



Validation of an index of Sensitivity to Movement-Evoked Pain in patients with whiplash injuries

Alan K. Wan^a, Pierre Rainville^b, Shaun O'Leary^a, Rachel A. Elphinston^c, Michele Sterling^c, Christian Larivière^d, Michael J.L. Sullivan^{e,*}

Abstract

Introduction: Sensitivity to Movement-Evoked Pain is a pain summation phenomenon identified in various chronic pain populations.

Objectives: This study investigated the validity of a procedure used to assess pain summation in response to a repeated lifting task in individuals with whiplash injuries.

Methods: Sixty-five participants completed measures of pain severity and duration, Temporal Summation (TS) of pinprick pain, pain catastrophizing and fear of movement, and work-related disability before lifting a series of 18 weighted canisters. An index of Sensitivity to Movement-Evoked Pain was computed as the increase in pain reported by participants over successive lifts of the weighted canisters. An index of TS was computed by dividing the pain reported in response to the final pinprick by the pain reported in response to the 1st pinprick in a train of 10 pinpricks.

Results: Analyses replicated previous findings showing a repetitive lifting task-induced pain summation in approximately 20% to 25% of a sample of individuals with whiplash injuries. Analyses also revealed significant correlations between SMEP, TS, and pain-related psychological variables. Hierarchical regression analyses showed that TS and pain catastrophizing made significant unique contributions to the prediction of SMEP. These findings join a growing body of research on movement-evoked pain in persistent spinal pain conditions.

Conclusion: The repeated lifting task used in this study successfully induced pain summation in a group of patients with whiplash injuries.

Keywords: Whiplash, Movement-Evoked Pain, Temporal Summation of pain

1. Introduction

Evoked pain refers to pain that is experienced in response to a specific noxious stimulus (eg, heat, cold, and pressure).³⁰ Evoked pain is distinguished from spontaneous pain, which is the term used to refer to the pain experienced by patients with

persistent pain conditions in the absence of specific noxious stimulation (eg, condition-related pain).^{18,34} There is growing interest in examining the response to repeated noxious stimulation in individuals with persistent pain conditions.^{2,31,35,47} There is increasing evidence that changes in pain in response to repeated noxious stimulation might represent a dimension of pain experience that is distinct, both in terms of mechanisms and prognostic value, from measures of spontaneous pain.^{1,31,47} There are indications that individuals who experience increasing pain as a function of repeated noxious stimulation may be at greater risk for a wide range of adverse pain outcomes.^{15,47}

Typical methods of assessing this sensitivity to repeated noxious stimulation include the assessment of Temporal Summation (TS) of pain. Temporal Summation of pain describes the progressive increase in reported pain intensity as a function of repeated noxious stimulation (eg, thermal, electrical, and mechanical).^{1,5,6,12,45} Enhanced TS has been observed in chronic pain conditions in which the pathophysiology of the disorder is believed to involve a maladaptive degree of central sensitization to pain (eg, fibromyalgia and some temporomandibular joint disorders).³⁶ Temporal Summation is considered to be a centrally driven phenomenon, maintained as a consequence of sustained C-fiber-afferent input.^{30,36} Pain catastrophizing and pain-related fears have also been shown to contribute to TS of pain.^{7,15}

Sponsorships or competing interests that may be relevant to content are disclosed at the end of this article.

^a Department of Physiotherapy, The University of Queensland, Brisbane, Queensland, Australia, ^b Département de Stomatologie, Université de Montréal, Montréal, QC, Canada, ^c Recover Injury Research Centre, The University of Queensland, Brisbane, Queensland, Australia, ^d Occupational Health and Safety, Research Institute Robert-Sauvé, Montréal, QC, Canada, ^e Department of Psychology, McGill University, Montréal, QC, Canada

*Corresponding author. Address: Department of Psychology, McGill University, 2001 McGill College, Montreal, QC H3A 1G1, Canada. Tel.: +1 514 512 7246; fax: +1 514 398 4896. E-mail address: michael.sullivan@mcgill.ca (M.J.L. Sullivan).

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Over the past decade, several studies have identified and described a phenomenon termed “Sensitivity to Movement-Evoked Pain” (SMEP).^{39–41} Sensitivity to Movement-Evoked Pain refers to an increase in pain in response to repeated physical activity such as repetitive lifting.^{26,39,40} Sensitivity to Movement-Evoked Pain has been associated with poor physical recovery and chronicity of symptoms.^{26,39,40} Individuals with whiplash injuries who show enhanced SMEP report greater functional limitations and are more likely to be occupationally disabled.²⁷

Compared to the typical methods of assessing pain sensitivity (ie, TS of pain), the SMEP procedure presents increased ecological validity by assessing natural pain reactions in response to repeated functional movements of the painful body region. The primary purpose of this study was to further validate the procedure used to assess SMEP in a sample of individuals with neck pain after whiplash injuries by (1) assessing whether the protocol induced pain summation in individuals with whiplash; (2) assessing the relationship between SMEP and clinical presentation (ie, pain severity, symptom duration, and work disability); (3) testing whether an index of SMEP correlated with another pain summation measure (ie, TS of pain); and (4) determining the relationship of SMEP scores to the psychological cofactors of pain perception (ie, pain catastrophizing and fear of movement).

2. Methods

2.1. Participants

Sixty-five individuals (15 women and 50 men) with whiplash injuries participated in the study. Individuals responded to advertisements placed in a physical rehabilitation clinic in Nelson, British Columbia, Canada. The mean age of the sample was 46.0 years with a range of 23 to 67 years. The mean time since injury was 7.8 months with a range of 2 to 24 months. All participants were employed at the time of their injury. Approximately half of the sample (57%) was work-disabled at the time of testing.

2.2. Procedures and apparatus

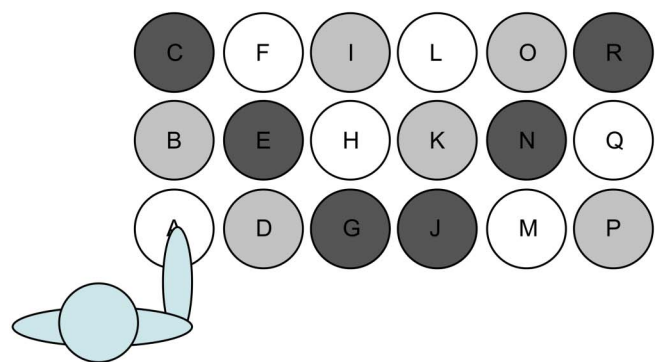
This research was approved by the Institutional Review Board of McGill University. Participants were told that the goal of the study was to examine different aspects of pain experience associated with whiplash injury. They were familiarized with the measures and procedures of the study. They were also informed that, because of the nature of the measurements, testing would lead to a transient increase in discomfort. Participants were also told that they were free to discontinue testing at any point.

On arrival at the laboratory, participants first completed the self-report measures of pain duration and spontaneous pain and pain-related psychological variables as well as a demographic information form. Participants then completed the tasks required to derive indices of SMEP and TS. The order of completion of the tasks used to assess movement-evoked pain and pinprick TS was counterbalanced. Spontaneous pain levels were required to return to baseline between the 2 procedures.

2.2.1. Movement-evoked pain measures

Participants were asked to perform a simulated occupational lifting task designed to assess movement-evoked pain. In this task, participants stood in front of a height-adjustable table and lifted and replaced a series of 18 weighted canisters. The canisters weighed 2.9, 3.4, or 3.9 kg and were arranged on the

table in 3 rows of 6 columns. The 3 canister weights were arranged such that each weight was represented twice in each location of a double Latin square. This counterbalancing strategy was used to reduce participants' ability to anticipate the weight of the canisters (Fig. 1). The height of the table was adjusted for each participant such that the handle of the canisters in front row (ie, closest to the participant) was at standing elbow height. The locations of the canisters corresponded to 3 functional anthropometric reach positions: normal, maximum, and extreme; (1) in the normal reach position (ie, first row of canisters), participants stood straight with their elbow bent at 90° (position 1); (2) in the maximum reach position (ie, second row of canisters), participants stood straight with their arm fully extended (position 2); (3) in the extreme reach condition (ie, the third row of canisters), participants were forward flexed with their arm fully extended (position 3). In other research, it has been estimated that the mean net moments (ie, force × distance corresponding to the weight and body segments) are approximately equivalent across columns, varying from 17.3 to 17.9 Nm at the shoulder and from 34.0 to 35.0 Nm at the back (L4/L5 joint).³ The corresponding mean percentage of strength estimates varies from 40.3% to 41.5% at the shoulder and from 20.2% to 20.7% at the back.



Participant starting position

Weight 2.9kg = canisters C, E, G, J, N, R ●
 Weight 3.4kg = canisters B, D, I, K, O, P ●
 Weight 3.9kg = canisters A, F, H, L, M, Q ○

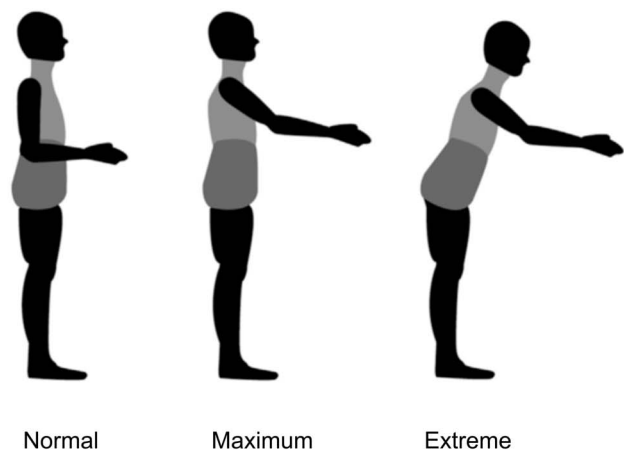


Figure 1. Canister positions, weight, lift sequence, and approximate reach postures associated with canister lifting from the 3 different rows.

All canisters were identical in appearance. The tops of all canisters were labeled with the letters A to R, and participants were asked to lift and replace each canister in alphabetical sequence (column 1 [A–C], column 2 [D–F], etc.), to a height of approximately 5 cm, for approximately 3 seconds. Participants were asked to provide verbal ratings of their pain as they lifted each canister. The lifting procedure was modeled for the participants to minimize interparticipant variation in approach to the task. Participants were asked to proceed through the task at their own pace.

2.2.2. Pinprick pain measures

Pinprick stimuli were administered using a Neuropen with 40-g tips. Capsaicin cream was applied to a 3-cm square area on the volar surface of each forearm. Fifteen minutes after application of the capsaicin cream, a train of 10 stimuli with the Neuropen were subsequently given at 1-second intervals. The participants were asked to give a verbal pain rating after the 1st and 10th stimuli. The ten stimuli trains were administered twice to each forearm. The application of capsaicin to the skin is known to increase the painfulness of suprathreshold stimuli (ie, noxious pinprick pressure applied by the Neuropen). Previous research has shown that the gain of wind-up of pain induced by repeated noxious stimulus remains unchanged after the application of intradermal capsaicin.²⁴

2.3. Measures

2.3.1. Numerical Rating Scale

Participants provided their pain ratings on a 11-point (0–10) Numerical Rating Scale (NRS) with endpoints (0) no pain and (10) excruciating pain.

2.3.2. Spontaneous pain

At the start of the session, participants provided a rating of their current pain severity on a 11-point (0–10) NRS with endpoints (0) no pain and (10) excruciating pain.

2.3.3. Mean movement-evoked pain

Participants provided their pain ratings on the NRS immediately after they lifted each of the 18 weighted canisters. The mean of the movement-evoked pain across the 18 lifts was computed. Higher values reflect greater average pain ratings.

2.3.4. Index of Sensitivity to Movement-Evoked Pain

Participants provided their pain ratings on the NRS immediately after they lifted each of the 18 weighted canisters. The index of SMEP was computed by subtracting mean pain ratings provided for the first 3 lifts from the mean pain ratings provided for the last 3 lifts of the 18 canisters. Higher values reflect greater increase in pain across successive lifts.

2.3.5. Mean pinprick pain

Participants provided verbal ratings on the NRS after the 1st and 10th stimulation with the Neuropen, delivered at 1-second intervals. The mean of the pinprick pain ratings was calculated using the pain ratings for the 1st and 10th pinpricks for both the dominant and nondominant arms across the 2 trials.

2.3.6. Temporal Summation of pinprick pain (Temporal Summation Index)

Participants provided verbal pain ratings on the NRS after the 1st and 10th stimulation with the Neuropen, delivered at 1-second intervals. The pinprick wind-up ratio (TS Index) was computed by dividing the pain rating provided in response to the 10th Neuropen stimulation by the pain rating provided in response to the 1st Neuropen stimulation. Higher values reflect greater increase in pain across successive stimulations.

2.3.7. McGill Pain Questionnaire

The McGill Pain Questionnaire (MPQ) was used as a measure of spontaneous pain associated with participants' whiplash injury.²⁵ On this measure, participants are asked to endorse the adjectives that best describe their pain experience. The MPQ Pain Rating Index (PRI) was computed as the weighted sum of all adjectives endorsed. The MPQ-PRI has been demonstrated to be a reliable and valid measure of chronic pain experience.⁴⁴

2.3.8. Catastrophizing

The Pain Catastrophizing Scale (PCS)⁴³ was used to assess catastrophic thinking related to pain. On this measure, respondents rate the frequency with which they experience each of 13 different thoughts and feelings when in pain. The PCS has been shown to have high internal consistency (coefficient alpha = 0.87) and to be associated with pain experience, pain behavior, and disability.³⁸

2.3.9. Fear of movement/reinjury

The Tampa Scale for Kinesiophobia (TSK)²² was used to assess fear of movement and reinjury associated with pain. On this measure, respondents indicate 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 = 0.77)⁴⁶ and significantly correlated with measures of disability.¹⁴

2.3.10. Work disability

Employment status at the time of testing was categorized as unemployed, employed part-time, or employed full-time. Participants who reported being employed full-time or part-time were grouped into a single "employed" category. Work disability was defined as a current status of unemployment.

2.4. Data analytic approach

SPSS 24 (SPSS, Inc, Chicago, IL) was used for all statistical analyses. Mean values and SDs were computed for all pain measures and pain-related variables as well as distribution characteristics. Independent sample *t* tests were used to identify any sex differences for all variables.

Pearson correlations were conducted to assess the relationships between the key study variables (SMEP Index, TS Index, and other pain-related variables including pain severity, pain duration, and pain-related psychological variables). To assess the contribution of TS and pain-related psychological variables to the prediction of SMEP, hierarchical regression analyses were conducted. Variance inflation factors for variables included in the regression analyses ranged from 1.0 to 1.42, and tolerance

levels were all above 0.7, suggesting that the regression results were not adversely affected by multicollinearity.

3. Results

3.1. Sample characteristics

Table 1 presents the mean values and SDs on demographic and pain-related variables for men and women. T tests for independent samples revealed no significant sex differences for age, body mass index, education, pain duration, spontaneous pain, or any of the evoked pain measures ($P > 0.05$). Mean time since injury was similar to previous studies on pain summation after whiplash injuries,^{26,39} but overall clinical severity (ie, MPQ-PRI scores and mean movement-evoked pain scores) was lower (by greater than 1 SD) in the current sample than in samples investigated in past studies.^{26,39} Scores on the indices of SMEP and TS, however, were similar (within 1 SD) to those which have been reported in previous research addressing pain summation in patients with persistent pain.^{25,26,39} Scores on measures of catastrophizing and fear of movement were also similar to those reported in previous pain summation research.^{4,40}

3.2. Induction of pain summation during Sensitivity to Movement-Evoked Pain and Temporal Summation protocols

Figure 2 shows the change in mean pain across the 2 pain summation protocols. Paired sample *t* tests were performed for each test, with analyses revealing a significant increase in pain severity between the first and last stimuli of both the mechanical TS protocol and the SMEP protocol. An increase of 2 points or greater on the visual analogue scale over the course of the 18 lifts was considered a significant change. This cut-off value was determined based on previously reported values for minimum clinically significant difference in visual analogue scale pain scores (12mm on a 100mm scale, 95% CI 9mm to 15mm²¹ and 13mm

on a 100mm scale, 95% CI 10mm to 16mm¹³). Of the 65 participants, 15 (23%) reported an increase in pain of 2 points or greater. The proportion of the sample that experienced pain summation is similar to that which has been reported in an earlier study on activity-related summation of pain in individuals with whiplash injuries.³⁹

3.3. Correlates of key study variables

Table 2 shows the relationships among study variables. Higher scores on the SMEP Index were associated with higher scores on the TS Index ($r = 0.458, P < 0.001$) (**Fig. 3**), longer pain duration ($r = 0.550, P < 0.001$), higher scores on the PCS ($r = 0.513, P < 0.001$), and higher scores on the TSK ($r = 0.375, P = 0.003$). Higher scores on the TS Index were associated with longer pain duration ($r = 0.259, P = 0.048$) and current work disability ($r = -0.301, P = 0.021$). The TS index was not significantly correlated with the PCS ($r = 0.221, P = \text{ns}$) or the TSK ($r = 0.083, P = \text{ns}$). The SMEP Index was not significantly correlated with work disability in the present sample ($r = -0.183, P = \text{ns}$).

3.4. Regression analysis examining predictors of Sensitivity to Movement-Evoked Pain

Hierarchical regression analyses were conducted to examine the predictive value of TS and pain-related psychological variables for SMEP scores. For the regression, TS Index was entered in the first step of the analysis, and pain catastrophizing and fear of movement were entered in the second step. This order was chosen to allow for examination of the unique contribution of TS and psychological cofactors of pain in the variance observed in SMEP scores.

The results of the hierarchical regression are presented in **Table 3**. The first step of the regression predicted 19.4% of variance in SMEP. The inclusion of pain catastrophizing and fear of movement contributed a further 16.3% of the variance in SMEP

Table 1
Mean values and SDs on demographic and pain-related variables.

| Variables | Male (n = 50) | Female (n = 15) | P |
|----------------------------------|---------------|-----------------|-------|
| Age | 45.7 (9.2) | 46.9 (9.6) | 0.660 |
| BMI | 27.3 (4.6) | 25 (3.5) | 0.072 |
| Education (y) | 13.3 (2) | 13.1 (2.3) | 0.807 |
| Preinjury occupation | | | |
| Laborer | 29 | 2 | |
| Nursing | 4 | 5 | |
| Admin/clerical | 4 | 2 | |
| Technical | 6 | 1 | |
| Sales | 7 | 5 | |
| Pain duration (mo) | 7.3 (5.5) | 9.7 (6.5) | 0.146 |
| Spontaneous pain NRS (0–10) | 3.2 (1.5) | 3.5 (2.4) | 0.665 |
| MPQ-PRI | 13.1 (8.5) | 14.1 (12.3) | 0.708 |
| Pain catastrophizing | 17.9 (11.2) | 17.6 (11.9) | 0.919 |
| Fear of movement | 38.9 (8.6) | 35.6 (11.8) | 0.249 |
| Mean movement-evoked pain (0–10) | 1.7 (1.5) | 2.2 (1.6) | 0.296 |
| Mean pinprick pain (0–10) | 1.9 (1.3) | 2.3 (1.3) | 0.410 |
| SMEP Index | 1.1 (1.4) | 1.2 (1.6) | 0.954 |
| TS Index | 2.8 (1.6) | 3.7 (2.1) | 0.093 |

Values in parentheses are SDs. Significance tests are 2-tailed.

BMI, body mass index; MPQ-PRI, McGill Pain Questionnaire Pain Rating Index; NRS, Numerical Rating Scale; SMEP, Sensitivity to Movement-Evoked Pain; TS, Temporal Summation.

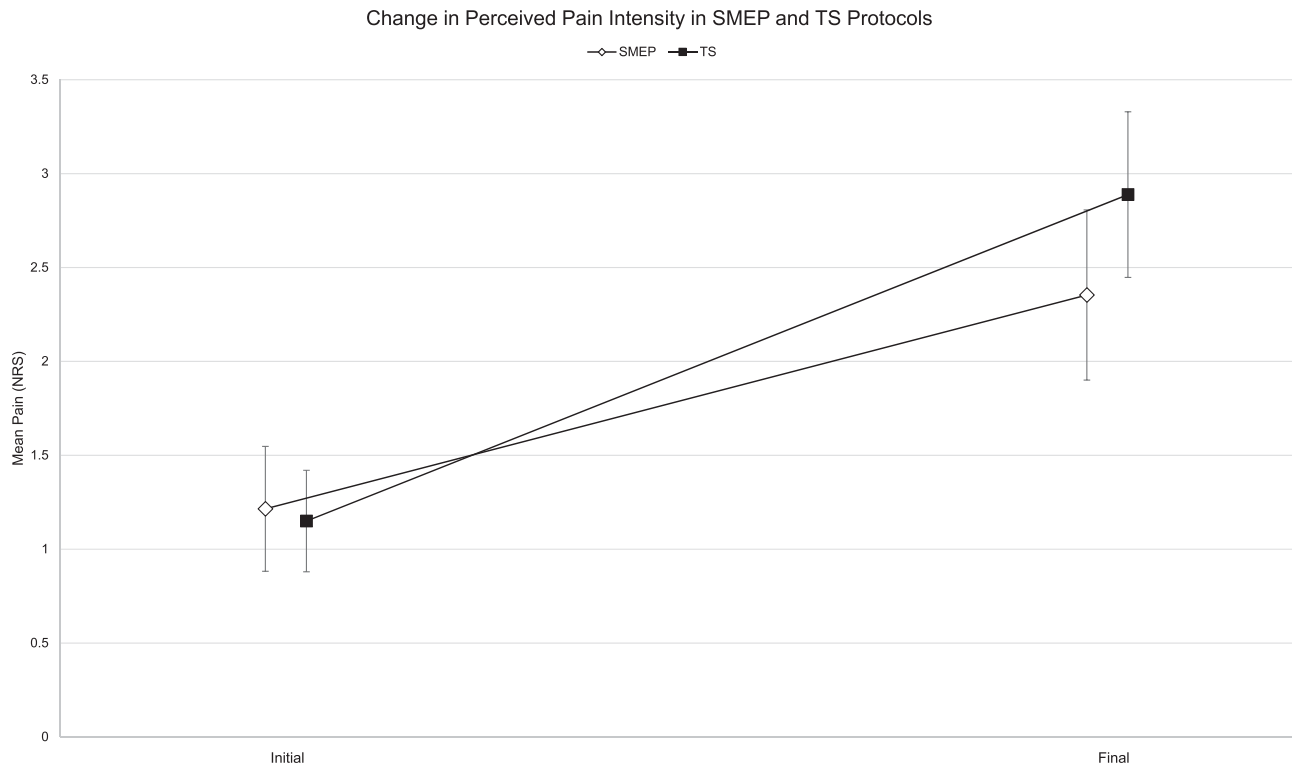


Figure 2. Changes in pain from the initial to final stimulus in the SMEP and TS protocols. SMEP, Sensitivity to Movement-Evoked Pain; TS, Temporal Summation.

scores. In the final regression, only the TS Index and pain catastrophizing remained significant predictors of SMEP.

4. Discussion

The primary objective of this research was to provide further validation of a standardized repeated lifting task as a method of inducing and evaluating pain summation in individuals with neck pain associated with whiplash injuries. The findings replicate previous research in showing that a proportion of individuals with persistent musculoskeletal pain experience increasing pain in response to repeated physical activity, even when physical demands are kept constant.^{26,39} The findings also replicate

previous research showing significant relationships between pain duration and SMEP as well as between pain-related psychological variables and SMEP.^{39,41} Finally, the findings extend previous research in showing that TS and pain catastrophizing contribute unique variance to the prediction of SMEP.

In our sample, 15 participants (23%) reported an increase in pain severity of 2 points or greater over the course of the 18 lifts in the SMEP protocol. In this subgroup of the sample, this represents more than a 50% increase in pain from the first column to the last column of canisters. It should be noted that despite lower scores on the MPQ-PRI and lower mean movement-evoked pain compared with those reported in earlier studies,^{26,39} the magnitude of the pain summation effect resulting

Table 2

Correlations between key study variables.

| | SMEP | TS | Age | Sex | BMI | Duration | Disability (y/n) | MPQ-PRI | PCS | TSK |
|------------------|--------|---------|--------|--------|--------|----------|------------------|---------|--------|-----|
| SMEP | — | | | | | | | | | |
| TS | 0.458* | — | | | | | | | | |
| Age | 0.157 | 0.051 | — | | | | | | | |
| Sex | 0.023 | -0.221 | -0.056 | — | | | | | | |
| BMI | 0.040 | 0.011 | 0.118 | 0.225 | — | | | | | |
| Duration | 0.550* | 0.259† | 0.270† | -0.182 | 0.036 | — | | | | |
| Disability (y/n) | -0.183 | -0.301† | 0.081 | 0.108 | 0.060 | -0.105 | — | | | |
| MPQ-PRI | 0.143 | 0.245 | -0.045 | -0.048 | 0.140 | -0.071 | -0.423* | — | | |
| PCS | 0.513* | 0.221 | 0.015 | 0.013 | -0.149 | 0.327* | -0.228 | 0.428* | — | |
| TSK | 0.375* | 0.083 | -0.119 | 0.151 | -0.120 | 0.069 | -0.157 | 0.481* | 0.510* | — |

N = 65. Significance tests are 2-tailed.

* $P < 0.01$.

† $P < 0.05$.

BMI, body mass index; MPQ-PRI, McGill Pain Questionnaire Pain Rating Index; PCS, Pain Catastrophizing Scale; SMEP, Sensitivity to Movement-Evoked Pain; TS, Temporal Summation; TSK, Tampa Scale of Kinesiophobia.

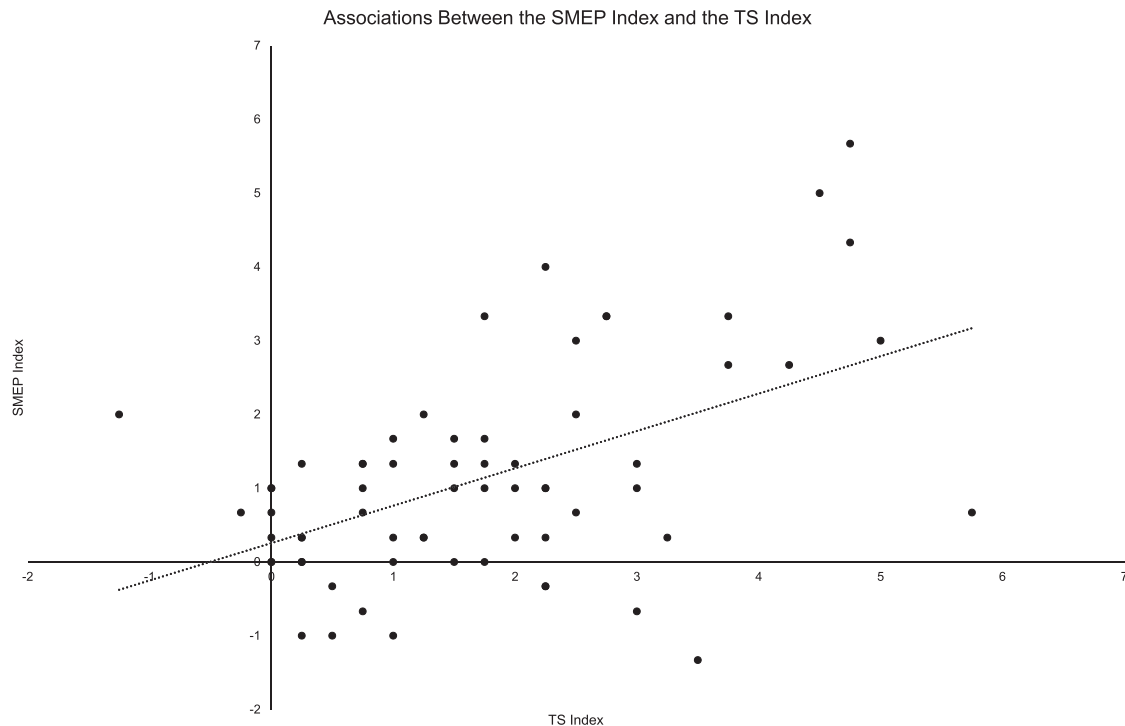


Figure 3. Scatterplot of SMEP Index vs TS Index. SMEP, Sensitivity to Movement-Evoked Pain; TS, Temporal Summation.

from the repeated lifting task was comparable with previously reported figures (within 1 SD).

Previous studies have shown SMEP measures to be predictive of persistent disability in patients with whiplash injuries.^{26,27} In this study, the relationship between SMEP and occupational disability was in the same direction as previously reported²⁷ but was not significant. The relationship between TS and occupational disability, however, was significant. It has been proposed that a susceptibility to pain summation in response to repeated painful stimuli or physical activity might present a barrier to the resumption of occupational activities after whiplash injury.²⁷ It should be noted that, although TS has been shown to be associated with self-reported disability in individuals with chronic low back pain,¹⁵ this is the first study to identify an association between TS and occupational disability.

Our results also revealed a significant relationship between SMEP and TS of pinprick pain in both zero-order correlations and hierarchical regression analyses. These findings are consistent with previous studies showing significant relationships among

different measures of pain summation. For example, TS of mechanical pain has been found to be related to an SMEP Index in response to walking in patients with knee osteoarthritis,⁴⁸ and TS of pinprick pain has been found to be associated with TS of thermal pain in individuals with knee osteoarthritis.¹⁶ The relationship between SMEP and TS of pinprick pain demonstrated in this study joins this growing body of literature on the shared variance among different indices of pain summation.

Temporal Summation accounted for only 20% of the variance in SMEP, suggesting that there are processes involved in SMEP that are distinct from TS. Such factors might be related to different pain mechanisms in response to movement-based tests of pain summation. It is possible that the lifting task, which involved the repeated loading of the shoulder and cervical spine (through their common muscle attachments), may have also triggered increased nociceptive activity through peripheral pathways.³² Whiplash is associated with known structural,^{8–10} behavioural,^{33,37} and functional changes²⁹ in the cervical motor system. Deficits in the physical support of the cervical spine during the lifting task may have contributed to the observed pain summation because of factors such as muscle fatigability and increased mechanical irritation of cervical structures.^{11,19,23,28} At present, the specific mechanisms underlying SMEP are unknown. Future investigation of potential peripheral drivers of SMEP may involve the concurrent use of measures of muscle activity (eg, electromyography) or motion capture (eg, three-dimensional motion analysis) of the cervical spine and shoulder girdle during the repeated lifting task.

The findings of this study also suggest that higher scores on the SMEP Index are related to higher scores on pain-related psychological variables, which are in agreement with previous studies.^{7,17,39} Analyses identified a positive correlation between the SMEP Index and both pain catastrophizing and fear of movement. Hierarchical regression analyses identified only pain

Table 3

Regression analyses examining the relationship between SMEP Index, TS Index, and psychological variables.

| | β | R^2 | R^2_{change} | F_{change} | P |
|----------|---------|-------|-----------------------|---------------------|--------|
| Step 1 | | | | | |
| TS Index | 0.440* | 0.194 | 0.194 | 12.995 | <0.001 |
| Step 2 | | | | | |
| TS Index | 0.361* | | | | 0.003 |
| PCS | 0.346* | | | | 0.009 |
| TSK | 0.112 | 0.357 | 0.163 | 6.597 | 0.391 |

N = 65. Significance tests are 2-tailed. Standardized beta weights are presented for each step of the regression.

* $P < 0.01$.

PCS, Pain Catastrophizing Scale; SMEP, Sensitivity to Movement-Evoked Pain; TS, temporal summation; TSK, Tampa Scale of Kinesiophobia.

catastrophizing as a significant unique predictor of SMEP. Pain catastrophizing and fear of movement contributed 16.3% of variance when controlling for TS. This unique variance might suggest that catastrophizing impacts on SMEP through pathways other than those associated with TS. One potential mechanism might be a repeated failure of coping strategies. Previous research has demonstrated associations between catastrophizing and lower pain coping efficacy in both condition-related pain (ie, osteoarthritis and rheumatoid arthritis)²⁰ and experimental pain.^{42,43} It should be noted that coping was not assessed in this study, so this explanation remains speculative.

The results of this study have both theoretical and clinical implications. From a theoretical perspective, the study adds to a growing body of research on pain summation by further validating the repeated lifting task as a method of inducing pain summation in individuals with whiplash injuries. This study also identified associations between TS of pinprick pain, pain catastrophizing, and SMEP. From a clinical perspective, a greater understanding of the overlap between measures of pain summation may prove particularly valuable in predicting which patients are at risk of adverse pain outcomes. The realities of clinical practice place limits on both the number of measures that can be included in assessment protocols as well as the feasibility of experimental procedures for TS. If SMEP and TS demonstrate similar findings (potentially representing similar underlying pathophysiological mechanisms), the procedure used to assess SMEP in this study (ie, lifting a series of weighted objects) could be used as an alternative measure to TS. Particularly, as the SMEP procedure seems to be an ecologically valid, time-, and cost-efficient assessment, with potential to assist the identification of those individuals at risk of adverse pain outcomes.

There are, however, limitations to this study. First, the study population may not be entirely representative of the wider population of whiplash sufferers, given the disproportionately large number of men in the sample (77%). Furthermore, measurements were taken from participants in a rehabilitation program who volunteered for a pain study. Therefore, there may be some risk of selection bias that may limit the generalizability of results. However, scores for the measures of spontaneous pain, pain catastrophizing, and fear of movement were comparable with those reported in previous research in individuals with whiplash.^{38,39} The study was also cross-sectional, thereby limiting inferences that can be made regarding direction of causality among study variables. Furthermore, without a matched control group, it is unclear whether the present findings are specific to individuals with a musculoskeletal pain condition, or whether similar findings would emerge in a healthy population. Finally, the reassurance given to participants about the expectation of pain and safety of the task (provided in the consent form) might have affected some of the observed relationships between reported pain and fear of movement.

Despite these limitations, the results of this study build on previous research on pain summation in response to repetitive physical loading in individuals with whiplash injuries. As a whole, the results suggest that the repeated lifting task successfully induced SMEP in the present sample and that SMEP is correlated with TS of pinprick pain and pain catastrophizing. The mechanisms underlying the pain summation observed in SMEP, however, are currently unknown. Future studies are required to replicate and extend on these findings in larger samples that include a matched control group and other persistent pain states in addition to whiplash-related neck pain. Future research may also investigate the potential for aberrant muscle activation

patterns, altered biomechanics, and other psychological cofactors of pain to influence SMEP.

Disclosures

The authors have no conflicts of interest related to material presented in this paper.

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