ORIGINAL ARTICLE

Reorganized Force Control in Elbow Pain Patients During Isometric Wrist Extension

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Introduction: Reorganized force control may be an important adaptation following painful traumas. In this study, force control adaptations were assessed in elbow pain patients. Increasing the contraction demand may overcome pain interference on the motor control and as such act as an internal control. It was hypothesized that elbow pain patients compared with controls would present greater change in the direction of force when increasing the demand of the motor task.

Methods: Elbow pain patients ($n=19$) and healthy participants ($n=21$) performed isometric wrist extensions at 5% to 70% of maximum voluntary contraction. Pressure pain thresholds were recorded at the lateral epicondyle and tibialis anterior muscle. Contraction force was recorded using a 3-directional force transducer. Participants performed contractions according to visual feedback of the task-related force intensity (main direction of wrist extension) and another set of contractions with feedback of the 3 force directions. Going from the simple to the detailed force feedback will increase the demand of the motor task. Force steadiness in all 3 dimensions and force directions was extracted. AQ6

Results: Compared with controls, elbow pain patients presented lower pressure pain thresholds at both sites ($P<0.05$). Force steadiness was not significantly different between groups or feedback methods. The change in force direction when providing simple visual feedback in contrast with feedback of all force components at all contraction levels was greater for patients compared with controls ($P<0.05$).

Conclusion: The larger change in force direction in pain patients implies redistribution of loads across the arm as an associated effect of pain.

Key Words: elbow pain, isometric force, sensory-motor control, lateral epicondylalgia

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Chronic elbow pain is one of the most frequently reported location of pain, involving around 1% to 3% of the population.[1] According to previous statistics, elbow pain is recognized as a prevalent work-related musculoskeletal disorder caused by different factors including repetitive work (91%), biomechanical factors (6%), work posture (1%), and mechanical vibrations (1%).[2] It has been estimated that around 50% of employees who perform repetitive tasks are prone to suffer a muscle injury.[3–5] The dominant arm is primarily affected by chronic elbow pain, and this condition is associated with poorly designed occupational frameworks.[6] In most of the cases, chronic elbow pain is accompanied with tenderness during palpation, and eventually pain with resisted wrist or finger movement.[7] Undoubtedly, chronic elbow pain represents a great challenge to the motor control and thus quality of performed tasks.[8]

Chronic elbow pain patients exhibit reduced strength in different motor tasks including grip and wrist extension/flexion.[9,10] In particular, lateral epicondylalgia patients present reduced extensor carpi radialis muscle activity,[11] and weakness in some of the elbow and shoulder muscles.[8,11] In addition to the force reduction, these patients commonly have active myofascial trigger points (MTrPs) in the forearm muscles,[12] which presumably increase pain sensitivity and affect the muscle synergies during a movement. This alteration of the limb kinetic may impact on the activity and coordination of the muscles involved in function of the wrist joint. Hence, force strength may not be sufficient to assess important aspects of the effects of elbow pain on the motor control.

Several studies have demonstrated that short-term experimental muscle pain reduces force steadiness[13,14] and induces reorientation of the net force in healthy individuals.[15,16] These changes in the force output may be associated with decreased proprioception in the wrist joint, which is also observed in chronic elbow pain patients.[17] Restraining the freedom of the contractions, that is, by increasing the information in the visual feedback, it is possible to compensate potential decrease in proprioception AQ7 caused by muscle pain.[16] Interestingly, sustained experimental elbow pain, elicited by intramuscular injection of nerve growth factor into the extensor carpi radialis brevis muscle, induces a reorientation of the force rather than a change in the force steadiness during an isometric contraction.[18] These characteristics of the force, steadiness, and direction could facilitate the development of new tools for assessment of manifestations in chronic elbow pain. However, there is no evidence about the effects of chronic elbow pain on the force control during isometric wrist extension.

The present study investigates the effect of chronic elbow pain on the motor control, focusing on force steadiness and direction of the force in isometric wrist contractions when going from simple feedback of force to 3-dimensional force feedback. It is hypothesized that chronic elbow pain induces reorganization of force direction rather than changes in force steadiness.

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METHODS

Participants

Chronic elbow pain patients (n = 19; 57% women; 42 ± 10 y; pain patient group) and sex-matched and age-matched healthy individuals (n = 21; 55% women; 36 ± 14 y; control group) participated in the study (Fig. 1). Participants who exhibited musculoskeletal pain in the elbow region for > 2 months were included in the patient group. Healthy participants were excluded if they presented pain in the lateral epicondyle region. Group size calculation was based on an estimated difference of 20% in main parameters (force steadiness), and on types I and II errors at 5% and 20%, respectively, requiring 15 participants for each group when using paired comparisons. The experimental procedures were approved by the Clinical Research Ethical Committee of the IDIAP Jordi Gol i Gurina (Ref. No, 06-04-27/4proju) and the Hospital Universitari Joan XXIII (Ref. No, 52/2013).

Experimental Protocol

Participants attended to a single session. Anthropometric data (weight and height), wrist passive range of motion, MTrPs, and pressure pain thresholds (PPTs) were assessed; pain and functional questionnaires were fulfilled. Participants sat upright in a chair with their back resting against a backrest. The shoulder was at 90 flexion degrees (Fig. 2). Maximal voluntary wrist extension (MVC) was recorded by performing 3 consecutive maximal isometric wrist extension trials for 10 seconds with an interval of 30 seconds inbetween. After a 120 seconds rest, 2 sets of isometric wrist extensions were performed at 5%, 30%, 50%, and 70% MVC in a randomized order. The contraction consisted of 5 seconds of ascending ramp, 10 seconds of steady phase, and 5 seconds of descending ramp. Contraction force was recorded in the task-related (*Fz*) as well as tangential directions (*Fy*, wrist radial-ulnar deviation and *Fx*, longitudinal movement of the wrist), as shown in Figure 2. Force was presented in real-time by a dynamic circle on a computer screen, whereas the force target was represented by a moving square. The center of the force target was represented by a black dot. Participants performed 2 sets of contractions: (1) with visual feedback including the tangential force directions (*Fy* and *Fx*) and (2) with only the visual feedback of the task-related force (*Fz*).[16] Inclusion of tangential directions in the visual feedback impose restriction on the contraction and demand higher force precision. After a 60 seconds rest, maximum isometric gripping force was recorded with a handgrip dynamometer (SP-5030J1; JAMAR). Three gripping MVCs were performed for 5 seconds with 90 degrees shoulder flexion and elbow extended. Pain intensities during wrist extension and grip force were scored after each trial on a visual analog scale (VAS) where 0 indicates "no pain" and 10 "the worst pain imaginable." Pain VAS scores of the maximal contractions were averaged between the trials.

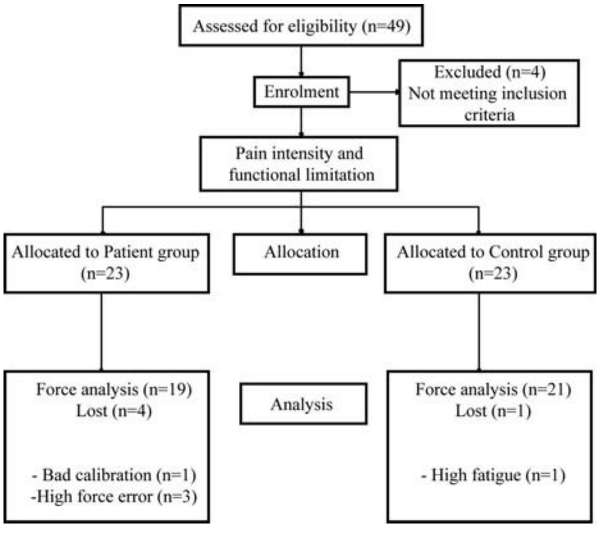


FIGURE 1. Time course and flow-diagram of participants.

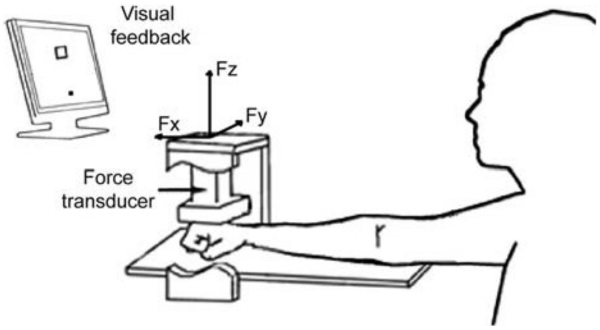


FIGURE 2. Experimental setup. Force was recorded in task-related (*Fz*) and tangential (*Fy*: wrist radial-ulnar deviation and *Fx*: longitudinal movement of the wrist) directions using a 3-dimensional force transducer.

Questionnaires and Assessment of Functional Limitation

Disability of the Arm, Shoulder, and Hand (DASH) Questionnaire in Spanish was used to assess upper-extremity disability: ranging from 0 (best functional state) to 100 (worst situation).[19] The Patient-rated Tennis Elbow Evaluation (PRTEE) Questionnaire was used to measure forearm pain and disability in the patients. The PRTEE is a 15-item questionnaire, and the task-related questions are scored ranging from 0 (no pain and no functional disability) to 100 (worst imaginable pain with a very significant functional disability).[20,21] The Spanish translation of McGill Pain Questionnaire was used to describe the quality and intensity of subjective pain experienced.[22] Two indexes were calculated from the McGill Questionnaire: Pain Rating Index and Present Pain Intensity. The Pain Rating Index depicts the sensory and affective characteristics of pain measurement on the basis of the ordinal value of the word chosen through 78 adjectives, and the Present Pain Intensity represents the pain intensity on a scale rating from 0, the better condition, to 5, the worst condition.[22] Active and passive range of wrist flexion and extension were measured.

Three-Dimensional Force Recordings During Contraction

Three-dimensional force was recorded using a 6-axis load cell transducer (MC3A 250; AMTI) with high sensitivity (0.054, 0.054, 0.0134 V/Nm for *Fx*, *Fy*, *Fz*; and 2.744, 2.744, 2.124 V/Nm for *Mx*, *My*, *Mz*). The analog output of the transducer was amplified, and low-pass filtered at 1 kHz (MSA-6; AMTI). The force signals were sampled at 2 kHz and stored after 12 bits A/D conversion.

Force recordings were digitally low-pass filtered at 20 Hz using a second-order Butterworth filter. The analysis was performed in the steady period of the contractions (2 to 8 s). SD was used to quantify force steadiness (FSD) in the task-related direction. The Centroid Position Difference (CPD) index was used to quantify change of force direction between the 2 sets of contractions with different feedback conditions.[16,23] The CPD is calculated from a 2-dimensional histogram (5×5 bins) representing the range of the *Fy* (wrist radial-ulnar deviation) and *Fx* (longitudinal movement of the wrist) direction. Coordinates of the center of gravity were extracted from the histograms for each set of contractions, and absolute difference between centroids was computed for each direction. In the present study, the CPD values were calculated contrasting the force recordings during the feedbacks with and without including the information of the tangential force directions, obtaining 2 values: (1) CPD in the longitudinal movement of the wrist (*Fx* direction) and (2) CPD in the wrist radial-ulnar deviation (*Fy* direction).[16] In addition, force error sum of squares (ESS) was computed at each force level as the difference between the force target and the force measured in the task-related force.

Pressure Algometry and MTrP Examination

A handheld electronic pressure algometer (Ten FDX 50; Wagner Instruments) with a 1 cm^2 circular probe was used to quantify PPT. The PPT was assessed over the lateral epicondyle area and tibialis anterior muscle on the right leg as a control outlying site (5 cm lateral to the tibial tuberosity, in the upper one third of the muscle belly).[24] The location for each measure was alternated, and the procedure was repeated 3 times at 30-second intervals. The average of the PPT values was used for further analysis.

The total number of active and latent MTrPs was assessed on the extensor carpi radialis brevis, extensor carpi radialis longus, and extensor digitorum communis muscles. The procedure was performed according to established criteria for MTrPs examination.[25,26] An active MTrP was defined by the presence of a taut muscle band, local twitch response, and most tender spot upon digital palpation generating spontaneous and familiar referred pain. Latent MTrP shared the same inclusion criteria except that the referred pain, if occurring, was unfamiliar.[27]

Statistical Analysis

Data are presented as mean values and SD throughout the text. Normal distribution was tested using the Kolmogorov-Smirnov test. Two-sided independent-samples *t* tests were used to compare group differences for age, weight, height, PPT, grip force, and MVC. Data not normally distributed, including DASH, PRTEE, McGill, wrist MVC, and grip VAS scores, and number of MTrPs between groups were tested using the Mann-Whitney *U* test. The χ^2 Test was performed to assess sex distribution.

To test whether elbow pain affects force characteristics, a mixed-model analysis of variance (ANOVA) model were applied to FSD (steadiness), force ESS (force error), and CPD (direction of force) with group (pain patient or control) as a between-subject factor and contraction level (5%, 30%, 50%, 70% of the MVC force) as a within-subjects factor. A similar ANOVA model was used to test whether wrist VAS scores changed across groups and level of contractions. In case of significant main effects or interactions, the Newman-Keuls (NK) post hoc tests were applied, correcting for multiple comparisons. *P*-values <0.05 were regarded as significant.

RESULTS

Self-reported Pain and Assessment of Arm Functionality

Sex, age, weight, height, dominant arm, or wrist range of motion were not significantly different between groups. Within the patient group, 79% presented the dominant arm affected ($n=15$), whereas 21% showed pain in the nondominant arm ($n=4$). The patients reported higher PRTEE, DASH, and McGill compared with the control group (Table 1).

PPTs and Trigger Point Assessment

The patients showed lower PPTs in the elbow region and at the tibialis anterior muscle (Table 1, $t_{40}=-6.17$, $P<0.05$) compared with the control group. Active MTrPs were found only in patients (patient, 1.32 ± 1.60 vs. control, 0 ± 0; $U=90$; $P<0.001$). Latent MTrPs were presented in both groups, although the patient group presented higher number of latent MTrPs compared with the control group ($U=95.5$; $P=0.008$; Table 1).

Force Strength and Contraction-induced Pain

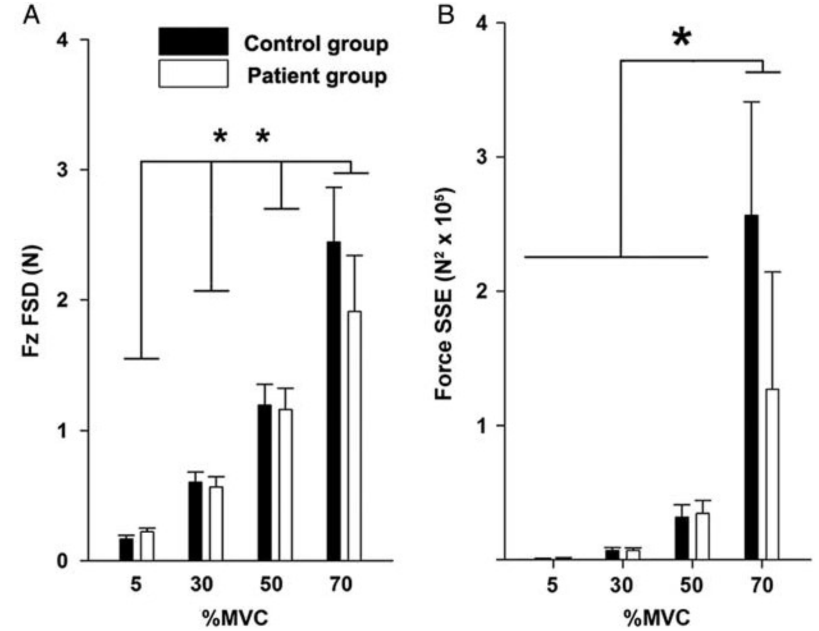
The patient group showed reduced MVC during wrist extension force (patient, 4.6 ± 1.8 N/cm vs. control, 5.9 ± 1.9 N/cm; $t_{36}=2.2$; $P=0.03$) and higher pain VAS scores during wrist MVC compared with the control group (patient, 5.2 ± 2.5 cm vs. control, 0.1 ± 0.4 cm; $U=4$; $P<0.001$). There was no statistical difference in maximal grip force in the patients compared with the control group (patient, 27.3 ± 11.6 kg vs. control, 34.1 ± 11.3 kg; $t_{38}=-1.88$; $P=0.068$), and the patient group reported greater pain VAS during grip force assessment (patient, 4.3 ± 3.2 cm vs. control, 0.1 ± 0.4 cm; $U=45$; $P<0.001$).

TABLE 1. Descriptive Data of Participants, Pain, and Functionality Test

	Patient Group (n = 19)	Control Group (n = 21)	P
Sex (male/female)	9/10	10/11	0.99
Age (y)	41 (11)	37 (13)	0.29
Weight (kg)	70.0 (16.4)	68.9 (12.5)	0.81
Height (cm)	166.3 (2.3)	161.5 (8.3)	0.39
Dominant arm (left/right/ambidextrous)	16/0/3	19/2/0	0.075
Active flexion (deg.)	85.7 (20.8)	83.4 (21.7)	0.79
Passive flexion (deg.)	93.0 (21.2)	96.6 (11.7)	0.73
Active extension (deg.)	62.2 (21.1)	69.5 (12.6)	0.33
Passive extension (deg.)	68.2 (20.7)	78.1 (11.1)	0.10
Epicondyle PPT, N	15.8 (8.7)	35.8 (11.5)	0.000
Tibialis anterior PPT, N	57.4 (20.2)	71.5 (18.8)	0.029
Active MTrPs	1.3 (1.6)	0.0 (0.0)	0.005
Latent MTrPs	2.5 (1.1)	1.4 (1.2)	0.008
McGill PRI (0-78)	25.4 (14.3)	0.00 (0.0-0.0)	0.000
McGill PPI (0-5)	2.4 (0.6)	0.0 (0.0-0.0)	0.000
PRTEE (0-100)	42.2 (18.5)	0.1 (0.5)	0.000
DASH (0-100)	25.0 (15.6)	0.7 (2.4)	0.000

Values are mean (SD) except for sex and dominant arm (n).

DASH indicates The Disabilities of the Arm, Shoulder, and Hand; MTrP, myofascial trigger point; PPI, present pain intensity; PPT, pressure pain threshold; PRTEE, The Patient-rated Tennis Elbow Evaluation Questionnaire; PRI, Pain Rating index.



AQ10 **FIGURE 3.** Mean (SD) of the force error sum of squares (ESS), and SD of the task-related force (FSD) during the isometric wrist extensions. Both groups showed maximum error during the highest level of contraction (*$P < 0.001$). FSD was also increased monotonically for the level of contractions (**$P < 0.05$).

Force Steadiness and Direction During Wrist Extension

There were no significant differences in FSD nor in the ESS between patients and controls (Fig. 3). However, greater changes in the direction of the force were found between groups in the longitudinal movement of the wrist direction (Fx; Fig. 4; CPD_x patient, 2.91 ± 0.03 vs. control, 3.04 ± 0.03; ANOVA, $F_{1,37} = 6.81$; $P = 0.01$). The post hoc analysis revealed higher CPD in the patient group compared with the control group (NK: $P < 0.05$). This result reflects a greater reorganization of the direction of the force between submaximal contractions in the patient group caused by an increasing demand of force control required by changing the visual feedback. A significant interaction between group and contraction level (ANOVA, $F_{3,111} = 45.75$; $P < 0.001$) was found for pain VAS scored during the submaximal wrist extensions (Table 2). Patients reported higher VAS scores during 30%, 50%, and 70% MVC compared with the 5% MVC (NK: $P < 0.05$), and for all contraction levels when compared with the control group (NK: $P < 0.05$).

DISCUSSION

This study demonstrates the force control reorganization in chronic elbow pain patients. The patients presented a reduction of muscle strength and had a larger change in the direction of the force when increasing the demand of the force task (from excluding to including tangential force information) in comparison with the asymptomatic participants (control group), which implies that chronic pain impairs the force control. However, although the patients generated lower intensity of wrist maximal extension effort, not all the force characteristics results were significantly affected by chronic pain, as force steadiness was not different compared with the control group. The force reorganization found in the chronic patients is consistent with the pain assessment results. The patients had lower PPT on the elbow region, higher arm functional disability, and greater pain during the motor tasks, as compared with the control group. These findings suggest that chronic elbow pain alters the motor strategy, rather than the force precision.

Chronic Elbow Pain

The reduced PPT found on the epicondyle and tibialis anterior areas indicate widespread hypersensitivity in the elbow pain patients. Such widespread hypersensitivity has been previously associated with chronic musculoskeletal pain.[10,24] In chronic lateral epicondylalgia, patients present longer pain duration and widespread pain during acute experimental muscle pain compared with healthy individuals,[28] and also have reduced threshold for nociceptive flexion reflex, suggesting spinal cord hyperexcitability.[29] Taken together, facilitated central mechanisms are likely in chronic elbow pain patients.

Another phenomenon observed in the present study is the higher number of active and latent MTrPs in the extensor muscles in patients compared with asymptomatic participants. These MTrPs may cause an unbalance between muscle activation, increasing antagonistic muscle activities and overloading muscle fibers in synergist muscles.[30,31] It has been proposed that chronic pain distorts the body image, by affecting the proprioception, exteroception, and interoception information,[32] which may affect the motor strategy used by the patients.[33]

Peripheral sensitization mechanisms have also been associated with chronic elbow pain. For instance, in lateral epicondylalgia, changes in the connective tissue have been observed in chronic stages.[34,35] This degeneration seems to cause a reduction in proprioception,[36] which might affect the force control of chronic pain patients. In the current study, the patients showed distorted estimation of the developed force. Likewise, chronic low-back pain patients have shown reduced proprioception, and it has been

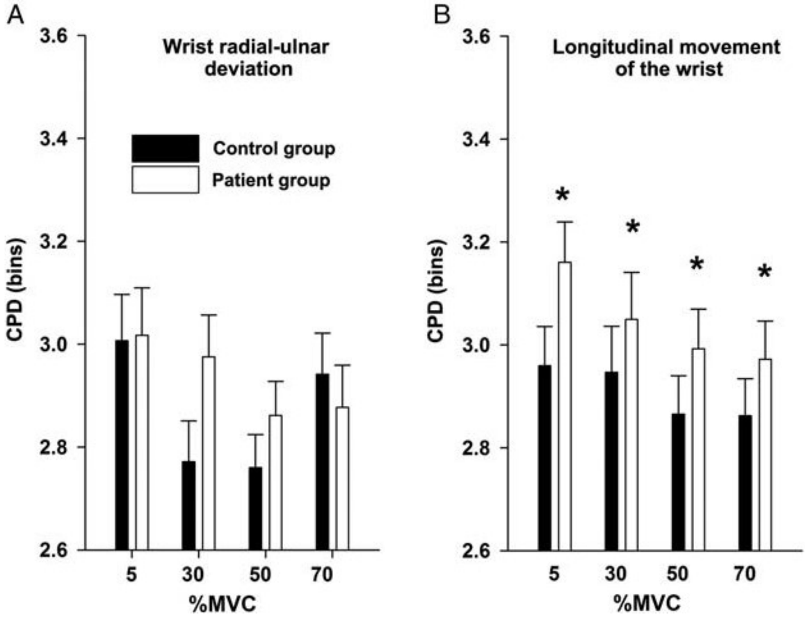


FIGURE 4. Mean (SD) of distribution of Centroid Position Difference (CPD) of the orthogonal axes: *Fy* (wrist radial-ulnar deviation) and *Fx* (longitudinal movement of the wrist). Data represent the change in the force direction when increasing the restriction of the force contraction (feedback of the task-related force vs. feedback including the tangential force components). The patient group showed a greater change in the direction of the force when changing the restriction of the contraction (*$P<0.05$).

suggested that reweighting the proprioceptive inputs from different parts of the body might counteract the localized reduction of proprioception.[37]

Effect of Chronic Elbow Pain on the Force and Functionality

Chronic elbow pain represents a great challenge to the motor control. One of the changes observed in patients is the decrease of maximal force capability, which might be associated to several causes. For instance, it could be related to inhibitory effects of pain, or to a peripheral effect caused by long inactivity of the muscles. Another possibility is that patients spontaneously adopt a nonoptimal position during the maximal tests. Lateral epicondylalgia patients are prone to flex the wrist during gripping test.[38] Even though participants were guided and visually inspected during the maximal task in the experiment, slight changes in the position of the wrist might have occurred as the result of a consolidated adaptation in patients, affecting the outcome of the maximal effort test. It is worth noting that force weakness may play a major role in the muscle imbalance of forearm muscles and, consequently, in the arm functionality,[11] as also observed in the arm functionality questionnaires in the current study.

TABLE 2. Mean (SD) VAS Scores After Isometric Wrist Extension

	5% MVC	30% MVC	50% MVC	70% MVC
Patient group (n = 19)	0.8 (0.2)	1.7 (0.4)	4.7 (0.4)	6.2 (0.4)
Control group (n = 21)	0.0 (0.2)	0.0 (0.4)	0.0 (0.4)	0.2 (0.4)

MVC indicates maximal voluntary wrist extension; VAS, visual analog scale.

In contrast to reduction of maximal effort, there were no significant differences between groups for steadiness and error of the force. These results concur with previous findings showing that force steadiness is reduced during acute pain, associated with search for a potential beneficial motor strategy, whereas when pain is persisted and a new strategy is found, force steadiness is increased around the new solution.[18] It has previously been found that short-term muscle pain in the elbow region can cause a decreased force steadiness in isometric wrist extension.[18] However, the effect of chronic elbow pain on force steadiness has not been studied before. In other chronic pain conditions, several studies have shown unchanged force steadiness. For example, force steadiness is unaffected for subacromial impingement syndrome patients when performing isometric shoulder abduction,[39] and similar results are observed for low-back patients during control of their upright trunk posture.[40]

The key finding of the present study is that chronic elbow pain patients presented greater changes of the direction of the force compared with asymptomatic participants when changing the demand of the motor task. In other words, patients under pain have higher reorganization between 2 strategies used when performing motor tasks with different demands. There are several mechanisms that could account for the reorientation of the force. First, muscle pain can induce nonuniform activity in the motor unit population and, consequently, alter the direction of the force.[15] Second, the presence of MTrPs itself can affect the direction of the force. These discrete hardness points, localized within the region of the muscle, may impact on the capability of force development of muscle fibers, causing a diminishing contribution of functional sarcomeres acting in a particular force direction.[25,41]

The results could be consider from the contemporary theory of pain effects on the motor control, which propose that changes in strategies to perform a motor task facilitate redistribution of loads across the involved structures, and this protects the system in the short term, although it may have deleterious effects in the long term because of overloading of some healthy structures.[42] The patients involved in the present study most likely were in the later stages of the motor adaptations, that is, where motor adaptations are consolidated. Nevertheless, it is clear that the strategies used by patients to achieve each task were different when increasing the demand, even though they reported pain in both motor tasks. It has been suggested that the system used a consolidated strategy to resolve a familiar motor task, but when the demand is increased and the strategy is no longer convenient, a new strategy may be required.[33] Most likely, the central nervous system would try to preserve a consolidated strategy to resolve the motor task whenever it is convenient, even though the strategy might not be the optimal solution.

Implications of the Results for Physical Treatment

Conventional treatments for chronic elbow pain, such as lateral epicondylalgia, are based on the restoration of muscle balance and pain relief of the arm.[43] The most effective therapeutic programs include concentric[44] and/or eccentric exercise,[45] resulting in strengthening of extensor muscles of wrist and hand, which is essential for obtaining the best outcome.[43,46,47] However, the design and follow-up of patients during the treatments rely on subjective feedback, generally consisting of the description of pain and functional limitations of the patients. The implications of results from the present study are 2-fold. First, treatments for chronic elbow pain should target the central levels, that is, target the relearning of the optimal motor strategy. In this regard, chronic low-back pain patients have shown to achieve the same accuracy as the asymptomatic participants when sufficient learning period of a motor task is provided.[48] Second, changing the demand between 2 isometric force tasks, and assessing the variation of the direction of the force, could serve as an objective index to assess effectiveness of different treatments, as the increase in the reorientation of the force could be directly associated with worst imbalance of the muscle activity.

The implications of the current study might not be extended to all chronic conditions, because the population were elbow pain patients, although it is unknown whether other pain conditions would reproduce the same pain pattern. Another potential limitation presented is that examination of pain threshold and myofascial pain syndrome, before the force assessment, may condition the motor performance, because of pain caused by the assessments.

CONCLUSION

The current study shows that changing the demand of the visual feedback during isometric wrist extensions resulted in greater reorientation of the force in the chronic pain elbow patients. On the contrary, alteration of force steadiness seems to lack relevance in the chronic elbow pain condition.

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