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PII: S1526-5900(18)30676-X
DOI: <https://doi.org/10.1016/j.jpain.2018.09.011>
Reference: YJPAI 3642



To appear in: *Journal of Pain*

Please cite this article as: Sanneke Don , Maarten Venema , Margot De Kooning , Bart van Buchem , Jo Nijs , Lennard Voogt , Does sensorimotor incongruence trigger pain and sensory disturbances in people with chronic low back pain? A randomised cross-over experiment, *Journal of Pain* (2018), doi: <https://doi.org/10.1016/j.jpain.2018.09.011>

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Highlights

- Distorted visual feedback caused sensory disturbances in healthy volunteers
- Sensorimotor incongruence had no effect on pain in people with chronic low back pain
- The hypothesis of sensorimotor incongruence as a contributor to pain is not supported

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Does sensorimotor incongruence trigger pain and sensory disturbances in people with chronic low back pain? A randomised cross-over experiment

Sanneke Don^{1,2,3}, Maarten Venema, Margot De Koning^{1,2}, Bart van Buchem⁴,
Jo Nijs^{1,2}, Lennard Voogt^{1,3}

- ^{1.} Pain in Motion international research group, www.paininmotion.be
- ^{2.} Department of Rehabilitation Sciences and Physiotherapy, Human Physiology and Anatomy (KIMA), Faculty of Physical Education and Physiotherapy, Vrije Universiteit Brussel, Brussels, Belgium
- ^{3.} Department of Physiotherapy, Rotterdam University of Applied Sciences, Rotterdam, The Netherlands
- ^{4.} Department of Medical Psychology and Psychotherapy, Erasmus MC, Rotterdam, The Netherlands

Running title:

The effect of SMI on sensory disturbances and pain in people with CLBP

Address correspondence and reprint requests to: Sanneke Don, Vrije Universiteit Brussel, Medical Campus Jette, Building F-Kima, Laarbeeklaan 103, BE-1090 Brussels, Belgium (email: sanneke.don@vub.ac.be; website: www.paininmotion.be).

Disclosures: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors. No conflicts of interest are declared.

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Abstract

Chronic low back pain (CLBP) has major public health implications and underlying mechanisms are still unclear. Sensorimotor incongruence (SMI) – an ongoing mismatch between top down motor output and predicted sensory feedback - may play a role in the course of chronic non-specific low back pain. The hypothesis of this study was that the induction of SMI causes sensory disturbances and/or pain in people with CLBP and healthy volunteers. A sample of 66 people (33 people with CLBP and 33 healthy volunteers) participated in a visual feedback experiment involving real time images of the own lower back – either during movement or in a static position - provided via a live video feed. Experimental SMI was induced via distorting visual feedback of the lower back during movement. There were no significant differences in sensory disturbances or pain intensity between experimental SMI and the other movement conditions in people with CLBP and healthy volunteers ($p > .05$). Static visual feedback had a significant effect on the intensity of sensory disturbances in people with CLBP ($p = .038$) and healthy volunteers ($p < .001$). In conclusion, experimental SMI did not affect sensory disturbances or pain in either group. Therefore, the research hypothesis was not supported.

Perspective

The results of this study show that sensorimotor incongruence does not cause additional symptoms and pain in people with chronic low back pain. The conceptual premise that sensorimotor incongruence is an underlying contributor in the course of pain in this population is not supported.

Keywords

Spinal pain, Chronic pain, Visual feedback, Sensorimotor integration, sensorimotor incongruence

Introduction

Chronic low back pain (CLBP) is a common, complex and hard to treat disorder [20; 21; 40; 42]. The global point prevalence of low back pain (LBP) was estimated at 9.4% in 2010, with the highest prevalence of 15% in Western Europe [21]. When pain persists and becomes chronic, it has a vast socioeconomic impact [42]. Overall, unravelling the underlying mechanisms of CLBP is important to improve the effectiveness of care.

It is proposed that sensorimotor incongruence (SMI) – a mismatch between motor intention and sensory feedback – may help in unravelling the mechanisms of CLBP. Disturbed integration of sensorimotor information processes is associated with pain and symptoms (e.g., balance and motor control deficits) in people with CLBP [37]. The SMI-hypothesis, proposed by Harris [18], states that a mismatch in sensorimotor integration is present in people with nonspecific chronic pain. This mismatch might be related to maladaptive plastic changes within the central nervous system [18] and is thought to inevitably contribute to the generation of pain. In a similar manner as motion sickness is generated when vestibular information is discordant to visual information [18]. Sensory disturbances, which occur in a sensorimotor incongruent state, might be warning signals produced by the central nervous system. It is hypothesised that when this incongruent state lasts long enough, or is strong enough to reach the individual's threshold, pain will occur [29; 31].

Bimanual coordination experiments were conducted to test SMI experimentally [7-9; 16; 30; 32; 36; 43]. In these experiments, participants sit with a mirror between their limbs while performing bimanual movements in a synchronous or asynchronous manner. When asynchronous movements are performed, a conflict is created between proprioceptive information from the body and visual

information provided by the mirror. This artificial conflict between vision, proprioception and motor intention is called experimental SMI.

There is evidence that experimental SMI causes pain and sensory disturbances, such as feelings of discomfort or peculiarity in people with chronic musculoskeletal pain [3; 7; 8; 14; 30]. While experimental SMI caused no pain in healthy individuals, sensory disturbances were often reported [9; 14; 16; 32; 36; 43]. Furthermore, SMI has been investigated via a live video feed of the neck in people with neck pain, since the relevance of investigating SMI via limb movements in people with spinal pain seems arbitrary. It was shown that SMI – e.g. distortions in visual feedback of the neck during movement - caused more sensory disturbances but no pain in people with whiplash associated disorder [13].

SMI has been studied in various musculoskeletal pain conditions [7-9; 30; 36], but not in people with LBP. Given the established impairments in neuromuscular control [6; 19; 23], findings of impaired body schema [44] and structural or functional brain changes [24] in people with CLBP, a role for SMI in people with CLBP seems plausible. The objective of this study was to determine the effect of experimental SMI on sensory disturbances and/or pain in people with CLBP and healthy volunteers. It is hypothesised that experimental SMI increases the intensity and frequency of sensory disturbances and/or pain in people with CLBP. Furthermore, it is hypothesised that people with CLBP experience a higher intensity and frequency of sensory disturbances and/or pain during experimental SMI than healthy volunteers.

Methods

Design

This study applied a randomised cross-over experimental design.

Participants

Study participants were recruited via physiotherapists and general practitioners, pamphlets in medical gyms and via social media in the Netherlands. In order to be eligible for participation in this study, participants needed to meet the criteria for chronic nonspecific LBP, which was defined as having back pain 'localised below the costal margin and above the inferior gluteal fold'[1] as the main symptom, with or without leg pain, for a minimum of 3 consecutive months[1; 26]. People with CLBP were excluded from the study if there was any evidence of specific spinal pathology (e.g. hernia, spinal stenosis, spondylolisthesis, infection, spinal fracture or malignancy), back surgery in the past 12 months or a severe chronic disease (e.g. a rheumatological-, cardiovascular-, neurological- or psychiatric disorder). Healthy pain free volunteers were recruited via participants (partners or life companions), pamphlets in medical gyms and via the staff of the primary practices for physiotherapy. Pain free, healthy volunteers were excluded if they had sought medical care for LBP in the past 6 months, or when suffering from any acute or chronic disease at the time of study participation.

All participants needed to be over 18 years old and proficient in Dutch language. People with severe visual impairments, epilepsy, pregnant women (until 1 year after giving birth) and people who had any former experience with mirror visual feedback treatment were excluded from the study. All participants had to discontinue the use of analgesic and anti-inflammatory drugs for 48 hours prior to

the experiment and were instructed to refrain from caffeine and alcohol, and to avoid physical exertion 24 hours prior to the experiment [10; 13].

Procedure

All participants were informed about the experiment via a booklet, but they were held naive to the purpose of the study. Participants were told that the goal of the study was to examine the effect of various kinds of visual feedback of the back in relation to motor control. Explicitly, no further explanation and no mentions were given about pain and other sensations to avoid reporting bias. Written informed consent was obtained prior to participation in the study. The study was approved by the Human Research Ethics Committee of the “Slotervaartziekenhuis en Reade”, Amsterdam in the Netherlands.

Baseline characteristics and general health information were collected via a questionnaire. In addition, participants were asked to complete a set of questionnaires in a standardised order at baseline: average back pain intensity over the last week was measured using a Numeric Rating Scale [22], pain related disability using the Roland Morris Disability Scale [35], the level of pain related catastrophizing using the Pain Catastrophizing Scale [38], kinesiophobia using the Tampa Scale of Kinesiophobia [39; 41] and the Central Sensitization Inventory [28] screened for the presence of symptoms of central sensitization.

After the baseline procedure, a 20 second practice trial was implemented, during which participants received visual feedback of the lower back during lateral flexion, in order for them to get acquainted

with the experimental set up. Thereafter, participants were subjected to the visual feedback experiment of the lower back. Waiting periods between conditions, where participants sat down in a chair, were implemented to allow for any provoked sensations to return to baseline status (maximum of 3 minutes). Measurements were performed by a (blinded) research assistant immediately after each condition. To prevent test-order bias, all conditions were performed in a computer-generated randomised order. To counter assessor bias, the research assistant was blinded to the medical history of the study participants (CLBP or healthy volunteer) and the order of the test conditions.

Visual feedback experiment

This experimental protocol was based on a previous study of our group in people with chronic whiplash associated disorder [10; 13] and adopted for the LBP population. The experiment consisted of 6 experimental conditions and 2 control conditions (Figure 1). All conditions lasted 20 seconds. During all experimental conditions, visual feedback was provided on a television screen placed in portrait mode in front of the standing participant (Figure 1). The camera (Logitech C920) was placed approximately 150 cm away from the participant, in such a way that the whole upper body was visible in a realistic fashion on the screen during the conditions. The distance between the participant and the screen was standardized at 90 cm (feet to screen).

Visual feedback of the back was provided either during movement (lateral flexion) or in a static position and either in a congruent or incongruent (distorted) manner. Visual feedback of the back during movement was provided in 2 conditions: the 'incongruent movement condition' and 'congruent movement condition'. The incongruent movement condition was the most relevant as this aimed to create experimental SMI. Participants were asked to continuously side flex the lower

back in a submaximal way guided by a metronome (www.metronomeonline.com) at a pace of 40 beats per minute during the movement conditions. In the congruent movement condition, the image of the participant's back on the television screen moved in the same direction as the participant was moving towards (congruent feedback). While, in the incongruent movement condition, the visual feedback was congruent during the first 6 side flexing actions, after which the image was suddenly switched whereby the side flexion was shown mirrored (incongruent visual feedback).

Static visual feedback was provided in 4 conditions. In 2 conditions, visual feedback of the back was provided from behind in a congruent or incongruent manner. In the 'congruent static back condition', the back was shown correctly. In the 'incongruent static back condition', the back was shown in a distorted manner as if it was positioned in a lateral lumbar shift. Static visual feedback of the left upper body, arm and hand – in a congruent and incongruent manner - was provided in 2 'arm conditions'. The 'congruent arm condition' showed the upper body, arm and hand in a congruent manner and the 'incongruent arm condition' showed the arm and hand in a distorted manner by bulging the image. Visual feedback of the upper body, arm and hand was provided to investigate the effect of visual feedback of a non-painful region (for the CLBP group). Participants were asked to keep their trunk as stationary as possible during the static conditions.

A picture of an apple was shown on the screen in the 2 control conditions; either during side flexion of the lower back (analogous to the movement conditions) or in a static position. The apple is considered as a neutral image since it has no association with body perception, therefore it controlled for sensations produced by moving the lower back (e.g., fatigue, muscle pain, stiffness). The image of the apple was also shown on the screen during the waiting periods between conditions.

Outcome measures

Sensory disturbances and pain (as a separate outcome) were the primary outcome measures. These outcomes were based on previous studies investigating SMI [32] and were assessed by the blinded research assistant directly after each condition. Sensory disturbances were divided into six categories: pain, discomfort, perceived temperature- or weight changes, perceived additional- or loss of limbs and feelings of peculiarity [7-9; 13; 32]. Perceived additional- or loss of limbs was substituted for balance disturbance for people with LBP. When participants experienced a painful feeling, this was defined as pain, whereas discomfort was defined as a sensation which felt uncomfortable (but did not feel painful). Similar, feelings of peculiarity constituted all sensations which did not feel uncomfortable but felt peculiar. All sensations combined were defined as sensory disturbances. These were assessed by asking 2 questions in the following order: 'How did it feel?' and 'Were you aware of any changes in your body?'. Participants rated perceived symptoms on a Visual Analogue Scale (VAS) (0 mm = no sensation to 100 mm = the worst possible sensation). Every single perceived symptom was individually rated on a VAS (e.g. when a participant reported pain and dizziness, both symptoms were individually scored on a VAS). The highest VAS score was used in the analysis.

The sense of body ownership over the lower back (presented) on the television screen was measured at baseline (during the practice trial) and during the incongruent movement condition to account for any loss of body ownership due to manipulation of visual feedback during movement which could interfere with the onset of SMI. Participants rated the perceived sense of body ownership over the lower back on the television screen via the question 'I felt as if the lower back on the screen was my own lower back' which was scored on a 7-point Likert scale, ranging from strongly disagree (---) to strongly agree (+++). This question was originally designed as a part of the rubber hand illusion questionnaire by Botvinick and Cohen [4] and was adapted for this study to the region of the lower back.

Sample Size

A priori, a sample size calculation for a between groups Mann-Whitney U test was performed using G*power 3.1. Data of reported sensory disturbances from the people with CLBP in the pilot trial (n=15) of this experiment were used for this calculation. Power was set at 0,8, alfa was set at 0,05 (two-sided) and the effect size was calculated at 0,75. Standard deviations of the group means were used to calculate the effect size. The mean of sensory disturbances in the CLBP group was 5.24 (\pm 11.85) and the mean of sensory disturbances in the healthy participants was 1.72 (\pm 21.34). Equal sized sample groups were assumed (meaning the allocation ratio of N1 to N2 is 1). For between group effects, the sample size was calculated at 31 participants per group.

Statistical analysis

Statistical analysis was performed using IBM SPSS version 22.0 for Windows (IBM Corp., Armonk, New York). Normality was tested with the Kolmogorov-Smirnov goodness-of-fit test combined with visual inspection of the data. Differences between groups on baseline characteristics were analysed using an independent t-test (age), a Pearson chi-square test (sex) and a Fisher's exact test (pain medication and antidepressants). A Friedman's test was used to compare the intensity of the outcomes (reported sensory disturbances and pain) across the movement and static conditions within each group. The movement conditions model tested for any increase in sensations due to experimental SMI (a mismatch between motor planning and sensory [visual] input), while the static conditions model tested for any increase in sensations solely due to a distortion of visual feedback of

the body. A Related-Sample Cochran's Q test was used to compare the frequency of reported outcomes across the movement and static conditions within each group. Herewith, the frequency of reported outcomes represented the number of people who reported sensations. In case of a significant result, pairwise comparisons were performed using a Dunn-Bonferroni correction for multiple comparisons. A Mann-Whitney Test was used to compare the intensity and Pearson chi-square test was used to compare the frequency of sensory disturbances between groups on all three incongruent conditions and the control condition with movement. A Wilcoxon signed rank test was used to test for any difference in the sense of body ownership over the lower back on the screen between baseline and the incongruent movement condition. For all comparisons, $p < .05$ (two-sided) was considered statistically significant. Data are reported as mean and standard deviation (SD) or median and inter quartile range (IQR).

Results

Baseline characteristics

A convenience sample of 66 people were included in this study (n=33 in the CLBP group and n=33 in the healthy volunteers group). All participants completed the experiment and there were no missing data for any of the sensory disturbance outcome measures. Groups were matched for gender and age. At baseline, there were no statistically significant differences between groups for any of the outcome variables or demographic characteristics (Table 1).

Sensory disturbances during the visual feedback experiment

Table 2 provides an overview of the frequencies of sensory disturbances which were reported during the visual feedback experiment. Pain, discomfort, balance disturbances and feelings of peculiarity were reported in both groups (range 0,4% - 22,4%), while perceived temperature or weight changes were not reported. No other symptoms were reported.

Within-group differences of reported sensory disturbances between movement conditions

The Friedman analysis showed no significant effect of visual feedback during movement on the intensity of sensory disturbances in people with CLBP ($\chi^2(2) = 2.111, p = .348$) and healthy volunteers ($\chi^2(2) = 2.947, p = .229$). Table 3 provides an overview of the effects of the movement conditions on sensory disturbances. The Related-Sample Cochran's Q test showed no significant effect of visual feedback during movement on the frequency of sensory disturbances in people with CLBP ($\chi^2(2) = .545, p = .761$) and healthy volunteers ($\chi^2(2) = 2.333, p = .311$).

Within-group differences of reported pain between movement conditions

Visual feedback during movement had no significant effect on pain intensity in people with CLBP ($\chi^2(2) = 2.136, p = .344$) and healthy volunteers ($\chi^2(2) = 2.000, p = .368$) (Table 3). The Related-Sample Cochran's Q test showed no significant effect of visual feedback during movement on the frequency of pain in people with CLBP ($\chi^2(2) = .600, p = .741$) and healthy volunteers ($\chi^2(2) = 2.000, p = .368$).

Within-group differences of reported sensory disturbances between static conditions

Static visual feedback had a significant effect on the intensity of sensory disturbances in people with CLBP ($\chi^2(4) = 10.143, p = .038$) and healthy volunteers ($\chi^2(4) = 21.560, p < .001$). Whereas, post-hoc comparisons revealed no significant differences between the static visual feedback conditions in both groups. Table 4 provides an overview of the effects of the static visual feedback conditions on sensory disturbances.

Static visual feedback had a significant effect on the frequency of sensory disturbances in people with CLBP, $\chi^2(4) = 10.261, p = .036$. Post-hoc comparisons revealed no significant differences between conditions. Static visual feedback had a significant effect on the frequency of sensory disturbances in healthy volunteers, $\chi^2(4) = 19.000, p = .001$. Post-hoc analysis revealed that the frequency of sensory disturbances was significantly higher during the incongruent static back condition (21.2%) than the static control condition (0%), $p_{\text{adjusted}} = .031$. Furthermore, the frequency of sensory disturbances was significantly higher during the incongruent "arm" condition (24.2%) than the congruent "arm" condition (3%), $p_{\text{adjusted}} = .031$, and significantly higher during the incongruent "arm" condition (24.2%) than the static control condition (0%), $p_{\text{adjusted}} = .007$. Figure 2 provides an overview of the frequency of reported sensory disturbances during the static visual feedback conditions.

Within-group differences of reported pain between static conditions

Static visual feedback had no significant effect on pain intensity in people with CLBP ($\chi^2(4) = 4.654$, $p = .325$) and healthy volunteers ($\chi^2(4) = .000$, $p = 1.000$). Furthermore, static visual feedback had no significant effect on the frequency of pain in people with CLBP, $\chi^2(4) = 6.222$, $p = .183$. None of the healthy volunteers reported pain during all static conditions.

Ownership

There were no significant differences in the sense of body ownership over the lower back on the screen between baseline and the incongruence movement condition in both groups ($p > .05$; data not shown).

Between-group differences

There was a significant difference between people with CLBP and healthy volunteers in the median intensity of sensory disturbances ($U = 350.5$, $p = .002$) and the frequency of sensory disturbances ($\chi^2(1) = 8.9$, $p = .003$) during the incongruent movement condition. Table 5 provides an overview of the between-group differences. There were no significant differences between people with CLBP and healthy volunteers in sensory disturbances during the incongruent static back condition and the incongruent arm condition ($p > 0.05$). Furthermore, there was a significant difference between people with CLBP and healthy volunteers in the median intensity of sensory disturbances ($U = 335.5$, $p < .001$) and the frequency of sensory disturbances ($\chi^2(1) = 11.9$, $p = .001$) during the control condition with movement.

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Discussion

The aim of this study was to determine the effect of experimental SMI on sensory disturbances and/or pain in people with CLBP and healthy volunteers. The results of this study show that experimental SMI does not affect sensory disturbances or pain in either group, therefore the research hypothesis - that incongruent visual feedback increases sensory disturbances and/or pain – is not supported. The intensity and frequency of sensory disturbances were not higher during experimental SMI. The same results were found for pain as an outcome. Although a significant effect of static visual feedback on sensory disturbances was found in both groups, post hoc analyses did not reveal any significant differences between conditions in the CLBP group. However, the healthy volunteer group showed an increase in frequency of reported sensory disturbances when static visual feedback of one's own body was shown in a distorted manner.

The results of this study show that experimental SMI is not related to the onset of sensory disturbances and/or pain in people with CLBP. Current results are consistent with studies that were unable to find a within-group association of SMI and bodily sensations [13; 43]. In contrast, there are studies which do show an effect of SMI on sensory disturbances in healthy individuals [5; 16] and people with whiplash associated disorder [7; 8]. Similarly, a recent meta-analysis showed that movement of the arms with incongruent visual feedback (maximum incongruence) increased the odds of pain compared to movement with congruent visual feedback (minimum incongruence) in people with fibromyalgia and complex regional pain syndrome (OR = 1.67; 95% CI 1.25 - 2.24), however not in people with chronic whiplash associated disorder [3]. Although, these results partly support the hypothesis of SMI, the odds are moderate and could also reflect the analgesic effect of congruent visual feedback in people with fibromyalgia and complex regional pain syndrome. This is substantiated by impaired analgesic responses to visual feedback of the neck in people with chronic whiplash associated disorder [10]. In general, results are inconsistent and further studies with

rigorous methodology are needed to clarify underlying mechanisms and replicate current results of SMI in people with CLBP.

Pain, discomfort, balance disturbances and feelings of peculiarity were reported in both groups during the experiment. This is in line with the results of reported sensory disturbances in previous studies [5; 7-9; 13; 16; 30; 32; 36; 43]. In this study, the highest frequencies in people with CLBP were found for pain (22%) and discomfort (11%), while frequencies were lower in the healthy volunteer group (pain 0% and discomfort 6%). Furthermore, the intensity of sensory disturbances was significantly higher in people with CLBP than healthy volunteers during experimental SMI. However, this difference between people with CLBP and healthy volunteers was also found during the control condition with movement. Aggravation of sensations due to movement could be a logical explanation for this result. It seems less plausible that a conflict between vision and proprioception played a role in this increase of sensory disturbance reports in people with CLBP. This is consistent with the study of Boesh et al, which showed that the odds for experiencing sensory disturbances due to a sensorimotor conflict was not significantly different between people with chronic pain and healthy volunteers [3].

Interestingly, in healthy volunteers, more sensory disturbances were reported when viewing a distorted image of one's own back. While a similar pattern was found in the CLBP group, post hoc analyses did not find such differences. This could be due the conservative nature of post hoc analyses combined with the relatively high frequency of sensory disturbances during the control condition in people with CLBP. There are previous studies that support a symptom-increasing effect of distorted visual feedback in people with chronic pain [33], while others show an opposite analgesic effect of distorted visual feedback in people with pain and healthy volunteers [12; 27; 34]. Furthermore, there is increasing evidence of the analgesic effect of congruent visual feedback in healthy volunteers and

people with (low) back pain [11; 12; 45]. We found a (non-significant) lower number of reported sensory disturbances during congruent static visual feedback compared to incongruent static visual feedback, which might be reflected by the positive effect of this intervention in people with CLBP. This might have important implications for developing new visual feedback interventions for people with CLBP. However, until now, effects seem highly variable and future research is needed to further elucidate the effects of distorted and congruent visual feedback.

Limitations

The results need to be interpreted with caution due to some limitations. It remains unknown whether experimental SMI created a warning signal that was threatening enough to cause a sensorimotor conflict, as proposed by Harris in his SMI theory [18]. In the current study, the mirrored movements shown on the screen during side flexion created incongruence between top down motor planning and real time visual feedback. It is proposed that sensory disturbances reported during SMI are warning signals due to this incongruence. The idea is that when this incongruence lasts or reaches the individual threshold, this might result in pain [29; 31; 32]. Visual feedback sessions were delivered for a short time interval (20 seconds). Even though this interval is congruent with previous research, this might be too short to trigger pain due to incongruence. According to the theory of SMI, there is a (continuous) internal mismatch within the sensorimotor system which drives the nociceptive system in people with chronic pain [15; 18]. Placing someone in an environment of incongruence will therefore increase the level of threat and exacerbate existing symptoms. In this study, people did often report that they felt confused by the sudden mismatch between visual feedback and motor output, which might indicate that the mismatch was effective in generating a conflict, however this mismatch did not evoke significantly more bodily sensations compared to the other conditions. Participants could, however, have a clear understanding of what caused the mismatch, which might have diminished the level of threat. It remains uncertain whether our

experimental set-up - placing someone in an environment of conflicting visual feedback (from a third person perspective) for 20 seconds - was threatening enough to cause an error in information processing. It seems unlikely that any loss of body ownership during the manipulation of visual feedback interfered with the onset of SMI, since there were no differences between baseline ownership and ownership during the incongruent movement condition. Adapting questions from the rubber hand illusion questionnaire, to measure the sense of body ownership during different experimental set ups, has been done before to discriminate between experimental conditions [2; 17; 25; 27]. Despite, the validity of the current ownership-measure in people with CLBP remains unknown. Additionally, the lower back was (partly) visible in side view during the 'arm' conditions. Even though participants were clearly instructed to focus solely on their arm, it remains possible that some participants have also focussed on their lower back during the 'arm' conditions. This means that during these conditions, some participants could have experienced sensations because of focussing on their whole upper body and back and not solely by focussing on their arm.

Strengths of this study include the randomized cross-over experimental design, the multiple conditions controlling for various major sources of bias, blinding of the research assistant, sample size compliant with the a priori sample size calculation, recruitment of people through various primary care settings to limit selection bias and the computer-generated randomisation of measurement order and order of test conditions. While previous studies have focussed of the effects of SMI on pain in people with musculoskeletal pain, this is the first study to investigate SMI in people with CLBP.

Conclusion

The results of this study show that a sensorimotor conflict, created by a live video feed, does not increase sensory disturbances or pain in people with CLBP and healthy volunteers. Therefore, the hypothesis that SMI increases sensory disturbances or pain in people with nonspecific chronic pain is not supported. Further studies are needed in order to substantiate these results of the effects of incongruent visual feedback during movement in people with CLBP.

Acknowledgements and conflict of interest statement

No funding sources or conflicts of interest are declared. The authors are grateful for the technical help of Orson Baars in the development phase of the experiment.

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Figure Legends

Figure 1 Visual feedback experiment of the back

Top row; the experimental setup of the visual feedback experiment of the lower back.

Middle row (from left to right); visual feedback of the back shown during a static position correctly, visual feedback of the back during a static position shown distorted, visual feedback of the back during movement shown correctly and visual feedback of the back during movement shown mirrored.

Bottom row; visual feedback of the left upper body and arm shown correctly, visual feedback of the left upper body and arm shown bulged and the image of the apple which was provided during the static and movement control conditions.

Figure 2 Healthy volunteers experience more sensory disturbances due to distorted visual feedback of their own body

Abbreviations: CLBP, chronic low back pain

* Significant post hoc comparisons

Table Legends

Table 1 Participant characteristics

* Values are mean \pm SD unless otherwise indicated.

Abbreviations: m, median; IQR, interquartile range; NA, not applicable; NRS, Numeric Rating Scale, RMDS, Roland Morris Disability Scale, TSK, Tapa Scale of Kinesiophobia, PCS, Pain Catastrophizing Scale, n, number.

§ a Pearson chi-square test was used to conduct the analysis.

̄ an independent t-test was used to conduct the analysis.

‡ a Fisher's exact test was used to conduct the analysis.

Table 2 The frequencies of sensory disturbances reported in both groups

Abbreviations: CLBP, chronic low back pain.

Table 3 The effect of visual feedback during movement on reported sensory disturbances and pain in people with chronic low back pain (n=33) and healthy volunteers (n=33)

Abbreviations: VAS, Visual Analogue Scale (0 – 100); CLBP, chronic low back pain; HV, healthy volunteers.

Table 4 The effect of static visual feedback on reported sensory disturbances and pain in people with chronic low back pain (n=33) and healthy volunteers (n=33)

Abbreviations: VAS, Visual Analogue Scale (0 – 100); CLBP, chronic low back pain; HV, healthy volunteers.

[§] The frequency of sensory disturbances was significantly higher during the incongruent static back condition than the static control condition based on post-hoc testing.

[†] the frequency of sensory disturbances was significantly higher during the incongruent arm condition than the congruent arm condition and significantly higher during the incongruent arm condition than the static control condition based on post-hoc testing.

Table 5 Differences between people with chronic low back pain and healthy volunteers in reported sensory disturbances

Abbreviations: CLBP, chronic low back pain; VAS, Visual Analogue Scale (0 – 100)

* Values are median (interquartile range).

[§] A Mann-Whitney Test was used to conduct the analysis.

[†] a Pearson chi-square test was used to conduct the analysis.

Table 1 Participant characteristics*

| | Chronic Low Back Pain (n=33) | Healthy volunteers (n=33) | P Value |
|----------------------------------|-------------------------------------|----------------------------------|-------------------|
| Sex (female), n (%) | 21 (63.6%) | 21 (63.6%) | 1.0 [§] |
| Age, years | 39.6 ± 11.9 | 39.2 ± 12.9 | .914 [†] |
| Range in years | 21 – 66 | 20 – 61 | |
| Disease duration, m (IQR) | 36 (4.5 - 150) | NA | |
| Range in months | 3 – 540 | | |
| Pain (NRS) | 5.2 ± 2.0 | NA | |
| Range | 2 - 9 | | |
| Pain location, n (%) | | | |
| Unilateral | 13 (39.4%) | NA | |
| Bilateral | 20 (60.6%) | | |

| | | | |
|------------------------------------|------------|--------|-------------------|
| Pain medication, n (%) | 4 (12.1%) | 0 (0%) | .114 [‡] |
| Antidepressants, n (%) | 2 (6.1%) | 1 (3%) | 1.0 [‡] |
| Disability (RMDS) | 6.0 ± 4.2 | NA | |
| Range | 0 - 18 | | |
| Kinesiophobia (TSK) | 31.0 ± 6.0 | NA | |
| Range | 26 - 47 | | |
| Pain catastrophizing (PCS) | 11.5 ± 8.3 | NA | |
| Range | 0 - 34 | | |
| Central sensitisation (CSI) | 30.9 ± 9.6 | NA | |
| Range | 16 - 55 | | |

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Table 2 The frequencies of sensory disturbances reported in both groups

| Sensory disturbances categories | Visual feedback experiment | |
|---------------------------------|----------------------------|----------------------------------|
| | <i>CLBP group (n=33)</i> | <i>Healthy volunteers (n=33)</i> |
| Pain | 22,4% | 0,4% |
| Discomfort | 10,7% | 5,5% |
| Temperature changes | 0% | 0% |
| Weight changes | 0% | 0% |
| Balance disturbances | 1,8% | 0,4% |
| Feelings of peculiarity | 4,0% | 4,0% |

Table 3 The effect of visual feedback during movement on reported sensory disturbances and pain in people with chronic low back pain (n=33) and healthy volunteers (n=33).

| Group | Variable | Congruent Moving | Incongruent Moving | Control Moving | P-value |
|-------|-------------------------------|------------------|--------------------|----------------|-----------------|
| CLBP | <i>Sensory disturbances</i> | | | | |
| | Median intensity (VAS), (IQR) | 0 (0 - 44.5) | 0 (0 - 40) | 0 (0 - 46) | p = .348 |
| | Frequency, n (%) | 13 (39.4) | 15 (45.5) | 14 (42.4) | p = .761 |
| | <i>Pain</i> | | | | |
| | Median intensity (VAS), (IQR) | 0 (0 - 16.5) | 0 (0 - 35) | 0 (0 - 28) | p = .344 |
| | Frequency, n (%) | 10 (30.3) | 12 (36.4) | 11 (33.3) | P = .741 |
| HV | <i>Sensory disturbances</i> | | | | |
| | Median intensity (VAS), (IQR) | 0 (0 - 0) | 0 (0 - 0) | 0 (0 - 0) | p = .229 |
| | Frequency, n (%) | 1 (3) | 4 (12.1) | 2 (6.1) | p = .311 |
| | <i>Pain</i> | | | | |
| | Median intensity (VAS), (IQR) | 0 (0 - 0) | 0 (0 - 0) | 0 (0 - 0) | P = .368 |
| | Frequency, n (%) | 0 (0) | 0 (0) | 1 (3) | P = .368 |

Table 4 The effect of static visual feedback on reported sensory disturbances and pain in people with chronic low back pain (n=33) and healthy volunteers (n=33).

| Group | Variable | Congruent back | Incongruent back | Congruent arm | Incongruent arm | Control (static) | P-value |
|-------|-------------------------------|----------------|-----------------------|---------------|-----------------------|------------------|---------------------|
| CLBP | <i>Sensory disturbances</i> | | | | | | |
| | Median intensity (VAS), (IQR) | 0 (0 - 0) | 0 (0 - 37) | 0 (0 - 3.5) | 0 (0 - 63) | 0 (0 - 26) | p = .038 |
| | Frequency, n (%) | 5 (15.2) | 13 (39.4) | 7 (21.2) | 12 (36.4) | 11 (33.3) | p = .036 |
| | <i>Pain</i> | | | | | | |
| | Median intensity (VAS), (IQR) | 0 (0 - 0) | 0 (0 - 0) | 0 (0 - 0) | 0 (0 - 0) | 0 (0 - 0) | p = .325 |
| | Frequency, n (%) | 3 (9.1) | 6 (18.2) | 5 (15.2) | 7 (21.2) | 7 (21.2) | P = .183 |
| HV | <i>Sensory disturbances</i> | | | | | | |
| | Median intensity (VAS), (IQR) | 0 (0 - 0) | 0 (0 - 4.5) | 0 (0 - 0) | 0 (0 - 3.5) | 0 (0 - 0) | p = <.001 |
| | Frequency, n (%) | 2 (6.1) | 7 (21.2) [§] | 1 (3) | 8 (24.2) [†] | 0 (0) | p = .001 |
| | <i>Pain</i> | | | | | | |
| | Median intensity (VAS), (IQR) | 0 (0 - 0) | 0 (0 - 0) | 0 (0 - 0) | 0 (0 - 0) | 0 (0 - 0) | P = 1.00 |
| | Frequency, n (%) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | P = 1.00 |

Table 5 Differences between people with chronic low back pain and healthy volunteers in reported sensory disturbances

| | CLBP (n=33) | Healthy volunteers (n=33) | P Value |
|-------------------------------|------------------------|--------------------------------------|---------------------|
| Incongruent Moving | | | |
| Median intensity (VAS), (IQR) | 0 (0 - 40) | 0 (0 - 0) | .002 [§] |
| Frequency, n (%) | 15 (45.5) | 4 (12.1) | .003 [‡] |
| Incongruent back | | | |
| Median intensity (VAS), (IQR) | 0 (0 - 37) | 0 (0 - 4.5) | .257 [§] |
| Frequency, n (%) | 13 (39.4) | 7 (21.2) | .111 [‡] |
| Incongruent arm | | | |
| Median intensity (VAS), (IQR) | 0 (0 - 63) | 0 (0 - 3.5) | .132 [§] |
| Frequency, n (%) | 12 (36.4) | 8 (24.2) | .288 [‡] |
| Control Moving | | | |
| Median intensity (VAS), (IQR) | 0 (0 - 46) | 0 (0 - 0) | < .001 [§] |
| Frequency, n (%) | 14 (42.4) | 2 (6.1) | .001 [‡] |