LUND UNIVERSITY

Quantitative sensory testing of temperature thresholds: Possible biomarkers for persistent pain?

Malmström, Eva-Maj; Stjerna, Johanna; Högestätt, Edward; Westergren, Hans

Published in:
Journal of Rehabilitation Medicine

DOI:
10.2340/16501977-2024

2015

Link to publication

Citation for published version (APA):
Malmström, E.-M., Stjerna, J., Högestätt, E., & Westergren, H. (2015). Quantitative sensory testing of temperature thresholds: Possible biomarkers for persistent pain? *Journal of Rehabilitation Medicine*, *48*(1), 43-47. https://doi.org/10.2340/16501977-2024

Total number of authors:
4

General rights
Unless other specific re-use rights are stated the following general rights apply:
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.
• Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
• You may not further distribute the material or use it for any profit-making activity or commercial gain
• You may freely distribute the URL identifying the publication in the public portal

Read more about Creative commons licenses: https://creativecommons.org/licenses/

Take down policy
If you believe that this document breaches copyright please contact us providing details, and we will remove access to the work immediately and investigate your claim.

LUND UNIVERSITY

PO Box 117
221 00 Lund
+46 46-222 00 00

Download date: 09. Dec. 2025

J Rehabil Med 2016; 48: 43–47

ORIGINAL REPORT

QUANTITATIVE SENSORY TESTING OF TEMPERATURE THRESHOLDS: POSSIBLE BIOMARKERS FOR PERSISTENT PAIN?

Eva-Maj Malmström, RPT, PhD[1,2], Johanna Stjerna, RPT, MD[1], Edward D. Högestätt, MD, PhD[3] and Hans Westergren, MD, PhD[1,4]

From the [1]Department of Pain Rehabilitation, SUS, [2]Department of Clinical Sciences, [3]Clinical Chemistry and Pharmacology, Department of Laboratory Medicine and [4]Department of Health Sciences, Lund University, Lund, Sweden

Objective: **To investigate the reproducibility of thermal thresholds, as measured by repeated quantitative sensory testing (QST) in healthy controls, and to asses if temperature sensitivity differs between healthy controls and a cohort of patients with persistent pain.**

Subjects: **A total of 54 healthy controls were compared with 25 consecutive patients selected for pain rehabilitation by multidisciplinary assessment teams.**

Methods: **Heat and cold detection and pain thresholds in the forearm and neck were determined by QST. Reproducibility was evaluated by 2 consecutive tests 6–9 months apart.**

Results: **Thermal detection and pain thresholds were reproducible in a subgroup of 20 healthy controls. The patients had slightly increased heat and cold detection thresholds, but significantly lower thresholds for cold and heat pain. The most clear-cut differences between patients and healthy controls were observed for cold pain thresholds. Calculation of the differences between thermal detection and pain thresholds (delta values) further strengthened the differences between patients and healthy controls.**

Conclusion: **Thermal detection and pain thresholds are reproducible over time, allowing longitudinal assessment of sensory function using QST. Although increased sensitivity to cold pain was the most prominent finding in this cohort of patients with persistent pain, calculation of the differences between thermal detection and pain thresholds may prove superior in detecting sensory alterations.**

Key words: QST; pain threshold; detection threshold; persistent pain; biomarker.

J Rehabil Med 2016; 48: 43–47

Correspondence address: Hans Westergren, Department of Pain Rehabilitation, Skane University Hospital, Lasarettsgatan 13, SE-582 85 Lund, Sweden. E-mail: hans.westergren@skane.se

Accepted Aug 27, 2015; Epub ahead of print Oct 9, 2015

INTRODUCTION

Persistent pain is a complex mixture of nociceptive input, and cognitive and emotional experiences with wide variation between individuals (1). This variation can occur in the same individual at different time-points and in different situations due to factors such as biomechanical demands and constraints. Although persistent pain is a major health problem in European society (2), there are a limited number of clinical biomarkers (3). The task of finding and establishing clinically useful biomarkers is important for both patients and caregivers in order to find objective diagnostic tools and methods for monitoring treatment responses (4, 5).

The Department for Pain Rehabilitation in Lund, Sweden, assesses approximately 1,000 patients with persistent non-malignant pain every year. Patients with persistent pain living in Scandinavia in general report worsening of their pain symptoms during the, often cold and damp, winters. This led us to speculate that increased sensitivity to cold might be a common trait in persistent pain. Interestingly, most patients with fibromyalgia are sensitive to cold (6), indicating that cold hypersensitivity may serve as a biomarker in fibromyalgia (7). Although many patients with persistent pain satisfy the criteria for fibromyalgia, several patients experience persistent pain without fulfilling the fibromyalgia criteria (8, 9).

As suggested by Sterling et al., increased cold sensitivity may serve as a prognostic factor for poor recovery (10, 11), development of post-traumatic stress (12) and increased Neck Disability Index (13) in patients with pain and disability after whiplash trauma. Wallin et al. (14) also found a correlation between temperature sensitivity and psychological distress in patients with neck pain after whiplash trauma. Other studies have demonstrated different patterns in temperature sensitivity between healthy controls and patients with chronic back pain or fibromyalgia (15) and no sensory differences between post-stroke patients with or without shoulder pain (16).

Quantitative sensory testing (QST) is the most frequently used method to assess thermal detection and pain thresholds (i.e. hyper/hyposensitivity) (17). This method has been used extensively by the German Research Network on Neuropathic Pain (18). Several phenotype patterns and subgroups have been identified in healthy volunteers (19, 20). One major advantage of QST is that it allows the quantification, not only of sensory loss, but also of increased sensitivity (21, 22). A review article by Cruz-Almeida & Fillingim (23) summarizes the potential clinical usefulness of QST and emphasizes the need for clinically manageable protocols for QST assessment in defined subgroups of patients before and after treatment.

This pilot study explores the potential usefulness of temperature sensitivity, measured using QST in the forearm and neck, as a biomarker for monitoring persistent pain. Firstly, the reproduc-

© 2016 The Authors. doi: 10.2340/16501977-2024

Journal Compilation © 2016 Foundation of Rehabilitation Information. ISSN 1650-1977

ibility of temperature threshold recordings in healthy controls were assessed. To our knowledge, the variations in thermal detection and pain thresholds have not been investigated over longer time periods (24–25). Secondly, thresholds for thermal detection and pain in healthy controls were compared with those for a group of patients with persistent pain. There are many studies investigating temperature sensitivity in relation to specific pain disorders, but to our knowledge no studies in patients selected for treatment by multiprofessional rehabilitation teams.

METHODS

Thermal thresholds were investigated with QST in healthy controls and in patients with persistent pain. A follow-up test was performed among the healthy controls after 6–9 months. Detection and pain thresholds for cold and heat were established on the volar side of the left lower arm and, paraspinally, in the neck, just below the hairline. The neck was chosen for assessment because most patients with persistent pain report pain in the neck and shoulders, and the volar side of the lower arm was chosen because few patients report pain from the flexor side of the arm. The study was approved by the Regional Ethics Committee in Lund, Sweden (476/2007 and 513/2008).

Subjects

Participants comprised 54 healthy controls recruited from employees and students at a specialist pain rehabilitation unit (13 males, 41 females; median age 42 years). None of the healthy controls had a history of persistent pain or continuous pain medication. Twenty of the 54 healthy controls were re-tested 6–9 months after the first test in order to evaluate the variability of the thermal thresholds over time. The Department for Pain Rehabilitation, Lund, Sweden, receives approximately 1,000 new referrals a year, mainly from primary care physicians in a catchment area of approximately 1 million inhabitants. Approximately 25% of all referred patients are selected for a pain rehabilitation programme. The patient group in this study comprised 25 consecutive patients (2 males, 23 females; median age 36 years). All the patients had a history of persistent pain, with a duration of at least 6 months (and often much longer) and were subjected to a 1-day evaluation by an multidisciplinary pain rehabilitation team, comprising a physician, physiotherapist, psychologist and social worker, all subspecialized in algology. This assessment includes surveying pain generators (muscles, nerves and joints), central nervous system (CNS) reactions to pain (e.g. sensitization, sleep disorders and cognitive dysfunction), psychological factors (e.g. depression and anxiety) and social factors (e.g. economy, insurance, family and work situation). The patients included in the study were all selected for treatment in a cognitive behaviour therapy-based pain management programme. The majority of patients ($n = 23$) reported pain from more than 1 area of the body. Ten patients reported pain from all 4 body quadrants, 22 reported pain from the neck and shoulders, and 4 reported pain on the volar side of the lower arm. All subjects received written information about the study, gave oral and written consent to participate, and were informed that they could stop the test at any time and for any reason.

Equipment

A Somedic Thermotest type I® device (Somedic AB, Hörby, Sweden) with a 25 × 50-mm Peltier-type probe was used for thermal stimulation. The baseline temperature of the probe was set at 32°C, and the rate of temperature change was 1°C/s. For safety reasons the maximum probe temperature was set at 52°C and the minimum at 10°C.

Testing procedures

All testing procedures were standardized, and instructions were read aloud to the subjects from a written protocol. All tests were run by 2 personnel trained by the same biomedical analyst. Subjects lay supine in a secluded environment at standard room temperature 20–22°C (23). Guiding sounds from the QST device were foreclosed, and subjects were unable to see the equipment display. They were informed of the temperature limits of the probe, in order to avoid fear of burns or frostbite. When testing in the arm, the probe was placed on the couch under the volar side of the patient's forearm. In the neck, the probe was unilaterally close to the spine, just under the hairline (left arm and left side of the neck in all tests). The subjects had a reset button in their contralateral hand, and were instructed to press the button as soon as they perceived the requested sensation (detection or discomfort/pain). At reset, the deviation from baseline was registered and the probe temperature returned to neutral skin temperature (32°C). All the tests were run without interruption, starting with detection thresholds followed by pain thresholds, first on the arm and then on the neck. Tests for detection thresholds were repeated 10 times. Tests for pain thresholds were repeated 5 times. Subjects were given the opportunity to discontinue the session between each new test. When testing pain thresholds, the subjects were instructed to press the reset button as soon as the thermal stimulus caused discomfort or pain. The investigation time for each subject was approximately 30 min.

Labels and units

In the following, C stands for cold, H for heat or warmth, DT for detection threshold, PT for pain threshold, "a" for the arm, and "n" for the neck. The variables are presented in the tables in the same order as they were tested. The delta value is the difference between detection and pain thresholds.

Statistical analyses

Ten separate registrations for cold and heat detection thresholds and 5 separate registrations for cold and heat pain thresholds were performed in each test, and each individual was represented by their own mean value for each test. Eight tests were performed for each investigation: cold detection threshold in the arm (CDTa), heat detection threshold in the arm (HDTa), cold detection threshold in the neck (CDTn), heat detection threshold in the neck (HDTn), cold pain threshold in the arm (CPTa), heat pain threshold in the arm (HPTa), cold pain threshold in the neck (CPTn), and heat pain threshold in the neck (HPTn). An independent samples *t*-test was used to compare the patients and controls, with guidance of Levene's test for equality of variances. A paired samples *t*-test was used for test–retest and calculations of stability over time in healthy controls, with 95% confidence intervals of the difference reported.

RESULTS

Reproducibility of quantitative sensory testing over time in healthy controls

No significant deviations in heat and cold detection or pain thresholds were detected between the first and second QST assessments in the arm or neck (Table I).

Comparison of measurements between the forearm and neck in patients and healthy controls

No significant differences were found in thermal thresholds between the arm and neck in patients or healthy controls.

Comparison of quantitative sensory testing between patients and healthy controls

Except for CDTa, thermal detection thresholds were significantly higher in the patients than in healthy controls (Table

Table I. *Paired samples and paired differences between measurement 1 and 2 in 20 healthy controls. Repeated tests with measurement 2 after 6–9 months*

Measurement	Measurement number	Paired samples Mean (SD) °C	*p*-value	Paired differences Mean	95% CI
CDTa	1	31.3 (0.3)	0.537	–0.04	–0.17 to 0.09
	2	31.4 (0.2)			
HDTa	1	33.6 (0.7)	0.830	0.03	–0.29 to 0.36
	2	33.5 (0.6)			
CPTa	1	14.2 (4.5)	0.181	–2.03	–5.08 to 1.02
	2	16.2 (6.6)			
HPTa	1	43.7 (1.6)	0.187	0.77	–0.41 to 1.95
	2	42.9 (2.9)			
CDTn	1	31.2 (0.9)	0.839	–0.04	–0.43 to 0.36
	2	31.3 (0.6)			
HDTn	1	33.5 (0.6)	0.600	0.08	–0.22 to 0.37
	2	33.4 (0.5)			
CPTn	1	19.2 (6.4)	0.388	–1.26	–4.24 to 1.72
	2	20.4 (6.5)			
HPTn	1	43.0 (2.5)	0.465	0.53	–0.95 to 2.01
	2	42.5 (3.0)			

CDTa: cold detection threshold in the arm; HDTa: heat detection threshold in the arm; CPTa: cold pain threshold in the arm; HPTa: heat pain threshold in the arm; CDTn: cold detection threshold in the neck; HDTn: heat detection threshold in the neck; CPTn: cold pain threshold in the neck; HPTn: heat pain threshold in the neck; SD: standard deviation; 95% CI: 95% confidence interval.

Table II. *Results from 25 patients and 54 healthy controls. Each individual is represented by a mean value of all recordings (detection 10 tests and pain 5 tests)*

Measurement	Mean (SD) °C	*p*-value
CDTa		
Patients	30.9 (1.4)	0.128
Healthy controls	31.3 (1.0)	
HDTa		
Patients	34.8 (2.8)	0.001
Healthy controls	33.4 (0.5)	
CPTa		
Patients	22.6 (6.3)	<0.001
Healthy controls	16.2 (6.0)	
HPTa		
Patients	41.8 (3.4)	0.039
Healthy controls	43.2 (2.2)	
CDTn		
Patients	30.4 (3.4)	0.030
Healthy controls	31.4 (0.6)	
HDTn		
Patients	34.6 (2.7)	0.001
Healthy controls	33.3 (0.6)	
CPTn		
Patients	26.0 (6.4)	<0.001
Healthy controls	19.6 (7.2)	
HPTn		
Patients	40.4 (3.7)	0.042
Healthy controls	42.3 (3.5)	

Equal variances assumed, except for CPTa and HPTn (according to Levene's test).
For abbreviations see Table I.

II). Thermal pain thresholds were significantly lower in both the arm and neck for the patient group (Table II). The most clear-cut differences between patients and healthy controls were observed for CPT. Calculation of the differences between thermal detection and pain thresholds (delta values) further strengthened the differences between patients and healthy controls (Table III).

DISCUSSION

Repeated QST measurements of temperature detection and pain thresholds in the arm and neck did not reveal any statistically significant deviations over time in 20 healthy controls. The fairly large variability in CPT values in the arm and neck reduced the power of the comparison. However, the variability of the CPT values was much smaller in the patient group than in healthy controls. In spite of these shortcomings, there were statistically significant differences in CPT in both arm and neck between patients and healthy controls, indicating a higher sensitivity to cold pain in the patient group. Differences, although smaller, between patients and healthy controls were also seen in heat pain threshold (HPT), indicating a higher sensitivity to heat pain in the patient group. In contrast to these findings, cold and heat perception, as measured by thermal detection thresholds, was weaker in patients than in healthy controls. These differences between patients and healthy controls in thermal detection and pain thresholds are also reflected in the delta values obtained by calculating the difference between detection and pain thresholds in each individual.

All subjects completed all investigations. However, when testing CPT in the arm, 9 out of 54 (17%) healthy controls and 1 out of 25 (4%) patients reached cut-off at 10°C. No patient

Table III. *Individual differences between cold and heat detection (mean of 10 recordings) and mean values for cold and heat pain (mean of 5 recordings): delta values. Recordings from 25 patients and 54 healthy controls*

	Paired samples Mean (SD) °C	*p*-value
CDTa–CPTa		
Patients	8.2 (5.9)	<0.001
Healthy controls	15.1 (6.1)	
HDTa–HPTa		
Patients	7.1 (3.3)	<0.001
Healthy controls	9.8 (2.3)	
CDTn–CPTn		
Patients	4.4 (5.3)	<0.001
Healthy controls	11.8 (7.1)	
HDTn–HPTn		
Patients	5.8 (3.4)	<0.001
Healthy controls	9.0 (3.5)	

For abbreviations see Table I.

or healthy control reached the heat cut-off at 52°C. Each studied individual was represented by the mean value of all registrations in the tests (10 for detection, 5 for pain). Newer versions of the QST device introduced a software solution, in which the first 2 registrations are excluded in each test, but re-analysis of the data using this software did not influence the findings of the study. Although most differences were statistically clear-cut, the findings must be interpreted with caution, as the number of patients examined was relatively small, and patients and healthy controls were not matched with regard to, for example, gender and age. However, exclusion of male subjects from the analysis did not affect any of the results in this study. Still, the highly significant differences observed between patients and healthy controls, especially in the delta values, may indicate a common trait in this selected group of patients with persistent pain.

The detection of thermal stimuli by primary afferents, the transmission of this information to the brain and the subsequent generation of the actual experience of temperature and pain in the individual involves interplay of central and peripheral sensory mechanisms that is not fully understood. It is, however, known that innocuous cold and heat sensation and cold and heat pain are mediated by different peripheral receptors and modulated by several mechanisms, including those driven by comorbidity in the CNS (26–30). It remains to be determined whether the characteristic QST profile observed in this cohort of patients reflects a common phenotype over-represented in patients with persistent pain or a common pathophysiological process that might be responsive to multimodal pain treatment. Future longitudinal QST studies in this cohort of patients before and after treatment for persistent pain may help to resolve this issue.

Many QST studies have been performed on volunteers (20, 31) with the objective of identifying phenotypic patterns, or on patients who are believed to share a common pathophysiology (16, 32, 33). The evaluation of QST data quickly becomes very complex and difficult to interpret when many factors are included in the analysis (19), as demonstrated in, for example, neuropathic pain (34). A review article by Cruz-Almeida & Fillingim (23) discusses the challenge of developing shorter and clinically manageable QST protocols in order to identify various "pain subtypes" and to select suitable clinical treatment strategies in individual patients. The results of this study indicate that a time-effective, non-invasive assessment of thermal detection and pain thresholds in the neck and forearm, using a limited QST protocol, can identify deviations in patients with persistent pain. It remains to be demonstrated whether such neurophysiological changes, particularly the difference between cold detection and pain threshold, are of clinical value as biomarkers for defining subgroups of patients with persistent pain and for assessment, monitoring and possibly prediction of treatment outcomes.

ACKNOWLEDGEMENTS

We wish to thank Assistant Nurse Inger Dahlqvist-Johansson and Biomedical Scientist Margita Boij for their assistance in the assessments and Bo Johansson, Somedic for technical advice. The study was financed by Region Skane, Lund University and Personskadeförbundet, RTP's research fund.

REFERENCES

1. Bushnell MC, Ceko M, Low LA. Cognitive and emotional control of pain and its disruption in chronic pain. Nature Rev Neurosci 2013; 14: 502–511.
2. Breivik H, Collett B, Ventafridda V, Cohen R, Gallacher D. Survey of chronic pain in Europe: prevalence, impact on daily life, and treatment. Eur J Pain 2006; 10: 287–333.
3. Arendt-Nielsen L, Nielsen TA, Gazerani P. Translational pain biomarkers in the early development of new neurotherapeutics for pain management. Exp Rev Neurotherapeut 2014; 14: 241–254.
4. Lygren H, Strand LI, Anderson B, Magnussen LH. Do ICF Core Sets for low back pain include patients' self-reported activity limitations because of back problems? Physiother Res Int 2014; 19: 99–107.
5. Stier-Jarmer M, Cieza A, Borchers M, Stucki G. How to apply the ICF and ICF core sets for low back pain. Clin J Pain 2009; 25: 29–38.
6. Berglund B, Harju EL, Kosek E, Lindblom U. Quantitative and qualitative perceptual analysis of cold dysesthesia and hyperalgesia in fibromyalgia. Pain 2002; 96: 177–187.
7. Hurtig IM, Raak RI, Kendall SA, Gerdle B, Wahren LK. Quantitative sensory testing in fibromyalgia patients and in healthy subjects: identification of subgroups. Clin J Pain 2001; 17: 316–322.
8. Wolfe F. Fibromyalgia research criteria. J Rheumatol 2014; 41: 187.
9. Wolfe F, Hauser W. Fibromyalgia diagnosis and diagnostic criteria. Ann Med 2011; 43: 495–502.
10. Sterling M, Jull G, Vicenzino B, Kenardy J. Sensory hypersensitivity occurs soon after whiplash injury and is associated with poor recovery. Pain 2003; 104: 509–517.
11. Sterling M, Jull G, Kenardy J. Physical and psychological factors maintain long-term predictive capacity post-whiplash injury. Pain 2006; 122: 102–108.
12. Sterling M, Hodkinson E, Pettiford C, Souvlis T, Curatolo M. Psychologic factors are related to some sensory pain thresholds but not nociceptive flexion reflex threshold in chronic whiplash. Clin J Pain 2008; 24: 124–130.
13. Sterling M, Hendrikz J, Kenardy J, Kristjansson E, Dumas JP, Niere K, et al. Assessment and validation of prognostic models for poor functional recovery 12 months after whiplash injury: a multicentre inception cohort study. Pain 2012; 153: 1727–1734.
14. Wallin M, Liedberg G, Börsbo B, Gerdle B. Thermal detection and pain thresholds but not pressure pain thresholds are correlated with psychological factors in women with chronic whiplash-associated pain. Clin J Pain 2012; 28: 211–221.
15. Blumenstiel K, Gerhardt A, Rolke R, Bieber C, Tesarz J, Friederich HC, et al. Quantitative sensory testing profiles in chronic back pain are distinct from those in fibromyalgia. Clin J Pain 2011; 27: 682–690.
16. Lindgren I, Ekstrand E, Lexell J, Westergren H, Brogardh C. Somatosensory impairments are common after stroke but have only a small impact on post-stroke shoulder pain. J Rehabil Med 2014; 46: 307–313.
17. Arendt-Nielsen L, Yarnitsky D. Experimental and clinical applications of quantitative sensory testing applied to skin, muscles and viscera. J Pain 2009; 10: 556–572.
18. Rolke R, Magerl W, Campbell KA, Schalber C, Caspari S, Birklein F, et al. Quantitative sensory testing: a comprehensive protocol for clinical trials. Eur J Pain 2006; 10: 77–88.
19. Hastie BA, Riley JL, 3rd, Robinson ME, Glover T, Campbell CM, Staud R, et al. Cluster analysis of multiple experimental pain modalities. Pain 2005; 116: 227–237.
20. Neziri AY, Curatolo M, Nuesch E, Scaramozzino P, Andersen OK, Arendt-Nielsen L, et al. Factor analysis of responses to thermal,

electrical, and mechanical painful stimuli supports the importance of multi-modal pain assessment. Pain 2011; 152: 1146–1155.
21. Heldestad V, Linder J, Sellersjo L, Nordh E. Reproducibility and influence of test modality order on thermal perception and thermal pain thresholds in quantitative sensory testing. Clin Neurophysiol 2010; 121: 1878–1885.
22. Pigg M, Baad-Hansen L, Svensson P, Drangsholt M, List T. Reliability of intraoral quantitative sensory testing (QST). Pain 2010; 148: 220–226.
23. Cruz-Almeida Y, Fillingim RB. Can quantitative sensory testing move us closer to mechanism-based pain management? Pain Med 2014; 15: 61–72.
24. Werner MU, Petersen MA, Bischoff JM. Test-retest studies in quantitative sensory testing: a critical review. Acta Anaesthesiol Scand 2013; 57: 957–963.
25. Moloney NA, Hall TM, Doody CM. Reliability of thermal quantitative sensory testing: a systematic review. J Rehabil Res Dev 2012; 49: 191–207.
26. Prescott SA, Ma Q, De Koninck Y. Normal and abnormal coding of somatosensory stimuli causing pain. Nature Neurosci 2014; 17: 183–191.
27. Vriens J, Nilius B, Voets T. Peripheral thermosensation in mammals. Nature Rev Neurosci 2014; 15: 573–589.
28. Ma Q. Labeled lines meet and talk: population coding of somatic sensations. J Clin Investig 2010; 120: 3773–3778.
29. Ma Q. Population coding of somatic sensations. Nuerosci Bull 2012; 28: 91–99.
30. Herbert MS, Goodin BR, Pero ST 4 th, Schmidt JK, Sotolongo A, Bulls HW, et al. Pain hypervigilance is associated with greater clinical pain severity and enhanced experimental pain sensitivity among adults with symptomatic knee osteoarthritis. Annals Behav Med 2014; 48: 50–60.
31. Coronado RA, Simon CB, Valencia C, Parr JJ, Borsa PA, George SZ. Suprathreshold heat pain response predicts activity-related pain, but not rest-related pain, in an exercise-induced injury model. PloS One 2014; 9: e108699.
32. Neziri AY, Limacher A, Juni P, Radanov BP, Andersen OK, Arendt-Nielsen L, et al. Ranking of tests for pain hypersensitivity according to their discriminative ability in chronic neck pain. Regional Anesthes Pain Med 2013; 38: 308–320.
33. Coronado RA, Simon CB, Valencia C, George SZ. Experimental pain responses support peripheral and central sensitization in patients with unilateral shoulder pain. Clin J Pain 2014; 30: 143–151.
34. Freeman R, Baron R, Bouhassira D, Cabrera J, Emir B. Sensory profiles of patients with neuropathic pain based on the neuropathic pain symptoms and signs. Pain 2014; 155: 367–376.