Arthritis & Rheumatism (Arthritis Care & Research)
Vol. 59, No. 5, May 15, 2008, pp 623–631
DOI 10.1002/art.23580

ORIGINAL ARTICLE

Thinking About Movement Hurts: The Effect of Motor Imagery on Pain and Swelling in People With Chronic Arm Pain

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Objective. **Chronic painful disease is associated with pain on movement, which is presumed to be caused by noxious stimulation. We investigated whether motor imagery, in the absence of movement, increases symptoms in patients with chronic arm pain.**

Methods. **Thirty-seven subjects performed a motor imagery task. Pain and swelling were measured before, after, and 60 minutes after the task. Electromyography findings verified no muscle activity. Patients with complex regional pain syndrome (CRPS) were compared with those with non-CRPS pain. Secondary variables from clinical, psychophysical, and cognitive domains were related to change in symptoms using linear regression.**

Results. **Motor imagery increased pain and swelling. For CRPS patients, pain (measured on a 100-mm visual analog scale) increased by a mean ± SD of 5.3 ± 3.9 mm and swelling by 8% ± 5%. For non-CRPS patients, pain increased by 1.4 ± 4.1 mm and swelling by 3% ± 4%. There were no differences between groups ($P > 0.19$ for both). Increased pain and swelling related positively to duration of symptoms and performance on a left/right judgment task that interrogated the body schema, autonomic response, catastrophic thoughts about pain, and fear of movement ($r > 0.42$, $P < 0.03$ for all).**

Conclusion. **Motor imagery increased pain and swelling in patients with chronic painful disease of the arm. The effect increased in line with the duration of symptoms and seems to be modulated by autonomic arousal and beliefs about pain and movement. The results highlight the contribution of cortical mechanisms to pain on movement, which has implications for treatment.**

INTRODUCTION

Pain emerges from the flow and integration of neural activity in several brain areas, usually including but not limited to neurons within the insular, thalamus, sensory, and cingulate cortices: the so-called pain matrix (1,2). When pain persists, this flow and integration between areas changes. This has several consequences, including up-regulation of the pain matrix and down-regulation of endogenous antinociceptive mechanisms (2). Such changes have been documented in a variety of chronic painful conditions, such as chronic back pain (3), complex regional pain syndrome (CRPS) (4), irritable bowel syndrome (5), arthritis (6), and fibromyalgia (7).

The consequence of these changes for the patient is that their pain becomes more easily evoked. Movement commonly evokes pain in people with chronic painful disease, presumably because movement activates nociceptors. Anecdotally, however, some patients report that "it hurts to just think about moving," which raises the possibility that the command to move can itself cause pain. We have previously documented this in a single patient with chronic CRPS, where imagined hand movements increased her symptoms (8). The current study aimed to determine whether motor imagery increases pain and swelling in patients with chronic arm pain. Because extensive data show functional brain changes in patients with CRPS, we hypothesized that patients with CRPS would be more affected than those with arthritic or rheumatic pain of similar intensity.

This study also aimed to interrogate 2 processes that

Supported by the Nuffield Dominions Trust, UK, the German Research Foundation, and the German Research Network on Neuropathic Pain.

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Submitted for publication July 17, 2007; accepted in revised form November 26, 2007.

Table 1. Characteristics of patients with complex regional pain syndrome type 1*

	Body part	Duration, months	RT^{RATIO}	$Size^{ratio}$	$P^{2\text{-day}}$	P^{spont}	TSK	PCS
Sex, age (years)								
M, 19	L wrist	24	1.103	112	48	24	31	30
F, 44	L wrist	14	1.402	105.8	90	14	50	33
F, 58	L finger	4	1.571	102	53	31	34	18
M, 42	R hand	5	1.228	100	80	24	25	18
F, 56	R hand	8	1.957	107.6	55	21	57	23
M, 62	L wrist	1	1.168	104	60	40	32	19
M, 62	L hand	3	1.169	100	41	13	29	18
F, 31	L wrist	8	1.368	109.7	42	53	55	25
M, 43	L hand	5	1.227	101.7	54	24	43	19
M, 22	R wrist	4	1.184	106	43	13	27	17
F, 27	R wrist	2	1.467	100	88	12	39	17
F, 28	L hand	7	2.251	106	87	21	48	36
F, 36	L wrist	1	0.956	96.4	77	31	28	20
M, 42	L hand	8	1.429	108	60	45	25	21
M, 32	R arm	6	1.368	109.7	45	32	22	18
F, 18	L hand	9	1.957	107.6	42	21	47	34
F, 48	L wrist	1	1.429	108	48	41	33	20
F, 44	R wrist	4	1.702	102	52	12	30	19
F, 58	R wrist	3	0.977	99	77	4	28	17
F, 55	R hand	9	2.637	112.1	26	11	47	30
Mean ± SD		6.1 ± 5.2	1.45 ± 0.43	104.55 ± 4.67	56.6 ± 19.7	23.7 ± 13.0	36.4 ± 10.5	22.4 ± 6.2

* RT^{RATIO} = mean response time for pictures of the affected arm as a proportion of that for the unaffected arm; $Size^{ratio}$ = mean finger circumference of the affected arm as a proportion of that of the unaffected arm; $P^{2\text{-day}}$ = average pain over the last 2 days (measured on a 100-mm visual analog scale [VAS]); P^{spont} = pain now (measured on a 100-mm VAS); TSK = Tampa Scale for Kinesiophobia; PCS = Pain Catastrophizing Scale; L = left; R = right.

may underpin an effect of cortical motor processes on pain and swelling. The first is disruption of the working body schema. The internal representation of the affected arm is distorted in chronic pain states (for review, see ref. 9), and proprioceptive and sensorimotor abnormalities are often associated with chronic painful disease (10–13). To interrogate working body schema, we used an implicit motor imagery task, which involves making left/right judgments of pictured arms. Motor imagery engages the working body schema (14) and can be delayed by experimentally disrupting the working body schema (15).

The second process that might underpin an effect of cortical motor processes on pain and swelling is a patient's beliefs about movement. Patients with chronic painful conditions are often frightened of movement (16) and subscribe to catastrophic thoughts about their pain (17). Such cognitive variables alter cortical motor performance (for review, see ref. 18). If such cognitive factors modulate the effect of motor imagery on pain and swelling, then we would expect a relationship between change in symptoms and cognitions about pain and movement. If the effect relates to fear of movement, then we would also expect an increase in sympathetic arousal before an increase in symptoms.

The primary hypotheses were that imagined movements increase pain and swelling in patients with chronic unilateral arm pain, and that the effect is greater in patients with CRPS than in those with non-CRPS pain of similar intensity. The secondary hypotheses were that the effect of imagined movements on pain and swelling would relate to 1) performance on the left/right hand judgment task, 2) the duration of symptoms, 3) catastrophizing and fear of movement, 4) changes in skin conductance early in the task, and 5) the vividness of the imagined movements.

SUBJECTS AND METHODS

Subjects. In order to investigate as homogenous a group of CRPS patients as possible, we focused on CRPS type 1 (CRPS 1) in this study. The CRPS 1 subgroup is distinguished from CRPS type 2 by the lack of a clinically obvious nerve lesion. Twenty-one patients who were diagnosed with CRPS 1 of one hand or wrist according to revised clinical diagnostic criteria (19) were recruited from hospital neurology, pain management, and physiotherapy departments. Eleven patients had also participated in a separate study (20). Eighteen patients with non-CRPS hand pain, wrist pain, or both were also recruited from the physiotherapy department. The age and sex of this group were similar to that of the CRPS group (Tables 1 and 2). Subjects were excluded if they had dystonia, had been diagnosed with any neurologic or psychiatric condition, or if they had current pain elsewhere. Written informed consent was obtained from all patients. All procedures conformed to the Declaration of Helsinki and were approved by the institutional human research ethics committee.

Primary outcome variables. Pain was assessed via a 100-mm visual analog scale (VAS). One VAS related to the question, "What is your pain level right now?" This primary outcome variable was called pain. A separate VAS related to the question, "What is your average pain level over the last two days?" This pain score was used to

Table 2. Characteristics of patients with non–complex regional pain syndrome type 1 pain*

	Body part diagnosis	Duration, months	RT^{RATIO}	$Size^{ratio}$	$P^{2\text{-day}}$	P^{spont}	TSK	PCS
Sex, age (years)								
F, 58	L hand OA	10	0.92	106.3	69	24	35	19
M, 42	R hand OA	5	1.041	99.6	55	31	38	19
F, 56	L finger laceration	11	0.857	99.7	70	14	24	18
F, 58	L hand fracture	14	1.119	100.3	56	40	36	26
M, 22	L hand fracture	12	1.134	103.9	56	31	29	20
F, 44	R hand OA	6	0.987	99.3	86	21	35	18
M, 19	L wrist fracture	5	0.804	100.4	78	12	39	17
M, 62	R hand idiopathic	8	0.882	100.8	87	2	23	5
F, 55	R hand OA	25	1.244	100.1	69	1	23	19
M, 32	L hand idiopathic	14	1.059	103.1	43	10	23	26
M, 62	L wrist OA	52	0.977	100.8	78	21	42	21
F, 28	L hand dislocation	5	0.995	105.7	39	44	33	20
F, 18	R wrist trauma/fracture	27	0.789	106.4	73	24	44	21
F, 48	L wrist fracture	1	1.105	106.2	79	55	10	20
F, 27	R hand tendon injury	43	1.078	105.5	60	34	25	19
M, 42	L hand fracture	11	0.774	100.9	35	41	27	15
F, 36	L wrist tendon injury	4	0.966	99.8	40	12	24	5
Mean ± SD		14.9 ± 14.2†	0.98 ± 0.13†	102.28 ± 2.75	63.1 ± 16.7	24.5 ± 15.2	30.0 ± 8.7	18.1 ± 5.6

* RT^{RATIO} = mean response time for pictures of the affected arm as a proportion of that for the unaffected arm; $Size^{ratio}$ = mean finger circumference of the affected arm as a proportion of that of the unaffected arm; $P^{2\text{-day}}$ = average pain over the last 2 days (measured on a 100-mm visual analog scale [VAS]); P^{spont} = pain now (measured on a 100-mm VAS); TSK = Tampa Scale for Kinesiophobia; PCS = Pain Catastrophizing Scale; L = left; OA = osteoarthritis; R = right.
† Different from complex regional pain syndrome 1 group, $\alpha = 0.05$.

ascertain that average pain was similar in the 2 groups. Each VAS was anchored at the left with "none" and at the right with "worst ever."

Swelling was assessed by taking the circumference of the wrist, thumb, and index finger (middle of proximal finger) of each hand with a finger tape (BSN-Jobst, Toledo, OH). The average of these measures of the affected arm was expressed as a proportion of that of the unaffected arm. This primary outcome variable was called swelling. This average measure was reliable (intraclass correlation coefficient [ICC] 0.98) and sensitive to change (minimum detectable change = 3 mm).

These assessments were performed and were immediately entered into a datasheet at 3 time points: before the motor imagery task (directly after the left/right judgment task), directly after the motor imagery task, and 60 minutes after the motor imagery task. These time points were based on previous work (8).

Secondary variables. Eighteen photographs of a right hand, matched to the sex of each subject and in various positions and alignments, were digitally mirrored to create a bank of 36 images. An in-house software program and a laptop computer were used to randomly present images from the appropriate image bank. Subjects were advised to use their nonpainful hand to press the left mouse button if the image represented a left hand and the right mouse button if the image represented a right hand. Subjects were advised to respond as quickly and as accurately as they could. Mean response time for correct responses to pictures that corresponded to the painful hand was expressed as a proportion of the mean response times for correct responses to pictures of the other hand. This variable was called RT^{RATIO}. This measure was repeatable (ICC >0.90, typical error <60 msec). The accuracy of responses was defined as the percentage of total responses that were correct. We analyzed accuracy data to verify that there was no accuracy–speed tradeoff (14). The duration of pain in months (duration variable) was also used for secondary analysis.

To estimate catastrophizing and fear of movement, we used the Pain Catastrophizing Scale (PCS) (21) and a modified version of the Tampa Scale for Kinesiophobia (TSK) (22). We modified the items of the TSK by replacing "exercise" with "move" in item 4 ("My pain would probably be relieved if I were to exercise") and item 17 ("No one should have to exercise when she/he is in pain").

To estimate arousal, skin conductance was recorded using surface electrodes (DE-2.3; Delsys, Boston, MA) placed over the palm and the back of the unaffected hand, prior to all other assessments. Skin conductance was then recorded throughout the other assessment process in order to identify if there was an effect of the assessments or the research setting on arousal. Prior to performing the motor imagery task, patients were advised to sit quietly for 5 minutes. Skin conductance during the first 20 seconds of the task was expressed as a proportion of the mean level during the first 20 seconds of the last minute of the 5-minute waiting period. This variable was sensitive to small changes in autonomic arousal and was useful for within-subject comparisons. This variable was called skin conductance. We chose to use skin conductance during the first 20 seconds of the task because pilot data suggested that pain did not increase during this period and we wanted to avoid the possibility that skin conductance would increase in response to an increase in pain.

After performing the motor imagery task, subjects completed a VAS that related to the question, "How vivid were your imagined hand movements?" This VAS was anchored at the left with "not at all" and at the right with "extremely," and this variable was called vividness.

Method check: muscle activity. To verify that there was no muscle activity during the motor imagery tasks, electromyographic activity was recorded using surface electrodes (DE-2.3; preamplified × 1,000, band filtered at 20–450 Hz) placed over the wrist extensors and wrist flexors of each arm.

Protocol. The motor imagery task used the bank of images described above. An in-house software program and a laptop computer were used to randomly present images from the image bank. Subjects were advised to imagine twice adopting the posture shown with a smooth and pain-free movement. Subjects were advised not to imagine watching themselves perform the movement, but to imagine actually performing the movement. When they had completed the imagined movements, they pressed a button to progress to the next image. In pilot testing, some patients reported that the task increased their symptoms after ~5 minutes. Mean time on each image was 8 seconds. We therefore chose to present each of 36 images once so that the number of imagined movements was constant but the duration of the task would vary between patients.

Statistical analysis. All statistics were performed using SPSS software, version 11.0.0 (SPSS, Chicago, IL). Systematic differences in the secondary variables were investigated via a multivariate analysis of variance (MANOVA) with group (CRPS or non-CRPS) as the fixed factor. The primary hypotheses were tested with 2 repeated-measures analyses of variance (ANOVAs; 1 for pain and 1 for swelling), each with 1 within-subjects factor (3 time levels: pretask, posttask, and 60 minutes posttask) and 1 between-subjects factor (group: CRPS or non-CRPS). If the initial MANOVA yielded a difference between groups on the secondary variables (RT^{RATIO}, duration, TSK, PCS, or vividness), those variables were entered as covariates.

Linear regressions were used to test the secondary hypotheses. Each regression had change in pain (or swelling) between pretask and posttask as the dependent variable and pretask pain (or swelling) as a covariate. The regressions were 1) to relate change in pain (or swelling) to performance on the left/right judgment task and to the duration of symptoms, where RT^{RATIO} and duration were independent variables; 2) to relate change in pain and swelling to fear of movement and catastrophizing, where TSK and PCS were independent variables; 3) to relate change in pain and swelling to autonomic arousal early in the task, where skin conductance was the independent variable; and 4) to relate change in pain and swelling to vividness of imagined movements, where vividness score was the independent variable. A Pearson's correlation was used to determine whether change in pain and change in swelling were related.

Patients were debriefed about the study after all assessments were obtained. They were given the opportunity to discuss the study and report any concerns that had been raised. Any comments volunteered by the patient about the effect of imagined movements were noted.

RESULTS

Subject data. One subject with CRPS of 1 hand was excluded because she had burned her opposite hand that morning. One subject from the control group chose not to participate. Full data sets were obtained from 20 patients with CRPS and 17 patients with non-CRPS pain (Tables 1 and 2). Mean skin conductance during the left/right judgment task was higher than the baseline level ($t[37] = 2.26$, $P = 0.03$). The mean ± SD duration of the imagined movement task was 5 minutes, 21 seconds ± 54 seconds.

The duration of symptoms was less in the CRPS group than in the non-CRPS group ($P < 0.05$). TSK, PCS, and RT^{RATIO} were greater in the CRPS group than the in non-CRPS group. Therefore, duration, TSK, PCS, and RT^{RATIO} were entered as covariates into the ANOVAs that tested the primary hypotheses.

Primary hypotheses. *Pain.* There was no across-time difference in pain between groups (no main between-subjects effect of group: $F[1,32] = 0.014$, $P = 0.908$). However, when patients imagined moving their arm to match the postures shown in pictures, pain was greater posttask than pretask (main across-group effect of time on pain: $F[2,64] = 4.87$, $P = 0.011$; post-hoc $P < 0.01$). The mean ± SD increase in pain between pretask and posttask was 5.3 ± 3.9 mm for the patients with CRPS and 1.4 ± 4.1 mm for the patients without CRPS (Figure 1). Seven patients had an increase in pain >20 mm. On *t*-tests, this increase in pain was significant for patients with CRPS ($P < 0.001$) but not for patients with non-CRPS pain ($P = 0.12$), and the ANOVA did not reveal a difference in pain increase between groups (no group × time interaction: $F[2,64] = 0.676$, $P = 0.512$).

Swelling. There was no across-time difference in swelling between groups (no main between-subjects effect of group: $F[1,32] = 0.522$, $P = 0.475$). However, when patients imagined moving their arm to match the postures shown in the pictures, swelling was greater posttask than it was pretask or 60 minutes posttask (main across-group effect of time: $F[2,64] = 56.71$, $P < 0.001$; post-hoc tests $P < 0.001$ for both comparisons). The increase in swelling was 8% ± 5% for patients with CRPS and 3% ± 4% for patients with non-CRPS pain (Figure 1), but there was no difference between groups on the MANOVA, which controlled for the effects of the secondary variables (time × group interaction: $F[2,64] = 1.695$, $P = 0.192$).

Secondary hypotheses. Data from all subjects were used in these analyses.

Change in pain and swelling was related to RT^{RATIO} and duration. Both the increase in pain and the increase in swelling posttask were positively related to performance on the implicit motor imagery task (making left/right judg-

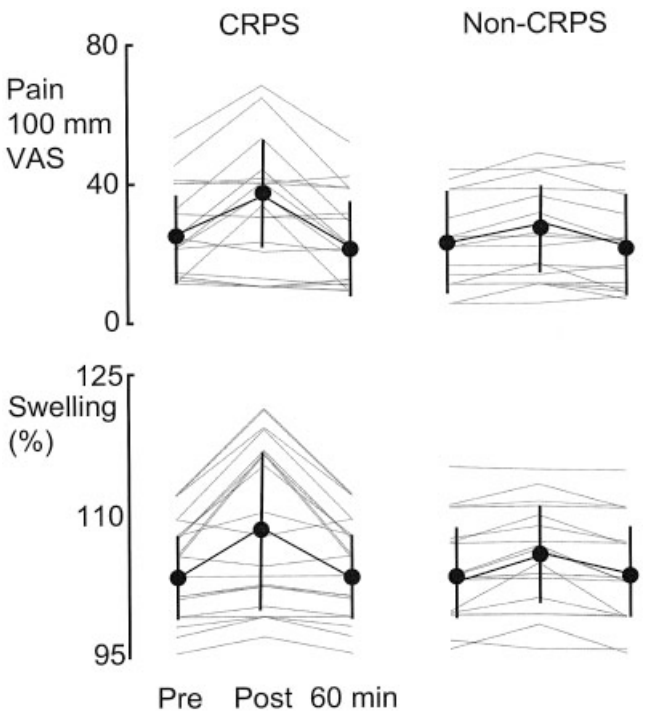

Figure 1. Pain and swelling (finger circumference of the affected hand as a proportion of that of the unaffected hand) in patients with complex regional pain syndrome (CRPS) and in those with non-CRPS pain of similar intensity, before, directly after, and 60 minutes after an imagined hand movement task. Individual subject data are shown and bold lines reflect mean values with SD bars. VAS = visual analog scale.

ments of pictured hands) and to the duration of their symptoms (r = 0.46, F[3,34] change = 3.10, $P = 0.039$ for pain; r = 0.74, F[3,34] change = 14.01, $P < 0.001$ for swelling) (Figure 2). Higher RT^{RATIO} and longer duration related to a larger increase in pain and swelling between pretask and posttask.

Change in pain and swelling was related to catastrophizing and fear of movement. Increase in pain was positively related to TSK and PCS. The higher the TSK or PCS score, the bigger the increase in pain with imagined hand movements. However, the relationships may have been dependent on pretask pain, because when pretask pain was included in the regression, PCS and TSK no longer contributed significantly to change in pain (r = 0.42, F[3,34] change = 2.42, $P = 0.082$). Increase in swelling was positively related to PCS and TSK, even when pretask swelling was included in the regression. Higher PCS and TSK scores related to a larger increase in swelling, regardless of pretask swelling (Figure 3). On questioning, all patients reported that they were not fearful of the imagined movements.

Change in pain and swelling was related to autonomic arousal early in the task. Increase in swelling, but not increase in pain, was positively related to skin conductance in the first 20 seconds of the task. The bigger the increase in skin conductance, the bigger the increase in swelling after imagined movements (r = 0.48, F[2,35] change = 5.18, $P = 0.011$). There was no relationship between change in pain and skin conductance (r = 0.114, F[2,35] change = 0.231, $P = 0.80$).

Change in pain and swelling was related to the vividness of imagined movements. The more vivid the imagined movements, the bigger the increase in pain and swelling during the task (Pearson's r = 0.681, $P = 0.01$ for change in pain; Pearson's r = 0.311, $P = 0.029$ for change in swelling) (Figure 4).

Does change in pain relate to change in swelling? Change in pain was positively related to change in swelling (Pearson's r = 0.553, $P < 0.001$).

Method check: electromyographic activity of arm muscles during the task. We were not able to attach electrodes to the arms of 3 subjects with CRPS because it was too painful to do so. The pain and swelling data for these 3 patients were unremarkable. In the remainder of the patients, there were no observable changes in electromyographic activity.

Did patients notice a change in symptoms? During debriefing, 15 patients (10 with CRPS) volunteered that their arm was more painful, 13 (9 with CRPS) said it felt more swollen or stiffer, 3 (all with CRPS) said it felt warmer, and 2 (both with CRPS) said it was a different color after imagined movements.

DISCUSSION

The primary hypothesis that imagined movements would increase pain and swelling in these patients with chronic arm pain is supported. This is evidenced by the main effect of time on resting pain and finger circumference. The hypothesis that the effect would be greater for patients with CRPS than those with non-CRPS pain of similar intensity was not supported. The finding that posttask pain was greater than pretask pain for patients with CRPS but not for those with non-CRPS pain suggests that the study may have been underpowered to detect a differential effect on pain between those with and without CRPS, but this remains to be verified. Although motor imagery activates cortical and cerebellar motor networks (23–27), whether motor imagery changes spinal excitability is not clear (i.e., one suggests it does and another suggests it does not) (28,29), and motor imagery does not usually activate muscles (30). Therefore, the increase in symptoms observed here is most probably mediated cortically rather than via stimulation of nociceptive afferents. Our failure to detect electromyographic activity corroborates that position, although we cannot exclude the possibility of activity in more proximal arm muscles.

How might imagined movements increase pain and swelling? The strong relationship between performance on the left/right judgment task and increased symptoms implicates difficulty in integrating body schema with motor processes. The fact that those who more vividly imagined the movements were more affected strengthens the finding because it implicates motor imagery rather than some other aspect of the task or experimental protocol. According to current theory in the relationship between perception and action (for review, see ref. 31), it is likely that those who experienced more vivid movements best re-

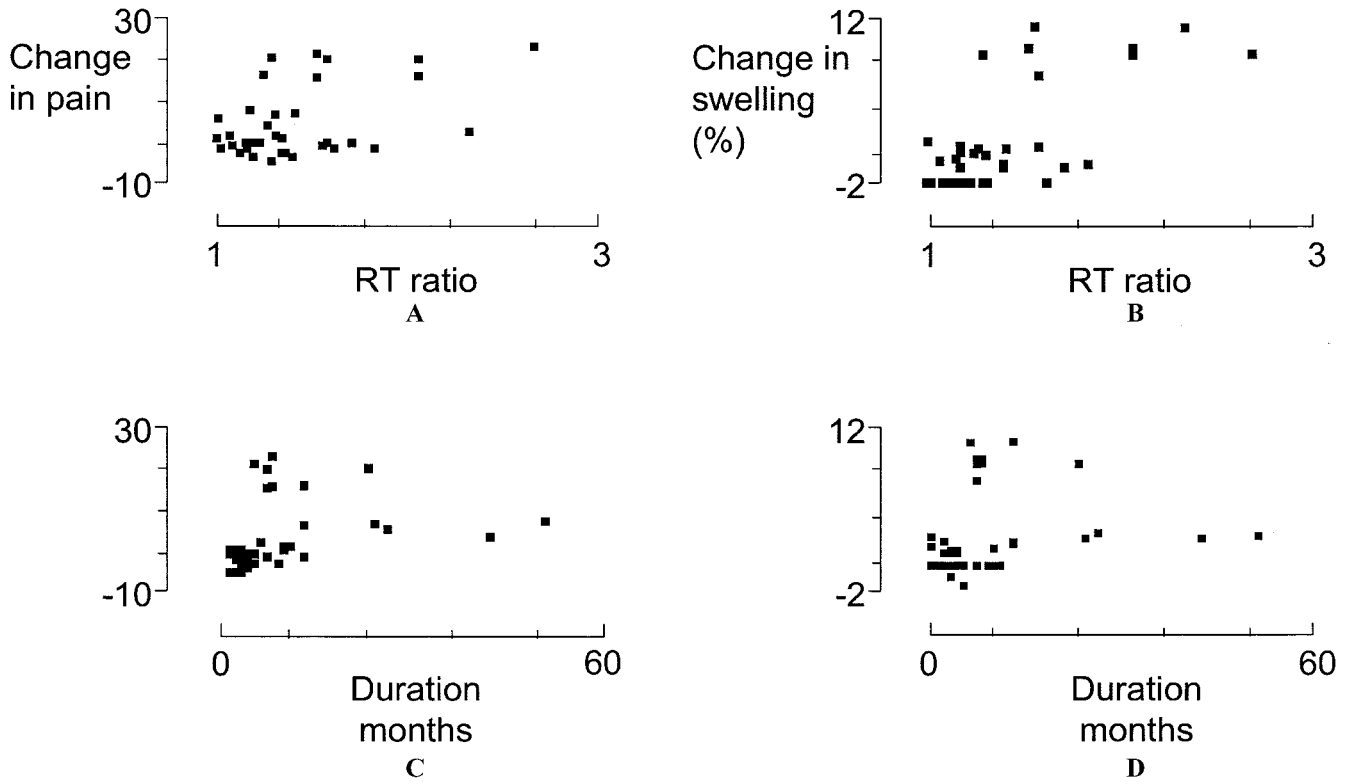

Figure 2. Scatterplots of change in pain (**A** and **C**, measured on a 100-mm visual analog scale) and change in swelling (**B** and **D**, finger circumference as a percentage of that of the unaffected arm), with imagined hand movements (vertical axis) and reaction time to correctly judge the laterality of pictured arms for pictures of the affected side versus the unaffected side (RT ratio; **A** and **B**) and duration in months since the onset of pain (**C** and **D**).

cruited motor commands, which again implicates the motor imagery itself in causing the effect.

Several changes in brain activity associated with pain have been identified in patients with chronic painful disease. For example, when patients with CRPS perform simple motor tasks, they show more activity than matched controls in medial and anterior inferior parietal lobes (32) where sensorimotor integration is thought to occur (33); disinhibition of the primary motor cortex (34,35); and, during motor imagery, less ipsilateral activation in premotor and insular cortices (36). These findings do not allude to a specific mechanism by which patients are more affected by motor imagery than healthy controls, but they do further implicate dysfunction within cortical networks associated with movement.

Sympathetic arousal positively related to increased swelling. During movement, patients with chronic pain show more activation of the right insular cortex (32), thought to hold representations of the sympathetic nervous system (37), than healthy controls. In (nonpain) stroke patients, sympathetic dysfunction parallels motor dysfunction (38), and in healthy subjects, sympathetic markers correlate with primary motor cortex activity (Schlindwein et al: unpublished observations). That increase in swelling related to fear of pain and catastrophizing suggests that cognitive variables may modulate the link between motor and sympathetic activities. Real-time inflammatory responses can be mediated by the autonomic nervous system, which also interacts closely with limbic systems important in memory (39). Perhaps it is the memory of the painful movement that evokes the response. Alternatively, perhaps it is a learned response. Centrally driven inflammatory responses are open to classic and behavioral conditioning (40).

Patients in this study did not report being fearful of imagined movements, which points further toward an implicit rather than consciously-driven mechanism. Movement-related networks in the amygdala could affect this mechanism (41), but without imaging data, one cannot verify this possibility. Regardless, the finding suggests that fear of movement affects motor processes and pain even when the individual has no intention to execute the movement. This corroborates the importance of cognitions in chronic pain (42–45), but demonstrates for the first time that cognitions may modulate pain processing in the absence of nociception. This is important because current theories of psychological modulation of pain emphasize down-regulation of nociception at brainstem or spinal centers (for review, see ref. 46). Those data are necessarily drawn from experimental paradigms in which psychological variables are related to brain activity evoked by peripheral noxious stimuli.

An alternative explanation for the current results is that motor imagery simply causes a shift in attention toward the affected arm. If patients in pain implicitly divert attention away from the arm as a way to reduce symptoms, directing attention toward the arm will reduce the efficacy of such a strategy. The fact that explicitly focusing atten-

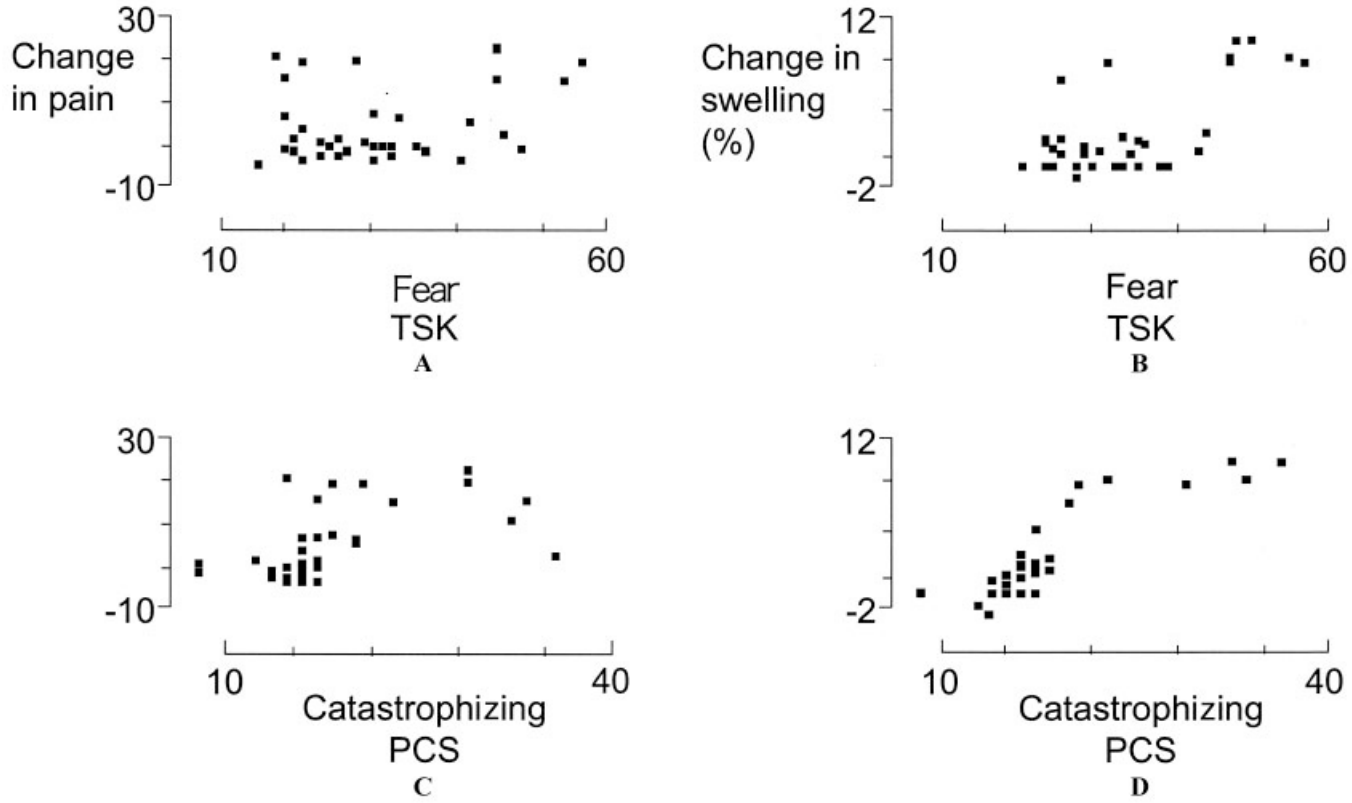

Figure 3. Scatterplots of change in pain (**A** and **C**, measured on a 100-mm visual analog scale) and change in swelling (**B** and **D**, finger circumference as a percentage of that of the unaffected arm) with imagined hand movements (vertical axis), and fear of movement measured by the Tampa Scale for Kinesiophobia (TSK; **A** and **B**) and catastrophic thought processes associated with pain measured by the Pain Catastrophizing Scale (PCS; **C** and **D**).

tion on the arm does not increase symptoms (47) suggests against this possibility, but it cannot be ruled out.

Finally, it is possible that the effect was caused by the stress of the research setting. We contend that such an effect would be limited, because 1) we accommodated patients to the setting prior to data collection, 2) skin conductance measures showed stress responses that were not associated with changes in symptoms, 3) pre-imagined movement task assessments were taken directly after the left/right judgment task, which increased arousal, and 4) the vividness of motor imagery was related to the change in symptoms, but not to skin conductance.

Are the changes seen here clinically meaningful? We did not explicitly assess this, but 15 patients volunteered that they noticed that their pain or swelling worsened during the task and the mean increase in pain was similar to that reported by patients in a clinical study as "slightly worse" (48). Notably, the task used here was shorter and less demanding than many tasks of everyday living. Longer and more demanding tasks may impart a greater effect.

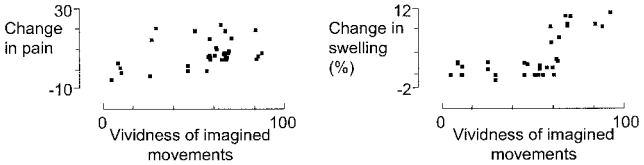

Figure 4. Scatterplots of change in pain (**left** panel, measured on a 100-mm visual analog scale [VAS]) and change in swelling (**right** panel, finger circumference as a percentage of that of the unaffected arm), with imagined hand movements (vertical axis) and the vividness of the imagined movements, measured on a 100-mm VAS where 0 = not at all vivid and 100 = completely vivid.

Interpretation of this study should consider several limitations. First, we did not assess skin temperature, which would have provided important information about the effect of the sympathetic response on local circulation. Second, the study may have been underpowered to detect a difference between groups and in detecting a relationship between TSK and PCS and increase in pain, the latter of which approached significance ($P = 0.06$). Finally, because we did not assess brain activity in the current study, we must rely on previous findings.

Despite limitations, our results shed new light on the pathophysiology of chronic pain states and the mechanisms that contribute to pain on movement in patients with chronic painful disease. There are clear clinical implications, and perhaps we need to train the brain before we train the body (49).

AUTHOR CONTRIBUTIONS

Dr. Moseley had full access to all of the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis.

Study design. Moseley, Birklein, Marinus, van Hilten.

Acquisition of data. Moseley, Zalucki, Luomajoki.

Analysis and interpretation of data. Moseley, Birklein, Marinus, van Hilten, Luomajoki.

Manuscript preparation. Moseley, Zalucki, Birklein, Marinus, van Hilten, Luomajoki.
Statistical analysis. Moseley, Marinus.

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