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Pain and the body schema

Evidence for peripheral effects on mental representations of movement

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Summary

Some accounts of body representations postulate a real-time representation of the body in space generated by proprioceptive, somatosensory, vestibular and other sensory inputs; this representation has often been termed the 'body schema'. To examine whether the body schema is influenced by peripheral factors such as pain, we asked patients with chronic unilateral arm pain to determine the laterality of pictured hands presented at different orientations. Previous chronometric findings suggest that performance on this task depends on the body schema, in that it appears to involve mentally rotating one's hand from its current position until it is aligned with the stimulus hand. We found that, as in previous investigations, participants' response times (RTs) reflected the degree of simulated movement as well as biomechanical constraints of the arm. Importantly, a significant interaction between the magnitude of mental rotation and limb was observed: RTs were longer for the painful arm than for the unaffected arm for large-amplitude imagined movements; controls exhibited symmetrical RTs. These findings suggest that the body schema is influenced by pain and that this task may provide an objective measure of pain.

Keywords: pain; body schema; plasticity; neglect; parietal

Abbreviations: RT = response time, CRPS = complex regional pain syndrome

Introduction

Take a moment to try the following experiment. With your eyes closed, place your left hand in front of you with the palm up and fingers pointed straight ahead. Now rotate your hand until the fingers point first to your right and then to your left. For the purposes of this paper, there are two noteworthy observations concerning your ability to perform the above tasks. First, the simple fact that such movements are made effortlessly and without vision suggests that there must be an on-line mental representation of body posture. That is, without real-time information concerning body position, it would be impossible to programme such efficient movements. Secondly, note that the movements to the right and left were not symmetrical: joint constraints on movement probably forced the movement to the left to be slower and more effortful than the movement to the right.

Classic neuropsychological observations led Head and Holmes to postulate an on-line representation of body posture, or 'body schema', derived from multimodal sensory inputs (including proprioceptive, vestibular, somatosensory and visual inputs) which interacted with motor systems and served to guide movements such as those in the above example (Head and Holmes, 1911–1912). More recently, several lines of evidence have provided support for the postulated body schema and its role in the guidance of movement. For example, Cole and Paillard observed striking impairments in even routine movements, such as reaching towards an object or maintaining balance while sitting in a chair, for two patients who were deprived of sensory input as a result of sensory neuropathy (Cole and Paillard, 1995). Interestingly, these patients were able to compensate partially for the lack of on-line information (e.g. proprioceptive) concerning body posture by constant visual guidance of movements. Such effortful compensation helps to highlight the normally automatic and seamless interaction between the body schema and motor systems.

Neuropsychological evidence also suggests that the monitoring and updating of body position as well as the ability to simulate body movements mentally may be impaired in patients with parietal damage (Sirigu *et al*., 1995, 1996; Coslett, 1998; Wolpert *et al*., 1998; Schwoebel *et al*., 2001). For example, Sirigu and colleagues observed strong correlations between the time to imagine and execute a series of finger movements for both normal subjects and patients with motor cortex damage: imagined and executed movements of the affected limb were both slowed for patients with motor cortex damage (Sirigu *et al*., 1995). However, imagined and executed movement times were poorly correlated for patients with parietal damage (Sirigu *et al*., 1996). Taken together, these data suggest that the parietal area is an integral component of the neural substrate for the body schema as it appears to be involved in monitoring the sensory and motor information necessary for accurate imagined and real movements.

Parsons further argues that the body schema underlies the performance of normal participants on a task that requires them to judge the laterality of pictured hands (Parsons, 1987*a*, *b*, 1994). On the basis of several lines of evidence, Parsons suggests that participants confirm laterality judgements by imagining their left hand moving into the orientation of left-hand stimuli and their right hand moving into the orientation of right-hand stimuli. Furthermore, such simulated movements appear to depend on on-line representations of the contralateral hand. Consistent with these suggestions, Parsons and colleagues (Parsons *et al*., 1998) found that the accuracy of laterality judgements was unimpaired in split-brain patients when the stimulus hand was contralateral to the perceiving hemisphere (e.g. a left-hand stimulus presented in the left visual hemifield), but that performance was not above chance when the stimulus hand was ipsilateral to the perceiving hemisphere. Furthermore, Parsons observed that the time required for such laterality judgements in normal participants increased as the stimulus hand was presented at orientations further from that of the participant's hand: the time required to judge the laterality of a palm-up stimulus hand was modified by whether a participant's own hand was palm-up or palm-down and by the degree of angular disparity between the stimulus hand and the participant's hand (Parsons, 1994). Strong correlations were also observed between the time required for hand laterality judgements and the time required for participants to actually align their hand with a stimulus. Importantly, laterality judgement times were also found to reflect biomechanical constraints on movement. Thus, just as lateral movements away from the body's midline are more effortful and time-consuming than medial movements towards the midline, hand laterality judgement times are also longer when they involve lateral rather than medial mental rotations of the hand. These findings, in conjunction with those of Sirigu and colleagues (Sirigu *et al*., 1995, 1996), suggest that both actual and mentally simulated movements may depend on the body schema. Moreover, functional neuroimaging findings suggest that laterality judgements are associated with activation in motor and parietal areas which substantially overlap with areas activated by actual movements (e.g. Stephan *et al*., 1995; Porro *et al*., 1996; Parsons and Fox, 1998). Parsons and colleagues state 'In summary, motor imagery appears generally to involve the same movement representation used by the executive motor processes—a unitary representation of movements as they occur, in accordance with the physical laws underlying motor control and implementing all physiological and pathophysiological constraints.' (Parsons and Fox, 1998, p. 586).

These and other (e.g. Lackner, 1988) lines of evidence suggest that the body schema represents on-line information concerning body posture and that it subserves both real and imagined movements. Furthermore, the body schema appears to be sensitive to central insults that affect motor performance, such as motor cortex lesions and basal ganglia dysfunction (Dominey *et al*., 1995; Sirigu *et al*., 1995). However, to our knowledge, few previous investigations have examined whether there are peripheral factors that influence the body schema (for a discussion of neural plasticity in the somatosensory cortex following amputation, see Ramachandran and Hirstein, 1998). The present experiment was designed to determine if pain influences the body schema. More specifically, we examined whether performance on a modified version of the hand laterality judgement task developed by Parsons (Parsons, 1987*a*) would differ when the judgements involved mental rotations of affected and unaffected limbs in patients suffering from chronic arm pain.

Methods

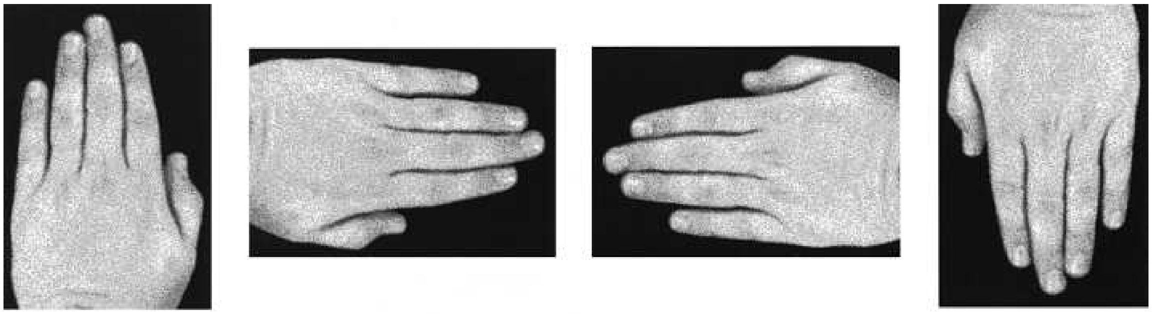
Participants

Participants included 13 (six with right arm pain, seven with left arm pain) patients with arm pain of at least 3 months duration. Patients were all diagnosed as suffering from complex regional pain syndrome (CRPS) and were referred from a pain control centre, where they were undergoing treatment. Table 1 shows information about patient characteristics, pain severity and treatment. The medications prescribed for these patients had a broad range of effects, from the pharmacological relief of pain to the anti-seizure effects of gabapentin and the antidepressant effects of amitriptyline, but we were interested primarily in within-subject comparisons of response times to left- and right-hand stimuli. Thus, the effects of medications are not likely to account for any differences in response times to left- and right-hand stimuli within a given patient. Eighteen right-handed, age-matched (mean age 47 years, SD 11 years) participants served as controls. Testing was approved by

Table 1 *Clinical details of patients with complex regional pain syndrome*

Patient	Age (years)	Sex	Dominant hand	VAS	Affected body part	Medications
B.C.	39	F	R	7	R arm	Morphine, amitriptyline clonazepam, tramadol
J.G.	46	F	R	8	R arm	Methadone, amitriptyline
R.H.	50	F	R	8	L arm	Amitriptyline, cyclobenzaprine
S.L.	55	F	R	6	L arm	Codeine, gabapentin, rofecoxib, paracetamol
R.L.	59	M	R	8	L arm	Gabapentin, amitriptyline
D.L.	48	F	L	9	L arm	Oxycontin, clonazepam, baclofen
J.D.	55	M	R	4	R arm	Methadone, gabapentin, ketamine
V.G.	31	M	R	8	R arm	Gabapentin, baclofen
A.P.	42	M	R	7	L arm	Amitriptyline, baclofen, clonazepam
F.S.	50	M	R	8	L arm	Methadone, gabapentin, zoloft
D.T.	42	M	R	9	R arm	Methadone, gabapentin, amitriptyline
S.T.	39	M	R	6	L hand	Oxycontin, gabapentin, amitriptyline
B.J.	35	M	L	7	R arm	Oxycontin, gabapentin
Mean (SD)	45 (8)			7 (1)		

VAS = visual analogue scale: pain severity rated from 0 = no pain to 10 = worst pain experienced. F = female; M = male.



0° 90° M 90° L 180°

Fig. 1 Examples of left-hand stimulus in the palm-down view at orientations of 0°, 90° medial, 90° lateral and 180°.

the Internal Review Board of Temple University and the participants' consent was obtained according to the Declaration of Helsinki.

Stimuli

Digitized pictures of a left or right hand were presented on a computer monitor in palm-up and palm-down views at 0° (facing up), 90° medial (facing towards the participant's midsagittal plane), 90° lateral (facing away from participant's midsagittal plane) and 180° (facing down) orientations (Fig. 1).

Thus, for both right and left hands there were a total of eight different stimuli. All stimuli were created by digitally manipulating one picture of a palm-up view and one picture of a palm-down view of the same hand in order to ensure that each stimulus was identical except for the change in orientation.

Design and procedure

For each patient, the 16 different stimuli (8 conditions × 2 hands) were presented eight times to give a total of 128 trials. Controls viewed each stimulus four times in a total of 64 trials.

Participants sat with their hands resting palm-down on the table in front of them with fingers resting on the response keys. On each trial, a single stimulus hand appeared centred on the computer screen and remained there until the participant indicated the laterality of the hand by pressing a key. For patients, responses were made by pressing a left or right key with the index or middle finger of their unaffected limb. Controls responded with the index and middle fingers of their right hand. All participants were instructed to respond as quickly and accurately as possible. Psyscope software (Cohen *et al.*, 1993) was used to generate a random order of stimulus presentation for each participant and to record response time (RT) and accuracy data.

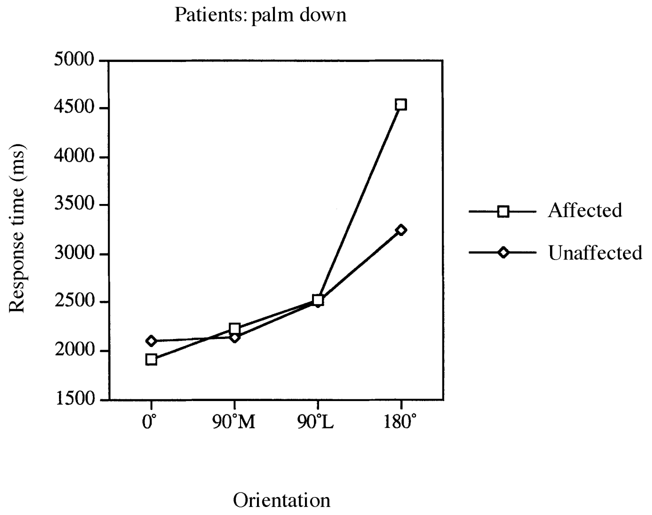


Fig. 2 Mean response times for laterality judgements involving the affected and unaffected limbs of patients for palm-down stimuli in the four orientation conditions.

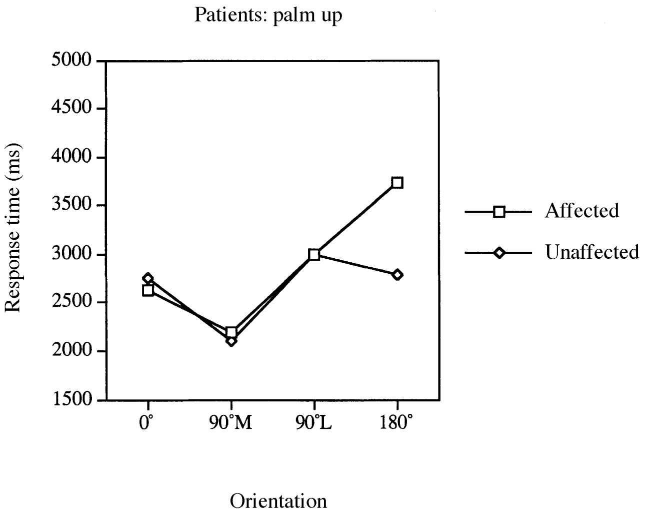


Fig. 3 Mean response times for laterality judgements involving the affected and unaffected limbs of patients for palm-up stimuli in the four orientation conditions.

Results

A 2 (limb: affected and unaffected arms) × 2 (view: palm up and palm down) × 4 (orientation: 0°, 90° medial, 90° lateral and 180°) repeated measures analysis of variance was used to analyse RT and accuracy data separately for patients and controls (for controls, limb refers to the left and right arms). Analyses of RT included only data for correct responses. RTs >2 SD above each participant's grand mean were also excluded from analyses (Ratcliff, 1993), resulting in the loss of 5% of trials for both patients and controls. For both patients and controls, RT outliers were distributed equally across responses involving motor imagery of the left and right (affected and unaffected) hands, but were more likely to occur when the disparity between the stimulus hand and the participant's hand was greatest (i.e. the 180° palm-up conditions).

Patients

As indicated in Figs 2 and 3, there was a significant main effect of orientation [$F(3,36) = 22.01$, $P < 0.001$], such that RTs increased as the difference between the orientation of the participant's hand and the stimulus hand increased. There was also a significant interaction between orientation and view [$F(3,36) = 5.44$, $P < 0.005$], indicating that RTs reflected the disparities between stimulus hands and the participant's own hand postures (i.e. 0° orientation and palm down) as well as the different movement constraints for palm-up and palm-down rotations of the hand. Furthermore, consistent with biomechanical constraints on medial and lateral movements, RTs were significantly longer for palm-up views of 90° lateral compared with 90° medial stimuli [palm down, $F(1,12) = 1.92$, $P < 0.19$; palm up, $F(1,12) = 32.13$, $P < 0.001$].

Of greatest import was the significant main effect of limb [$F(1,12) = 7.31$, $P < 0.03$], indicating slower RTs for mental rotations of the affected than the unaffected limb. This effect appears to be driven by slower RTs for the affected limb in the 180° condition, as indicated by a significant interaction between orientation and limb [$F(3,36) = 8.12$, $P < 0.001$]. Planned comparisons yielded significant differences between RTs involving the affected and unaffected limbs for the 180° conditions [palm down, $F(1, 12) = 9.58$, $P < 0.009$; palm up, $F(1,12) = 7.35$, $P < 0.02$].

This effect was also consistent across patients. Twelve of the 13 patients exhibited slower RTs for the affected limb compared with the unaffected limb for the 180° condition (sign test, $P < 0.002$). On average, mental rotations of the affected limb were 1123 ms (SD = 1136 ms) slower than those of the unaffected limb in the 180° condition.

Accuracy data for patients and controls are presented in Table 2. Consistent with the RT data, analyses of accuracy revealed a significant main effect of orientation [$F(3,36) = 19.29$, $P < 0.001$] and a significant interaction between orientation and view [$F(3,36) = 7.07$, $P < 0.001$], indicating that accuracy reflected the disparities between stimulus and participant hand postures as well as the different constraints on palm-down and palm-up rotations of the hand. There was no significant main effect of limb [$F(1,12) < 1$], suggesting an absence of speed–accuracy trade-offs. Overall accuracy for the affected and unaffected limbs was 84 and 83%, respectively.

Controls

As indicated in Figs 4 and 5, there was a significant main effect of orientation [$F(3,51) = 19.95$, $P < 0.001$] and view [$F(1,17) = 22.73$, $P < 0.001$] and an interaction between orientation and view [$F(3,51) = 8.76$, $P < 0.001$], suggesting that, consistent with the patient data, RTs reflected the

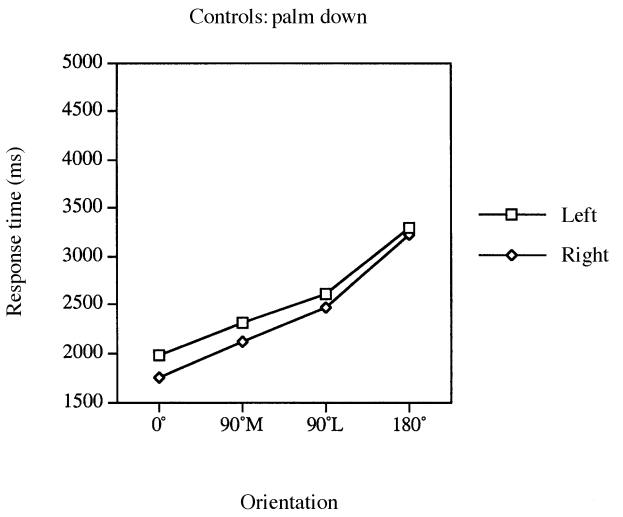


Fig. 4 Mean response times for laterality judgements involving the left and right limbs of controls for palm-down stimuli in the four orientation conditions.

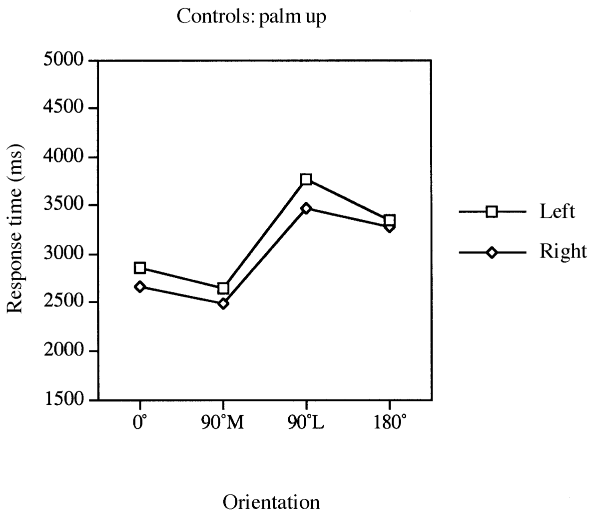


Fig. 5 Mean response times for laterality judgements involving the left and right limbs of controls for palm-up stimuli in the four orientation conditions.

Table 2 *Mean accuracy (proportion correct) for patients and controls*

	Patients		Controls	
	Affected	Unaffected	Left	Right
Palm-down views				
0°	0.93	0.94	0.94	0.99
90° medial	0.93	0.91	0.96	0.92
90° lateral	0.88	0.84	0.93	0.99
180°	0.57	0.51	0.63	0.68
Mean (SD)	0.83	0.80	0.87	0.90
	(0.17)	(0.20)	(0.16)	(0.15)
Palm-up views				
0°	0.86	0.88	0.86	0.83
90° medial	0.98	0.92	0.89	0.93
90° lateral	0.79	0.76	0.81	0.83
180°	0.76	0.87	0.83	0.81
Mean (SD)	0.85	0.86	0.85	0.85
	(0.10)	(0.07)	(0.04)	(0.05)

disparities between stimulus and participant hand positions and the different movement constraints on palm-up and palm-down rotations of the hand. Furthermore, there were longer RTs for palm-up views of lateral than medial stimuli [palm down, $F(1,17) = 2.19$, $P < 0.16$; palm up, $F(1,17) = 37.03$, $P < 0.001$], indicating that RTs reflected the biomechanical constraints on arm movements.

However, whereas the effect of limb approached significance [$F(1,17) = 3.83$, $P < 0.10$], reflecting a small but consistent advantage for responses involving the right (i.e. dominant) hand, there was no significant interaction between orientation and limb [$F(3,51) < 1$]. Thus, in contrast to the consistently slower RTs observed for the affected relative to the unaffected limbs in the 180° condition for the patient data (i.e. 12 out of 13), control participants exhibited no significant effect of limb. Eleven of 18 controls exhibited slower RTs for the left than for the right limb for the 180° condition (sign test, $P < 0.12$). RTs for the left limb were, on average, 74 ms slower (SD = 781) than those for the right limb.

Consistent with the RT data, analyses of accuracy indicated a significant main effect of orientation [$F(3,51) = 10.13$, $P < 0.001$] and a significant interaction between orientation and view [$F(3,51) = 7.29$, $P < 0.001$], indicating that accuracy reflected the disparities between stimulus and participant hand positions and the different movement constraints on palm-up and palm-down rotations of the hand. There was no significant main effect of limb [$F(1,17) < 1$], suggesting the absence of speed–accuracy trade-offs. Overall accuracy for the left and right limbs was 86 and 87%, respectively.

Discussion

Consistent with previous investigations (Parsons, 1987*a*, *b*, 1994; Parsons and Fox, 1998; Parsons *et al.*, 1998), analyses for both patients and controls demonstrated that RTs and accuracy were significantly influenced by the degree of imagined movement necessary to align participants' hands with stimuli. Furthermore, RTs were consistent with previously observed biomechanical constraints on movement (e.g. Parsons, 1994). These findings support the suggestion that the body schema underlies performance on the hand laterality task. The major, and novel, finding of the present investigation is that a brain representation of the body is influenced by pain. Patients, but not controls, exhibited slowed RTs when responses required large-amplitude mental rotations of their affected relative to their unaffected arm.

Before we discuss the theoretical implications of these data, it is important to emphasize that these findings cannot be attributed to pain inhibition of movement or 'guarding' for several reasons. First, patients did not, in fact, move the painful arm during the experimental task. Nor did patients report pain in the course of the imagined movements. Secondly, the slowing of RTs for the painful arm was observed only in the 180° condition; if guarding were elicited automatically by any stimulus depicting the painful extremity, one would have expected the slowing of RTs to be observed for stimuli in all four orientations. We postulate that slowing in the 180° condition occurred because, unlike the other conditions, the 180° condition required large-amplitude simulated movements at both distal and proximal joints and was thus more likely to involve painful regions of the arm that tended to include both the elbow and the shoulder.

These data complement and extend previous demonstrations that pathological conditions may alter the body schema. As previously noted, Sirigu and colleagues reported data from patients with parietal lesions, demonstrating that central lesions might disrupt the body schema (Sirigu *et al.*, 1996). Furthermore, using a task similar to that reported here, Coslett demonstrated that patients with right-hemisphere lesions resulting in left neglect, but not other patients with right hemisphere lesions, exhibited an impaired ability to identify pictures of left compared with right hands (Coslett, 1998). In the light of previous evidence suggesting that the identification of pictured hands depends on the body schema (Parsons, 1987*a*, *b*, 1994), this asymmetrical performance suggests that at least some features of the neglect syndrome may be attributable to disruption of the body schema.

The claim that a central representation of the body such as the body schema may also be altered by 'peripheral' factors is not without precedent. This phenomenon has been investigated most extensively in patients with phantom limbs. As noted by Ramachandran and Hirstein in a recent review, several lines of evidence suggest that, in both animals and humans, primary sensory and motor cortices may be 'remapped' after amputation or deafferentation of a body part (Ramachandran and Hirstein, 1998). However, the alteration in the body schema exhibited by our patients may differ from that exhibited by patients with phantom limbs. Whereas amputation or deafferentation may be expected to induce long-standing or even permanent changes (but see Ramachandran, 1993), the changes in the body schema associated with chronic pain may reflect the current state of nociceptive (and other sensory) feedback. In this sense, the alteration in the body schema exhibited by our patients may approximate more closely the distortions of body representations observed when inconsistencies are induced between multiple sensory inputs (Ramachandran and Hirstein, 1998) and tactile or muscle-stretch inputs (Lackner, 1988). If, as we have argued elsewhere (Coslett, 1998; Buxbaum and Coslett, 2001; Schwoebel *et al.*, 2001), the body schema is an on-line, real-time representation of the position and possible actions of the body, one might expect the changes we have observed to be influenced significantly by the severity of pain at the time of testing. This hypothesis is currently under investigation.

The sensory and motor remappings reported in patients and animals following amputation or deafferentation may also have an anatomical underpinning that differs from the alteration induced in the body schema by pain. Investigations in animals (Merzenich *et al.*, 1984; Pons *et al.*, 1991) as well as magnetoencephalogram and transcranial magnetic stimulation experiments in humans (Cohen *et al.*, 1991; Ramachandran, 1993; Yang *et al.*, 1994; Pascual-Leone *et al.*, 1996) suggest that the remapping after amputation occurs at the level of the primary sensory and motor cortices. In contrast, PET investigations of what we term the 'body schema' in humans have suggested that this representation is supported by posterior parietal and dorsolateral frontal cortices (Bonda *et al.*, 1996; Parsons and Fox, 1998). As a PET study using the hand laterality task reported in the present paper demonstrated activation in parietal cortex (Parsons and Fox, 1998), we believe that the pain-induced alteration in the body schema was likely to be mediated by higher-level sensory cortices of the posterior superior parietal lobes rather than the primary sensory cortex.

Working with patients suffering from CRPS also called reflex sympathetic dystrophy, Galer and colleagues (Galer *et al.*, 1995; Galer and Jensen, 1999; for a similar account, see Rommel *et al.*, 1999) have also suggested that the frequently observed reduction in movement associated with this syndrome may be attributable to a central neglect-like disorder. Their conclusions, however, were based on observations of movement and questionnaire data, raising the possibility that the findings were attributable to guarding. As noted previously, the findings from the present experiment, in which participants did not move or report pain, cannot readily be attributed to this factor.

In addition to the theoretical implications of the present findings, we note that the hand laterality task, after further examination and modification, may also be of clinical value. As a blind and objective measure, it may be that performance on the hand laterality task could provide a more reliable and valid measure of pain than the currently used self-reported ratings of pain. Furthermore, response time on the hand laterality task may prove to be a more sensitive measure of changes in pain than subjective ratings. Finally, we note that the use of the hand laterality task as an assessment tool need not be limited to patients suffering from CRPS, but can be used as an assessment or screening tool for diverse patient populations suffering from motor impairments.

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