PAIN 141 (2009) 70–78

PAIN

www.elsevier.com/locate/pain

Psychological influences on repetition-induced summation of activity-related pain in patients with chronic low back pain

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ARTICLE INFO

Article history:
Received 11 May 2008
Received in revised form 14 October 2008
Accepted 16 October 2008

Keywords:
Fear
Depression
Catastrophizing
Musculoskeletal pain
Temporal summation
Activity induced pain
Muscle pain

ABSTRACT

This study examined the role of pain catastrophizing, fear of movement and depression as determinants of repetition-induced summation of activity-related pain. The sample consisted of 90 (44 women and 46 men) work-disabled individuals with chronic low back pain. Participants were asked to lift a series of 18 canisters that varied according to weight (2.9 kg, 3.4 kg, 3.9 kg) and distance from the body. The canisters were arranged in a 3 × 6 matrix and the weights were distributed such that each 'column' of three canisters was equated in terms of physical demands. Participants rated their pain after each lift, and in a separate trial, estimated the weight of each canister. Mean activity-related pain ratings were computed for each Column of the task. An index of repetition-induced summation of pain was derived as the change in pain ratings across the six 'columns' of the task. Pain catastrophizing, fear of movement and depression were significantly correlated with condition-related pain (e.g., MPQ) and activity-related pain ratings. Women rated their pain as more intense than men, and estimated weights to be greater than men. A repetition-induced summation of pain effect was observed where pain ratings increased as participants lifted successive canisters. Fear of movement, but not pain catastrophizing or depression, was associated with greater repetition-induced summation of pain. The findings point to possible neurophysiological mechanisms that could help explain why fear of pain is a robust predictor of pain-related disability. Mechanisms of repetition-induced summation of activity-related pain are discussed.

1. Introduction

Numerous investigations have addressed the role of pain severity as a determinant of occupational disability following musculoskeletal injury [7,56]. Research findings have been mixed. Some studies have reported that pain severity immediately following injury is a significant predictor of prolonged pain and occupational disability [21,41]. Other studies have reported that pain severity is not a predictor of occupational disability [35,55]. Even when significant relations are found, pain severity rarely accounts for more than 10–20% of the variance in measures of occupational disability [7,11,36].

It is possible that the *disability-relevant* dimensions of pain have not been adequately assessed in previous research. The bulk of research examining the relation between pain severity and occupational disability has relied on static measures of pain [7,35,56]. For the purposes of this study, static measures of pain refer to measures that describe an individuals' pain experience at one point in time. Static measures of pain may not provide the best index of an individual's pain experience during physical activity, particularly the repeated nature of physical activity associated with the performance of occupational duties. Change in pain that occurs as a function of repeated physical activity might be a more *disability-relevant* dimension of pain than static measures of pain.

In other domains of pain research, it has been shown that repeated noxious stimulation can contribute to increases in pain, in spite of constant stimulus intensity [33]. *Temporal summation of pain* is a term used to describe increases in pain severity across repeated noxious stimulation. At least in animals, temporal summation of pain has been shown to result from sensitization of second-order neurons in the spinal cord [20,32,53]. In humans, temporal summation of pain has been demonstrated primarily in response to experimenter-delivered thermal, electrical or pressure stimulation, with standardized duration of stimulation and inter-stimulus intervals [1,8,53]. Summation of pain in response to self-initiated repeated physical activity has not been systematically investigated [2].

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0304-3959/$34.00
doi:10.1016/j.pain.2008.10.017

One objective of the present research was to examine whether summation of pain could be demonstrated in individuals with chronic low back pain (CLBP) in response to repeated low intensity physical activity. Individuals with CLBP rated their pain as they lifted canisters that varied according to weight and distance from the body. Since it cannot be assumed that the mechanisms of summation of pain are similar in response to repeated noxious stimulation and repeated physical activity, the term *repetition-induced summation of pain* will be used to refer to increases in pain following repeated physical activity.

An additional objective was to examine the psychological correlates of repetition-induced summation of pain in patients with CLBP. Variables such as pain catastrophizing, pain-related fears, anxiety and depression have been associated with more severe pain, and greater disability [13,16,48]. These psychological factors have also been shown to contribute to temporal summation of pain [9,15,34]. The relation between psychological variables and changes in pain in response to repeated physical activity has yet to be investigated.

2. Methods

2.1. Participants

The study sample consisted of 90 participants (44 women and 46 men) with CLBP. Participants were recruited through local pain treatment centres and newspaper advertisements in Montreal, Quebec. At the time of the assessment, all the participants were work-disabled due to their CLBP and were receiving disability benefits. The mean age of the sample was 40.6 years, with a range of 20–60 years. The mean number of years in pain was 7.3 years (SD = 6.9 years). The majority of participants were married or living common law (80%). The mean number of years of education was 13.1 (SD = 3.2). All participants underwent a medical evaluation in order to ascertain diagnosis and ensure that there were no medical contraindications to performing the physical manoeuvres involved in the lifting task.

2.2. Measures

2.2.1. Pain severity

The McGill Pain Questionnaire [23] was used as a measure of pain severity associated with participants' musculoskeletal condition (i.e., condition-related pain). Participants were asked to endorse adjectives that best described their back pain. The MPQ Pain Rating Index (PRI) was computed as the weighted sum of all the adjectives endorsed. The MPQ PRI has been shown to be a reliable and valid measure of chronic pain experience [52].

2.2.2. Mean activity-related pain

Participants were asked to rate their pain on an 11-point scale (0 = no pain, 10 = excruciating pain) as they lifted each of 18 weighted canisters (described in more detail below). Participants' pain ratings were averaged across lifts to yield an overall mean of activity-related pain.

2.2.3. Fear of movement/re-injury

The Tampa Scale for Kinesiophobia (TSK) [19] was used to assess fear of movement and re-injury associated with pain. Respondents indicated their level of agreement with each of 17 statements reflecting worries or concerns about the consequences of participating in physical activity. The TSK has been shown to be internally reliable (coefficient $\alpha = .77$) [54], and correlates with measures of disability [11].

2.2.4. Catastrophizing

The Pain Catastrophizing Scale (PCS) [43] was used to assess catastrophic thinking related to pain. Respondents rated the frequency with which they experienced each of 13 different thoughts and feelings when in pain. The PCS has been shown to have high internal consistency (coefficient $\alpha = .87$), and to be associated with pain experience, pain behavior and disability [42,44].

2.2.5. Depression

The Beck Depression Inventory II (BDI-II) [3] was used to measure severity of depressive symptoms. Respondents were asked to endorse phrases that best described how they had been feeling during the past two weeks. The BDI-II has been shown to be a reliable and valid index of depressive symptoms in chronic pain patients [31,46,55].

2.3. Procedure and apparatus

This research received ethical approval from the Institutional Review Board of the *Centre de recherche interdisciplinaire en réadaptation du Montréal métropolitain* (CRIR). Participants signed a consent form as a condition of participation in the research. Participants were asked to complete the MPQ, the TSK, PCS and the BDI-II prior to completing the lifting task. Participants were informed that the study was aimed at developing a new assessment procedure for chronic pain. They were made aware that the lifting task might lead to temporary increases in discomfort, and that they were free to discontinue at any point.

The lifting task was the same as that described in Sullivan et al. [47]. Participants stood in front of a table, and were asked to lift 18 canisters (4-l size paint canisters) that were partially filled with sand. The height of the table was adjusted so that the handle of the canisters in the first row (i.e., closest to the participant) was at standing elbow height. The canister weights were 2.9, 3.4 or 3.9 kg and were arranged in three rows of six canisters. The canisters were positioned such that each weight was represented twice in each location of a double latin square. Participants were asked to lift the canisters with their dominant arm in a pre-determined sequence (i.e., column 1, first, second, third row; column 2, first, second, third row; etc.). As shown in Fig. 1, the top of each canister was labelled with the letters A to R. Participants were instructed to begin by lifting canister A and proceed in alphabetical order to canister R. The experimenter modelled the lift of the first three canisters in order to minimize inter-individual variations in the approach to the lifting task.

As shown in Fig. 2, the canister locations required that the participant assume three functional anthropometric postural positions in order to complete the task. In the normal reach position, the participant stood erect with his or her elbow bent at 90 deg (position 1); in the maximum reach position, the participant stood erect with his or her arm fully extended (position 2); in the extreme reach condition, the participant was forward flexed with his or her arm fully extended (position 3) [4]. The task was designed such that the forward flexion and arm extension required to lift canisters further away from the body would increase the loading on the lumbar portion of the spine, momentarily increasing discomfort [51]. The canister lifting task used in the present study implicated intermittent back muscle contractions of low to moderate intensities, estimated to lie between 11% and 33% of the maximal strength across postures and weights [4].

The participants performed the lifting task twice. In one trial, they were asked to lift each of the 18 canisters, and to provide a pain rating after each lift. In a separate trial, they lifted each of the 18 canisters again and they were asked to estimate the weights of the canisters. The order of the pain rating and weight estimation trials was counterbalanced across participants. For the purposes of

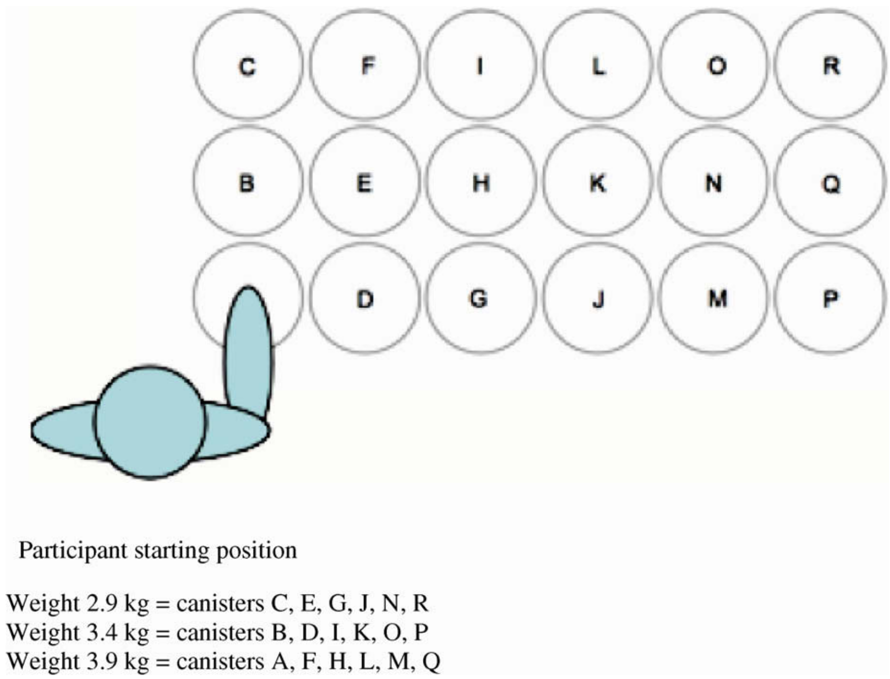

Fig. 1. Canister positions, weights and lift sequence.

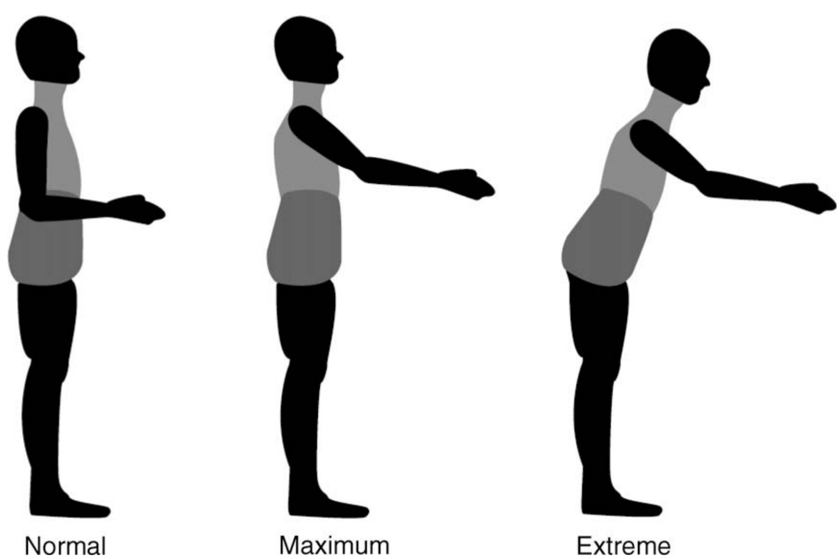

Fig. 2. Postural positions associated with the canister lifting task.

this study, weight estimates were used as an indirect measure of fatigue [17]. The duration of each canister lift as well as the duration of rest periods between lifts was recorded. An index of work output was computed by dividing lift duration by the duration of rest periods between lifts (for the pain rating task).

All canisters were identical so that participants were not able to visually discern the variations in weights. The counterbalancing of different weights in three different locations reduced participants' ability to anticipate the weight of the next canister. Counterbalancing was necessary to minimize expectancy effects on pain ratings and weight estimates. Unlike previous research on temporal summation of pain, stimulus presentation was not completely unpredictable given that participants could infer that weights further away from the body might be more difficult to lift. Depending on the actual weight of the canister (e.g., light or heavy) in the furthest position, the participants' expectancies might be confirmed or disconfirmed. Also different from previous research on temporal summation of pain, participants proceeded through the task at their own pace as opposed to receiving noxious stimuli at intervals fixed by the experimenter. These procedural differences might have implications for the comparability of process mechanisms underlying temporal summation of pain and repetition-induced summation of pain.

2.4. Data reduction

Participants were classified as 'high' or 'low' fear of pain, 'high ' or 'low' pain catastrophizing and 'high' or 'low' depression based on a median split of scores on the TSK (median = 44), PCS (median = 24) and BDI-II (median = 13), respectively.

As described above, the lifting task required participants to lift 18 canisters arranged in six "columns" of three canisters. Each weight was represented within each column, thus equalizing columns in terms of total physical demands. For the purposes of this paper, the average pain ratings and weight estimates within "Column" were used as the units of analysis. Average lift duration and average duration of inter-lift rest periods were also computed for each "Column".

Indices of repetition-induced summation of pain were derived using two different approaches. In one approach, repetition-induced summation of pain was derived by subtracting mean pain ratings provided while lifting canisters in the 1st Column from mean pain ratings provided while lifting canisters in the 6th Column. Higher values on this index of repetition-induced summation of pain reflect greater increase in pain across successive lifts. This approach proceeds from the assumption that the pain experience across each of the Columns is identical. However, it is possible that the subjective experience of the physical demands might vary as a function of the order in which the different weights are lifted. For example, the subjective experience of physical demands for a Column where the heaviest weight occurs on the position furthest away from the body might differ from the subjective experience of physical demands when the lightest weight occurs in the furthest position. As such, a second approach was also used where for each weight in each position, the pain rating provided during the first occurrence of the specific position-weight combination was subtracted from the second occurrence of that position-weight combination. Subsequently, all the nine difference scores were summed. As with the first index, higher values reflect greater increase in pain over successive lifts. Similar indices were computed for weight estimates.

Both approaches to computing indices of repetition-induced summation of pain (and weight) yielded the same pattern of findings. In order to depict the changes in pain across successive lifts, and to maintain consistency with the analyses of repeated measures, findings using the first approach to derive the indices of repetition-induced summation of pain (and weight) are presented in Section 3.

The pain ratings and weight estimation data from the lifting task were initially analyzed as a four-way mixed factorial level with Level of fear/catastrophizing/depression (high, low), Sex (women, men) and Task order (pain rating first, weight estimation first) as between groups factors and Columns (1–6) as the within groups factor. Initial analyses revealed main effects for Task order such that pain ratings and weight estimates were significantly greater when the respective tasks were performed second. Task order interacted only with Level of fear, $F(1,82) = 4.0$, $p < .05$, where participants with high pain-related fear rated their pain as more intense when they performed the pain rating task after the weight estimation task. Results are presented separately for Level of fear, catastrophizing and depression, and Task order is not included as a factor in the analyses reported below. For the repeated measures analyses of variance, in cases where sphericity was violated, the Greenhouse–Geisser corrected F is also reported.

Regression analyses were conducted to address whether psychological influences on repetition-induced summation of pain could be accounted for by fatigue, rest, and work output.

3. Results

3.1. Sample characteristics

Mean scores on measures of condition-related pain severity (MPQ), mean activity-related pain (MARP), the index of repetition-induced summation of activity-related pain (IRISP), fear of movement/re-injury (TSK), catastrophizing (PCS), and depression (BDI-II) are presented in Table 1. Scores on MPQ, PCS, TSK, PCS and BDI-II are comparable to those that have been reported in previous research with CLBP patients [6,49].

3.2. Correlations among measures

Correlations among the different pain measures, namely the MPQ-PRI, MARP, and the IRISP, and the psychological variables (PCS, TSK, BDI-II) are presented in Table 2. Consistent with previous research, correlational analyses revealed considerable variance overlap among measures of pain catastrophizing, fear of pain, and depression. The MPQ-PRI was significantly correlated with the MARP, $r = .40$, $p < .01$. Interestingly, the MPQ-PRI was not significantly correlated with the IRISP. All three psychological measures correlated significantly with the MPQ-PRI and MARP. Of the three psychological measures, only the TSK correlated significantly with the IRISP, $r = .26$, $p < .05$. The correlation between the PCS and the IRISP failed to attain statistical significance, $p = .07$.

Table 2 shows that MARP was significantly correlated with the IRISP, $r = .23$, $p < .05$. However, Table 3 shows that the magnitude of this correlation varied as a function of Column. Through the first three columns of the trial, the relation between the IRISP and column-specific pain ratings was near-zero. By the last three canisters, the magnitude of the relation between the IRISP and Column 6 pain ratings was comparable to that between the MPQ-PRI and Column 6 pain ratings. Unlike the relation between the IRISP and column-specific pain ratings, which increased in magnitude across successive lifts, the relations between the MPQ-PRI, the psychological measures and column-specific pain remained relatively constant across successive lifts.

A regression analysis was conducted to examine the shared and unique contributions of the MPQ-PRI and the IRISP to the prediction of pain ratings provided for Column 6 of the trial. The results of this analysis revealed that 36% of the variance in Column 6 pain ratings could be accounted for by the MPQ-PRI and the IRISP,

Table 1
Means and standard deviations for pain severity and psychological variables.

Variable	Mean	SD
MPQ-PRI	27.68	15.31
MARP	3.90	2.48
IRISP	1.01	1.40
PCS	24.29	12.23
TSK	43.73	9.45
BDI-II	15.85	11.17

Note: $n = 90$. MPQ – PRI, McGill Pain Questionnaire – Pain Rating Index; MARP, mean activity-related pain; IRISP, index of repetition-induced summation of pain; PCS, Pain Catastrophizing Scale; TSK, Tampa Scale for Kinesiophobia; BDI, Beck Depression Inventory II.

Table 2
Correlations among pain indices and psychological variables.

	MPQ-PRI	MARP	IRISP	PCS	TSK
MPQ-PRI					
MARP	.42**				
IRISP	.08	.23*			
PCS	.48**	.46**	.19		
TSK	.30**	.36**	.26*	.61**	
BDI-II	.37**	.25*	.10	.60**	.44*

Note: $n = 90$. MPQ – PRI, McGill Pain Questionnaire – Pain Rating Index; MARP, mean activity-related pain; IRISP, index of repetition-induced summation of pain; PCS, Pain Catastrophizing Scale; TSK, Tampa Scale for Kinesiophobia; BDI, Beck Depression Inventory II.
* $p < .05$.
** $p < .01$.

Table 3
Correlations among pain indices and psychological measures across columns.

	Column-specific activity-related pain					
	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6
MPQ-PRI	.41**	.38**	.39**	.40**	.40**	.42**
IRISP	.08	.08	.19	.31**	.34**	.47**
PCS	.42**	.43**	.50**	.48**	.43**	.47**
TSK	.27**	.31**	.36**	.40**	.36**	.39**
BDI-II	.29**	.26*	.26*	.26*	.19	.20

Note: $n = 90$. Col 1 to Col 6 = mean pain ratings within column. MPQ – PRI = McGill Pain Questionnaire – Pain Rating Index; IRISP, index of repetition-induced summation of pain; PCS, Pain Catastrophizing Scale; TSK, Tampa Scale for Kinesiophobia; BDI, Beck Depression Inventory II.
* $p < .05$.
** $p < .01$.

$R = .60$, $F(2,87) = 24.9$, $p < .001$. The MPQ-PRI ($\beta = .38$, $p < .001$) and the IRISP ($\beta = .44$, $p < .001$) made significant independent contributions to prediction. The contributions of the MPQ-PRI and the IRISP remained significant even when controlling for the contribution of the PCS, TSK and BDI-II.

Correlations among pain indices, psychological measures, lift duration, inter-lift rest periods and weight estimates are presented in Table 4. Higher scores on the MPQ-PRI, MARP, but not on the IRISP were associated with longer rest periods between canisters lifts. High scores on the PCS, TSK, and the BDI-II were also associated with longer rest periods between canister lifts. Neither the pain indices nor the psychological measures were correlated with the duration of canister lifts. Only the IRISP was correlated with the mean weight estimates. The magnitude of these correlations remained essentially unchanged when examined across the six Columns.

3.3. Repetition-induced summation of pain

Separate repeated measures analyses of variance (ANOVA) were conducted to examine the influence of pain catastrophizing, fear of movement/re-injury and depression on activity-related pain across the six Columns of the lifting task. The results of the analyses are presented in Fig. 3. A main effect for Sex was obtained in these analyses where women rated their activity-related pain ($M_{\text{women}} = 4.4$, SD = 2.6) as more intense than men ($M_{\text{men}} = 3.1$, SD = 2.2), $F(1,88) = 6.9$, $p < .01$. Sex, however, did not interact significantly with Columns, and as such, analyses below are presented collapsed across sex.

A two-way (Level of catastrophizing × Columns) ANOVA revealed significant main effects for Level of catastrophizing, $F(1,88) = 9.2$, $p < .01$, and Columns, $F(5,440) = 18.8$, $p < .001$ (Greenhouse–Geisser corrected tests yielded identical results). The interaction term was not significant, $F(5,440) = .79$, ns. The first panel of Fig. 3 shows that high catastrophizers reported more intense activity-related pain than low catastrophizers, and that pain intensity increased over Columns.

A two-way (Level of depression × Columns) ANOVA revealed a significant main effect for Columns, $F(5,440) = 18.8$, $p < .001$ (Greenhouse–Geisser corrected tests yielded identical results). The main effect for Level of depression, $F(1,88) = 2.7$, ns, and the interaction term, $F(5,440) = .57$, ns, failed to attain statistical significance.

A two-way (Level of fear × Columns) ANOVA revealed significant main effects for Level of fear, $F(1,88) = 4.7$, $p < .05$, and Columns, $F(5,440) = 18.8$, $p < .001$. The main effects were qualified

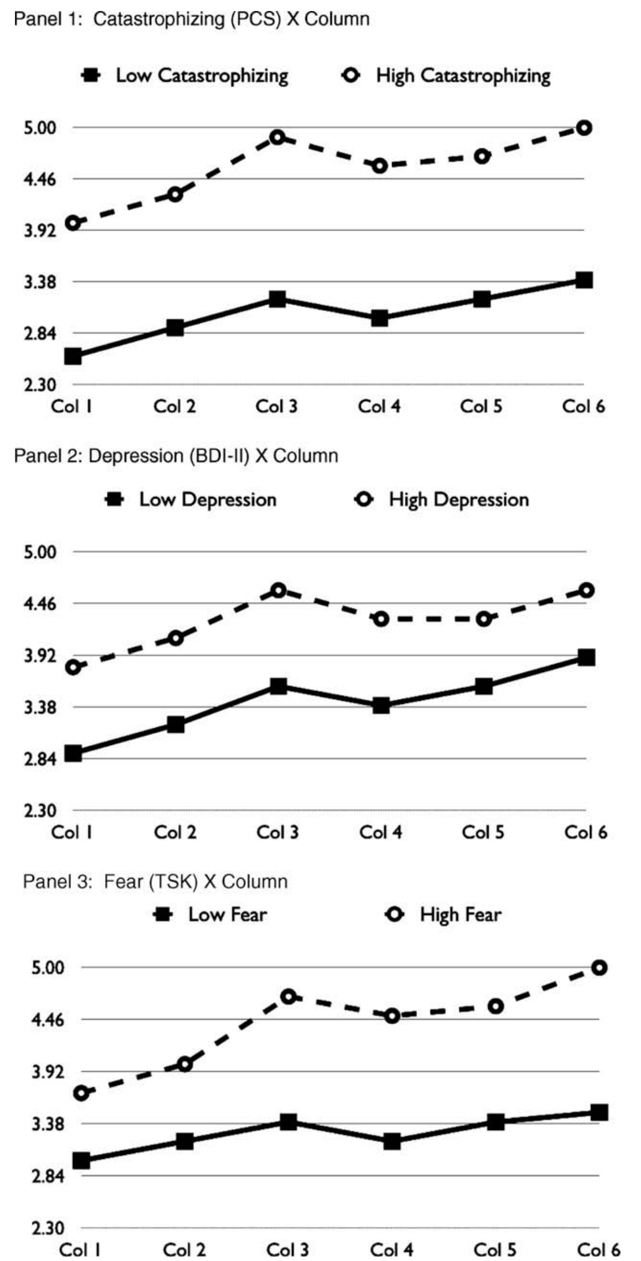

Fig. 3. Psychological influences on repetition-induced summation of activity-related pain. *Note:* Col 1 to Col 6 = Mean pain ratings provided while lifting canisters in each column. PCS, Pain Catastrophizing Scale; TSK, Tampa Scale for Kinesiophobia; BDI-II, Beck Depression Inventory II.

Table 4
Correlations between pain indices, psychological measures and task performance parameters.

	Lift duration	Rest periods	Weight estimates
MPQ-PRI	.04	.22*	.17
MARP	.12	.48**	.07
IRISP	−.11	.01	.23*
PCS	−.05	.38**	.12
TSK	.09	.38**	.01
BDI-II	.02	.37**	.05

Note: $n = 90$: Lift duration = mean lift duration across lifts during the pain rating trial; Rest periods = mean duration of inter-lift interval during the pain rating trial; Weight estimates = mean weight estimates provided during the weight estimation trial. MPQ – PRI, McGill Pain Questionnaire – Pain Rating Index; MARP, mean activity-related pain; IRISP, index of repetition-induced summation of pain; PCS, Pain Catastrophizing Scale; TSK, Tampa Scale for Kinesiophobia; BDI, Beck Depression Inventory II.
* $p < .05$.
** $p < .01$.

by a significant Level of fear by Columns interaction, $F(5,440) = 4.7$, $p < .001$ (Greenhouse–Geisser, $F(2.7,236.3) = 5.1$, $p < .01$). The third panel of Fig. 3 shows that high fearful participants reported more intense pain than low fearful participants. Pain intensity ratings increased to a greater extent over Columns for high fearful participants compared to low fearful participants.

A series of two-way ANOVAs were conducted in order to examine whether the work output of performing the lifting task also showed a repetition-induced summation effect and varied according to Level of catastrophizing, depression or fear. As shown in Table 5, work output decreased over the six Columns of the lifting task, $F(5,440) = 14.4$, $p < .001$. Main effects for Level of castrophizing, $F(1,88) = 2.1$, $p = .14$, Level of depression, $F(1,88) = 3.0$, $p = .08$, and Level of fear, $F(1,88) = 1.5$, $p = .22$, failed to attain statistical significance. There were no significant interaction effects.

3.4. Repetition-induced summation of weight estimates

Separate three-way (Level of catastrophizing/depression/fear × Sex × Columns) repeated measures ANOVAs were conducted to examine changes in weight estimates across Columns as a function of Level of catastrophizing, depression, fear and Sex. In these analyses, Sex did not interact with Columns, and as such, means are presented summed across Sex. These results are presented in Table 6.

Two-way ANOVAs for Level of depression and Level of catastrophizing revealed only a significant main effect for Columns, $F(5,440) = 21.4$, $p < .001$. As shown in Table 6, weight estimates increased across Columns.

A two-way (Level of fear × Columns) ANOVA revealed significant main effects for Columns, $F(5,440) = 21.4$, $p < .001$, and a significant Level of fear by Columns interaction, $F(5,440) = 2.1$, $p < .05$. The main effect for Level of fear was not significant, $F(1,88) = 1.1$, ns.

Table 5
Work output associated with performance of the lifting task.

	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6
Catastrophizing						
Low ($n = 44$)	3.2 (1.7)	2.5 (1.6)	2.4 (1.9)	2.0 (1.0)	2.1 (1.1)	2.2 (.9)
High ($n = 46$)	2.7 (2.5)	2.1 (1.4)	1.9 (1.2)	1.7 (1.6)	1.7 (1.1)	1.8 (1.2)
Depression						
Low ($n = 46$)	3.1 (2.3)	2.5 (1.8)	2.4 (1.9)	2.0 (1.6)	2.2 (1.3)	2.2 (1.2)
High ($n = 44$)	2.8 (2.0)	2.1 (1.1)	1.9 (1.1)	1.7 (.9)	1.6 (.9)	1.8 (.9)
Fear of pain						
Low ($n = 45$)	3.2 (2.0)	2.4 (1.4)	2.4 (1.9)	2.0 (1.0)	2.1 (.9)	2.1 (.9)
High ($n = 45$)	2.7 (2.3)	2.2 (1.6)	1.9 (1.1)	1.8 (1.5)	1.8 (1.4)	1.8 (1.2)

Note: Work output was computed by dividing lift duration by the duration of rest periods between each lift.

Table 6
Repetition-induced summation of weight estimates.

	Col 1	Col 2	Col 3	Col 4	Col 5	Col 6
Catastrophizing						
Low	3.0 (3.0)	3.6 (3.5)	4.1 (3.9)	3.5 (3.7)	4.0 (4.1)	4.2 (4.5)
High	2.9 (2.4)	3.3 (2.8)	3.7 (3.3)	3.4 (3.7)	3.6 (2.7)	3.9 (3.0)
Fear of pain						
Low	2.8 (2.4)	3.2 (2.8)	3.6 (3.2)	3.0 (2.6)	3.3 (3.0)	3.6 (3.2)
High	3.2 (2.9)	3.7 (3.5)	4.2 (4.0)	3.9 (4.5)	4.3 (3.8)	4.5 (4.3)
Depression						
Low	2.8 (2.7)	3.4 (3.2)	3.7 (3.6)	3.4 (3.5)	3.8 (3.9)	4.2 (4.3)
High	3.2 (2.7)	3.5 (3.1)	4.1 (3.7)	3.6 (3.8)	3.8 (2.9)	4.1 (3.3)

Note: $n = 90$. Weights estimates are in metric units (kg).

3.5. Potential mediators of the relation between fear and repetition-induced summation of activity-related pain

Two multiple regression analyses were conducted to examine the degree to which repetition-induced summation of pain in high fear participants was due to increased work output or changes in the perception of the weight of the canisters across Columns. The intent of these analyses was to determine if repetition-induced summation of weights estimates, used here as a proxy for increasing fatigue, mediated the relation between fear and repetition-induced summation of pain. For these analyses, an index of work output was computed by subtracting Column 1 work output from Column 6 work output, and an index of repetition-induced summation of weight estimates was computed by subtracting Column 1 weight estimates from Column 6 weight estimates. The index of repetition-induced summation of pain was significantly correlated with the index of repetition-induced summation of weight estimates, $r = .24$, $p < .05$, but was not significantly correlated with the index of work output, $r = -.15$, ns. As such, only the index of repetition-induced summation of weight estimates met criteria for a test of mediation.

In the first regression analysis, the IRISP was used as the dependent variable and Level of fear was used as the independent variable. This analysis revealed that Level of fear was a significant predictor of IRISP, $\beta = .27$, $p < .01$. In the second analysis, the index of repetition-induced summation of weight estimates was entered in the first step of a hierarchical regression, and, it contributed significantly to the prediction of IRISP, $R^2 = .05$, $F(1,88) = 4.9$, $p < .05$. Level of fear was entered in the second step of the analysis, and contributed significant variance to the prediction of IRISP, beyond the variance accounted for by repetition-induced summation of weight estimates, R^2 change = .06, $F(2,87) = 5.5$, $p < .01$. Examination of the beta weights for the final regression analysis revealed that the contribution of Level of fear, $\beta = .25$, $p < .01$, was only slightly reduced by the inclusion of repetition-induced summation of weight estimates in the analysis. These findings suggest that the contribution of Level of Fear to the prediction of IRISP is largely independent of repetition-induced summation of weight estimates.

4. Discussion

Consistent with previous research, analyses revealed that pain catastrophizing, fear of movement and depression were significantly correlated with the MPQ-PRI [14,45,50]. Psychological measures were also correlated with mean activity-related pain. Pain catastrophizing emerged as the strongest predictor of condition-related pain (i.e., MPQ-PRI) and activity-related pain (i.e., MARP). Of interest was that the MPQ-PRI was not correlated with the IRISP. The IRISP was correlated with MARP, but this relation varied as a function of task stage; the relation was only significant for pain ratings provided for the last nine lifts (i.e., 3 columns) of the trial.

A regression analysis was computed to assess the shared and unique contributions of the MPQ-PRI (i.e., condition-related pain) and the IRISP to the prediction of pain ratings for Column 6 of the trial. In this analysis, pain during Column 6 of the trial was used as an analog for pain that might be experienced in the context of repeated occupational activity. In this analysis, the MPQ-PRI and the IRISP made significant unique contributions to the prediction of activity-related pain. The predictive power of the regression equation was more than doubled by the inclusion of IRISP. The latter finding suggests that static measures of condition-related pain severity (i.e., MPQ-PRI), and changes in pain severity across repeated activity represent independent dimensions of pain experience. In addition, the findings suggest that considering both measures of pain provides better prediction of the degree of pain that an individual will experience during repeated physical activity than either measure alone.

The substantive increases in activity-related pain observed across successive lifts might be relevant to problems that many pain patients experience during the resumption of their occupational activities. The mean pain ratings provided by participants rose from 3.3 in Trial 1 to 4.3 in Trial 6. Although pain increased only 1 point on a 10-point scale, it represents nevertheless a 30% increase from initial pain ratings. A 30% increase in pain would be considered clinically meaningful [30]. For patients with high fear of movement, pain ratings increased from 3.7 in Trial 1 to 5.0 in Trial 6, representing a 35% increase in pain, compared to a 16% increase in pain for patients with low fear of pain. Given that the lifting task takes approximately 3 min to complete, much larger increases might occur over the course of hours of participation in typical domestic or occupational activities.

The findings of the present study are consistent with anecdotal reports of progressively increasing pain upon return to occupational activities [37]. Research also suggests that if an individual is not able to maintain employment, discontinuation of work is likely to occur within one month of work resumption [5,7,57]. If repetition-induced summation of pain is a contributor to failure to maintain work involvement, the present findings suggest that the negative impact of repetition-induced summation of pain might occur shortly following resumption of occupational activities. An important question for future research is whether the IRISP prospectively predicts problems with work retention.

In previous research, temporal summation of pain has been discussed as a central sensitization phenomenon [33,40]. In animals, research suggests that temporal summation occurs centrally in second-order neurons in the spinal cord as a consequence of sustained C-fiber afferent input [20,32]. In humans, it has been suggested that the modulation of temporal summation might also involve the activity of descending pain-inhibitory systems [33]. It has been suggested that psychological factors, such as catastrophizing, fear or anxiety, might augment temporal summation of pain by interfering with descending pain-inhibitory systems, or by increasing sensitization of brain areas involved in the modulation of the affective components of pain [9,38]. It is possible that similar mechanisms might be implicated in the relation between fear and repetition-induced summation of pain.

In previous research, temporal summation of thermal pain has been demonstrated with standard stimulus intervals of approximately 3 s, and stimulus presentation of approximately 1 s [33,39]. In the present study, participants varied according to the duration of canister lifts (i.e., stimulus presentation) and the rest periods in between canisters lifts (i.e., stimulus intervals). The average canister lift was 3.5 s (SD = 1.7) and the average rest period between lifts was 2.1 s (SD = 1.1). It is unclear whether these stimulus parameter differences might have implications for the nature of the central mechanisms underlying temporal summation of activity-related pain.

To date, animal and human studies have not identified any peripheral mechanisms that can effectively account for observed temporal summation effects [58]. In patients with low back pain, it has been difficult to identify peripheral mechanisms of activity-related pain primarily due to the challenges of recording direct activation of muscle nociceptors [2]. There are grounds, however, for considering the influence of peripheral mechanisms in repetition-induced summation of activity-related pain [29,38].

Intense exercise has been associated with the release of bradykinin and prostaglandins [2]. Bradykinin can directly stimulate muscle nociceptors, and prostaglandins have been shown to prolong the duration of bradykinin effects on muscle nociceptors [24]. Exercise can also result in hydrogen ion accumulation which can stimulate bradykinin release or act directly on small and large diameter afferents [28]. These mechanisms contribute to the soreness experienced following bouts of sustained strenuous activity [28].

Prostaglandins, bradikinin and hydrogen ions can also build up during less intense tasks [28]. Repeated or sustained muscle contractions, even of relatively low intensity, can lead to focal areas of ischemia in the muscles, which are hypothesized to have the potential to produce muscle pain [18]. Although ischemia per se is not painful, when combined with a muscle contraction, ischemia hampers the wash-out of metabolic by-products of muscle contraction [27,28]. Progressively increasing accumulation of these chemicals in the muscle tissue could yield progressively increasing pain sensation through direct and prolonged stimulation of nociceptors. The relation between muscle ischemia and fatigue might explain why pain patients' weight estimates increased over Columns [17]. As would be expected from this line of reasoning, the index of repetition-induced summation of pain was significantly correlated with the index of repetition-induced summation of weight estimates.

A number of studies have reported relations between fear of pain and muscle activation alterations during movement [12,22]. It has been suggested that individuals with chronic pain might be prone to sustained co-contraction of antagonist muscle groups in order to minimize movement of painful areas of the body [12,22]. In previous research, the threat of painful cutaneous electrical stimulations, has been shown to produce co-contraction patterns of the trunk muscles [25,26]. Greater co-contraction associated with pain-related fears might have led to irritation of musculoskeletal tissues of the spine resulting in increased pain over time [10,38].

Another possibility is that localized muscle ischemia and fatigue might have increased more rapidly for the group reporting higher fear of pain. Increased trunk muscle co-contraction due to fear might also contribute to muscle fatigue [10]. However, the multivariate statistical analysis showed that the relation between fear and repetition-induced summation of pain remained significant even when controlling for the repetition-induced summation of weight estimates. Additional analyses also showed that repetition-induced changes in work output did not account for the relation between fear and repetition-induced summation of pain. It is important to consider, however, that only indirect measures of muscle fatigue were used.

Caution must be exercised in the interpretation of the present findings. First, the present study did not replicate previous research showing a relation between catastrophizing, sex and summation of pain [9]. It is possible that the central mechanisms responsible for temporal summation of thermal or pressure stimuli might be distinct from those responsible for repetition-induced summation of pain. The interpretation of the results of the present study is also limited by the lack of direct measures of muscle ischemia and fatigue and by the lack of the localisation of pain sensations (back and/or shoulders).

In spite of these limitations, the findings suggest that static measures of pain and changes in pain over repeated activity might represent independent dimensions of pain experience. The findings also show that repeated non-aerobic activity of low to moderate intensity in participants with CLBP leads to progressively increasing pain severity. High levels of fear of movement appeared to augment repetition-induced summation of pain. To our knowledge, this is the first study to report evidence of psychological influences on summation of pain in patients with CLBP as a function of repeated physical activity. Although the mechanisms responsible for the relation between fear and repetition-induced summation of pain were not elucidated by this study, the findings nevertheless point to possible neurophysiological mechanisms that could help explain why fear of pain is such a robust predictor of pain-related disability. Future research will need to examine the prognostic value of indices of repetition-induced summation of pain for trajectories of recovery following musculoskeletal injury. Future research in this area will also need to address more directly the mechanisms that underlie repetition-induced summation of pain.

Acknowledgements

The authors thank Danica Layton, Nicole Davidson, and Beatrice Garfinkel for their assistance in data coding and data entry. This research was supported by grants from the Institut de recherche Robert-Sauvé en santé et en sécurité du travail (IRSST) and the Canadian Institutes of Health Research. None of the authors has any financial interests associated with the results of this study.

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