reference (allocentric), rather than mental rotation of one's own hand to match the picture (egocentric) and thus, does not engage the working body schema [22]. The order of the hand left/right judgement and the control left/right judgement conditions and the rotation of the pictures was randomised. Two sets of control left/right judgements and two sets of hand left/right judgements were performed by each participant (practice and trial), from which only the trial set was analysed. Each set presented 48 pictures for a total of 192 pictures. The dependant variables from these tests were the reaction time (ms) of the left/right judgement and the accuracy of the response. Only accurate left/right judgements were used when calculating reaction time.

Two-point discrimination

A digital sliding calliper (Craft Right, Digital Calliper) was utilised to measure two-point discrimination at the hand. The technique utilised was similar to previous studies [23]. Specifically, two-point discrimination was defined as the smallest distance between two-points that could be identified as two-points rather than one. Thirty measures were collected from the index, thenar and hypothenar sides of the hand. These were compared with the matched hand (dominant/non-dominant) of the control group. At each of the three locations, five ascending and five descending distances were assessed and the dependent variable was the mean of the smallest correct response. The sequence (index/thenar/hypothenar) of testing was randomised. The validity of two-point discrimination test has been previously shown through brain-imaging studies [24–26].

Measures of hand function

Self-reported function was assessed using the Disabilities of the Arm, Shoulder and Hand questionnaire (DASH) (0–100, with higher scores representing greater disability) [27]. Hand functional performance was assessed in two tests. The TEMPA [28] comprises nine tasks and each one was practiced once by all participants. These tasks included picking up and moving small objects, opening jars and completing other common daily activities involving the hand. A stop watch was used to assess performance speed and the total time across all tasks was the dependent variable. The validity and reliability of the TEMPA has been shown previously [29]. The Purdue Pegboard test involved placement of metal pins in holes on a standardised board as quickly as possible, and an assembly task in which participants combined a pin, washers and a collar in a predefined order. The dependant variables were the number of pins and assemblies that participants correctly inserted in 30 seconds and 1 minute, respectively. The validity and reliability of the Purdue tests has been shown previously [30].

Data processing and analysis

Data were statistically analysed using SPSS software version 22 (SPSS, Chicago, IL, USA). Prior to inferential analyses data were screened for normality (Shapiro–Wilk test) and the presence of outliers. Non-normality was observed in some instances (Reaction times and accuracy for the hand left/right judgment task, DASH, Purdue Pegboard, and Neglect-like scores). Reciprocal transformations were used to normalise reaction times of the control and hand left/right judgement tasks while logarithmic transformations were used for the DASH, and Purdue Pegboard scores. Following successful transformation of the data, two separate two-way mixed ANOVAs were used to compare the reaction time between groups for the hand left/right judgement and control left/right judgement tasks. Any significant interaction effect between picture rotation and group was investigated using independent samples *t*-tests. Independent samples *t*-tests tests were used to test differences between groups on single variables including TPD and hand function. Mann–Whitney *U* tests were used to analyse accuracy differences in the left/right hand recognition and control tasks. A

Table 2
Participants' characteristics

	Hand OA (n = 20)	Control (n = 19)
Age (years)	71.7 (6.9)	70.5 (7.7)
Females, n	15	14
Right hand dominant, n	18	18
Height (m)	1.64 (0.1)	1.66 (0.1)
Mass (kg)	69.1 (12.5)	68.8 (10.9)
BMI (kg/m^2)	25.7 (3.6)	24.9 (2.8)
Right hand most painful	11	–
Bilateral hand pain	15	–
Average number of painful joints	7.4 (7.2)	–
Average hand pain in the last week (NRS)[a]	4.6 (2)	–
Duration of pain (years)	14.7 (13)	–

Note: All values are mean (SD) unless otherwise specified. n = number of participants; BMI = body mass index; NRS = numerical pain rating scale (0–10, where 0 = no pain and 10 = worst pain you can imagine).

[a] In most painful hand.

Pearson chi-square test was used to examine differences in the frequency of neglect-like symptoms between groups. Pearson product–moment correlation coefficients or Spearman's rank correlation coefficients were used to calculate the strength of correlations between variables in the hand OA group. Based on previous experimental findings and our a-priori hypotheses, one-tailed tests with an alpha-level of 0.05 were used throughout the analysis.

Results

All results are presented as mean (SD). Table 2 presents participants characteristics. Handedness level measured through the Edinburgh Handedness Inventory was not different between the two groups (P = 0.82). In total, 40 participants were tested. Upon further examination, one participant in the control group revealed symptoms consistent with early osteoarthritis and we therefore excluded them from the final analysis.

Neglect-like symptoms

The hand OA group reported neglect-like symptoms significantly more often than the control group ($\chi^2(1)$ = 12.78, $P <$ 0.001, Cramer's V = 0.6). Individual scores for the hand OA and control groups are illustrated in Figure 2.

Hand left/right judgement task

Participants with hand OA were slower in performing the hand left/right judgement task when compared to controls. Specifically, there was a statistically significant main effect for group ($F_{1,33}$ = 3.261, $P <$ 0.05). There was also a significant interaction between rotation and group factors ($F_{3,99}$ = 3.002, $P <$ 0.05). Planned contrasts revealed that the hand OA group was significantly slower compared to the control in the 225°, 270°, and 315° hand rotation images (Fig. 3). The hand OA group (Mdn = 91.7, IQR = 77.1, 100) was also less accurate in identifying the pictures correctly during the hand left/right recognition task compared to the control group (Mdn = 100, IQR = 91.7, 100) (U = 129.5, $P <$ 0.05).

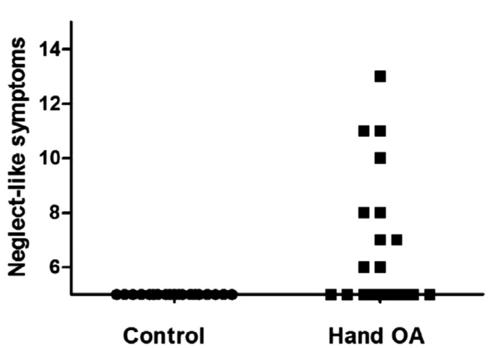

Fig. 2. Neglect-like symptom scores for the control and hand OA groups.

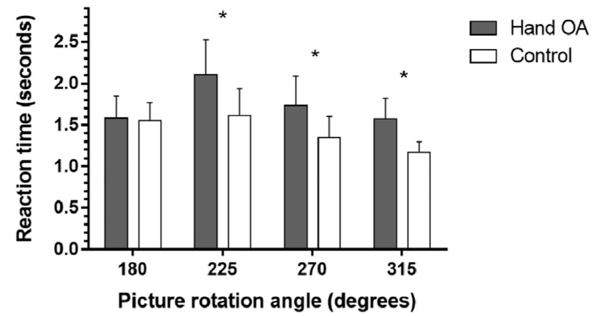

Fig. 3. Reaction time during the hand left/right judgement (egocentric) task for the most difficult picture rotations. Means and 95% CI are shown.

Control left/right judgement task

As predicted there was no group difference ($F_{1,36}$ = 0.85, P = 0.18) or interaction effect between picture rotation and group ($F_{3,108}$ = 0.184, P = 0.45) for the control left/right recognition task. Participants with hand OA did not differ on accuracy of the response when compared to controls (Mdn = 100, IQR = 100) (U = 189.5, P = 0.58).

Two-point discrimination

There was no significant difference in two-point discrimination threshold between the control group (M = 9.48, 95% CI: 8.66, 10.45) and the hand OA group (M = 10.31, 95% CI: 8.75, 12.44), (t_{37} = 0.9, P = 0.19).

Relationship between sensorimotor tests and their relation to pain

There was no correlation between the hand left/right judgement reaction time or accuracy and TPD thresholds (reaction time, τ_b = 0.04, P = 0.4; accuracy, τ_b = 0.006, P = 0.5). However, there was a correlation between pain intensity and both reaction time and accuracy (reaction time, r = 0.44, $P <$ 0.05; accuracy, τ_b = −0.4, $P <$ 0.05). No correlation was identified between pain intensity and TPD threshold (τ_b = 0.00, P = 0.5).

Measures of hand function

Participants with hand OA scored significantly lower on the DASH (t_{37} = −9.63, $P <$ 0.001) and Purdue assembly tasks (t_{37} = 2.196, $P <$ 0.05) compared to the controls. Additionally, the hand OA group was significantly slower at completing functional tasks in the TEMPA compared to controls (t_{37} = −3.28, $P <$ 0.05). No significant differences were found between groups for the Purdue unilateral test (t_{37} = 1.57, P = 0.063).

Relationship between sensorimotor tests and hand function

There was no correlation between the hand left/right judgement reaction time or accuracy and DASH (reaction time, r = 0.210, P = 0.19; accuracy, r = 0.23, P = 0.08), TEMPA (reaction time, r = 0.18, P = 0.23, accuracy, r = −0.15, P = 0.2), Purdue

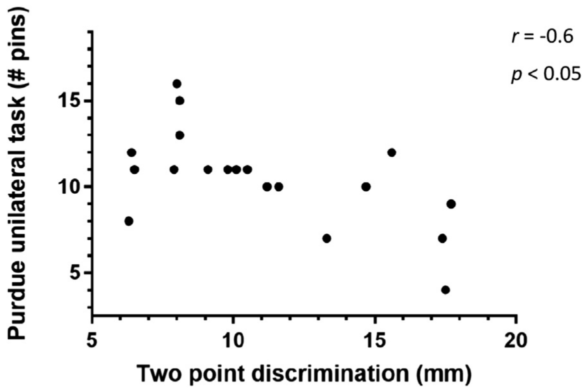

Fig. 4. The relationship between TPD thresholds and the Purdue unilateral score for the hand OA group. TPD, two-point discrimination at the hand; #, number.

unilateral (reaction time, $r = -0.1$, $P = 0.34$, $r = 0.12$, $P = 0.25$), or Purdue assembly (reaction time, $r = -0.093$, $P = 0.35$, accuracy, $r = 0.17$, $P = 0.17$) measures. However, two-point discrimination threshold at the hand was significantly correlated with the TEMPA total time ($r = 0.65$, $P < 0.05$). Two-point discrimination threshold was also negatively correlated with the Purdue unilateral ($r = -0.6$, $P < 0.05$), and the Purdue assembly scores ($r = -0.52$, $P < 0.05$) (Fig. 4). No significant correlation was found between the two-point discrimination threshold and the DASH total score ($r = 0.24$, $P = 0.16$).

Discussion

This study provides evidence of a disrupted working body schema in people with painful hand OA. We were unable to demonstrate a significant difference in tactile acuity, as measured by TPD. However, compared to matched control participants, people with hand OA more frequently reported neglect-like symptoms and were slower and less accurate in performing a hand left/right judgement task.

Previous research has observed similar neglect-like symptoms and deficits in the performance of left/right judgment tasks in participants with other chronic pain conditions including CRPS [31], chronic neck pain [32], and chronic upper or lower limb pain of various aetiologies [33–35]. Similarly, Stanton et al. [36] reported impaired accuracy of a foot left/right judgement task in people with knee OA but, in contrast to our findings, reaction time was unaffected. The difference may be explained by the nature of the left/right judgement tasks utilised. While mental rotation of the foot likely necessitates rotation of the whole lower limb, including the painful knee, it may be that relatively preserved proprioceptive input from the rest of the lower limb led to less disruption in left/right judgements of the foot in people with knee OA. Furthermore, Stanton et al. [36] were not able to account for rotation positions that have been defined as the most difficult during left/right judgement tasks [22] as their task involved only 10 pictures drawn randomly from a pool of 20. In contrast, we presented the same 48 pictures to all participants (in a random order) and were therefore able to assess the most difficult rotation positions for comparison between groups.

It is possible that other factors such as cognitive decline, or generally slower performance in choice reaction time tasks could account for impaired left/right judgements, unrelated to a disrupted working body schema. As such, we included a control left/right judgement task that, although contextually similar, involved mental rotation around an object-centred frame of reference (allocentric), rather than mental rotation of one's own hand to match the picture (egocentric). That only the egocentric task was affected suggests a specific deficit of the working body schema in people with hand OA.

Possible mechanisms of disrupted working body schema

This is the first study to explore the relationship between left/right judgement performance and TPD in hand OA. Similar to our findings, Stanton et al. [9] failed to demonstrate a correlation between left/right judgement accuracy and TPD in people with knee OA. In contrast, healthy controls and people with chronic low back pain showed a significant positive relationship between left/right judgement accuracy and tactile acuity [9]. Experimental studies have shown that body perceptual disturbances and deficits in left/right judgement can be induced by both altered proprioceptive input [37–41] and an increase in nociceptive input [37,38]. Thus, it could be that even with relatively preserved tactile acuity, nociceptive input from the arthritic joint(s) is sufficient to disrupt the working body schema in people with OA. Moreover, it has been suggested that a bias in attentional processing of sensory inputs away from the (most) painful limb or side of space may at least partially explain impaired left/right judgement performance, especially with respect to reaction time [42,43]. Our findings of an increased frequency of neglect-like symptoms in our study population provides support for such an attentional bias existing in people with hand OA.

Relationships between working body schema, tactile acuity and measures of hand function

Somewhat surprisingly, we could find no relationship between hand left/right judgement reaction time or accuracy and measures of hand function. This may relate to the nature of the functional tasks we assessed, which were largely quantified by the speed, rather than the quality of performance. It is possible that a disrupted working body schema impairs quality of movement more than speed of execution [16]. Nevertheless, we found that tactile acuity was associated with several measures of function and dexterity in people with hand OA. Previous studies across a range of different pathologies have shown a correlation between tactile acuity and hand function [44–48]. This relationship may be explained by the fine regulation of descending motor commands at the spinal level by interneurons that receive cutaneous inputs [49]. Interestingly, tactile acuity can be improved by interventions such as tactile discrimination training, even in chronic pain populations [50–52]. It is therefore possible that tactile discrimination training may prove a useful adjunct to rehabilitation in people with hand OA, leading to improvements in hand function and dexterity. However, this hypothesis needs to be formally tested.

This study is not without its limitations. Our hand OA sample was relatively small and heterogeneous in nature, including patients with carpometacarpal (CMC) OA, interphalangeal (IP) OA, or a mixture of both. This may have affected our ability to detect a difference in TPD between the OA and control groups. In this regard, tactile acuity was assessed as the mean TPD distance across 3 sites on the hand (thenar, hypothenar, and index finger), as pilot work ($n = 19$ healthy controls) showed this measure was more reliable than TPD distance taken from any one of these sites alone (Magni et al., unpublished observations). However, given the detailed representation of the hand in the primary somatosensory cortex [53] and the specificity of impaired tactile acuity observed in other chronic pain conditions [54], it is possible we would have observed a difference in TPD thresholds had we assessed this at the most painful site for each person with hand OA and the matched site in the control group. Unfortunately, this was not possible as, although we counted the number of painful joints, pain intensity was measured as the average pain intensity of the whole hand in the last week, rather than at each specific joint(s). Future research should aim to assess sensorimotor impairments according to pain location or in subgroups of people affected by CMC OA and IP OA. Finally, although we observed a significant association between pain intensity and left/right judgement performance, the cross-sectional nature of our study makes it difficult to determine the direction of this relationship. It is possible that higher pain intensity at least partially reflects greater nociceptive input to the brain, which in turn disrupts the working body schema. Alternatively, previous studies have suggested that a disrupted working body schema could in fact lead to an increase in pain [55,56]. In support of such a top-down mechanism, it has been shown that illusory resizing of the OA hand can produce immediate and, in many cases, substantial pain relief [57] and that this intervention can partially correct distorted perceptions of the size of the painful hand [10].

Conclusions

This study provides evidence of a disrupted working body schema in individuals with hand OA. Specifically, people with hand OA had more frequent neglect-like symptoms and were slower and less accurate than healthy controls at hand left/right judgements. No between group difference was found in two-point discrimination, suggesting a relative preservation of tactile acuity in people with hand OA. Furthermore, no significant relationship was observed between tactile acuity and left/right judgement accuracy or reaction time, suggesting that cutaneous inputs may be less important for an intact working body schema in people with OA. Despite evidence of a disrupted working body schema, we could not demonstrate a significant relationship between left/right judgement performance and measures of hand function in people with hand OA. In contrast, greater tactile acuity was associated with better performance in several measures of hand function in people with hand OA. Future studies may wish to examine whether interventions targeting sensorimotor dysfunction are effective at reducing pain and improving hand function and dexterity in people with hand OA.

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