6-1-2021

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Musculoskeletal Science and Practice 53 (2021) 102376

Contents lists available at ScienceDirect

Musculoskeletal Science and Practice

journal homepage: www.elsevier.com/locate/msksp

Original article

Sense of effort is distorted in people with chronic low back pain

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ARTICLE INFO

Keywords:
Spinal pain
Proprioception
Muscle spindle
Rehabilitation
Disability

ABSTRACT

Background: Proprioceptive deficits in people with low back pain (LBP) have traditionally been attributed to altered paraspinal muscle spindle afference and its central processing. Studies conducted in the upper limb demonstrated that sense of effort is also an important source of kinaesthetic information. **Objectives**: To better understand proprioceptive deficits in people with chronic LBP (cLBP), this study aimed to test whether sense of effort is affected in people with cLBP. **Design**: Cross-sectional study. **Method**: Fourteen participants with cLBP and fourteen healthy participants performed a 120 s force matching task with their trunk extensor muscles at a low intensity. **Results**: When visual feedback of the generated force was provided, both groups performed the task accurately. Removal of visual feedback resulted in an increase in error for both groups ($p < 0.0001$), but the increase in error was significantly larger for the cLBP group ($p = 0.023$). This larger error could be attributed to undershooting of the target force ($p = 0.020$). The control group did not consistently undershoot or overshoot the target force ($p = 0.93$). Furthermore, the amount of undershooting for the cLBP group increased as the task progressed ($p = 0.016$), which was not observed for the control group ($p = 0.80$). **Conclusions**: The results of this study revealed that sense of effort is affected in cLBP. People with cLBP overestimated the trunk extension force they generated, and the error increased as the trial progressed. With visual feedback however, people with cLBP were able to compensate and perform the task as accurately as people without cLBP.

1. Introduction

Proprioception encompasses different senses, such as detection of joint position and movement (kinaesthesia), sensation of force and heaviness accompanying muscle contractions, and sensations (e.g., effort) related to descending motor commands (Proske and Gandevia, 2012). The central nervous system receives input from a wide range of receptors concerned with monitoring the body's actions (Proske, 2005). A common view is that muscle spindles along with contributions from skin and joint receptors are responsible for the sense of position and movement, and tendon organs provide the sense of tension. Sense of effort or heaviness differs from the other senses as it is believed to be generated within the central nervous system and in its simplest form does not require input from peripheral receptors (de Morree et al., 2012).

Deficits in proprioception are commonly reported in people with low back pain (LBP), although a few studies have failed to show deficits (Laird et al., 2014; Tong et al., 2017). The experimental paradigms that have been used to evaluate proprioception in LBP have nearly all focussed on sense of position or movement. Because afferent signals from muscle spindles have been regarded as the main input for kinaesthesia, it has been logical to reason that altered paraspinal muscle

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https://doi.org/10.1016/j.msksp.2021.102376
Received 6 August 2020; Received in revised form 11 March 2021; Accepted 29 March 2021
Available online 2 April 2021

spindle afference and its central processing may be affected in people with LBP (Brumagne et al., 2000; Jones et al., 2012).

It has been argued however, that muscle spindles are not well suited as position sensors (Proske and Allen, 2019). Afferent discharges from spindles can result from muscle stretch but may also result from intrafusal muscle fibres contraction. This means that muscle spindles provide a potentially ambiguous signal for position sense (Macefield and Knellwolf, 2018). As a consequence, the notion that muscle spindles play the principal role in kinaesthesia may be overestimated. Similarly, the view that proprioceptive deficits in LBP reflect altered paraspinal muscle spindle afference or its central processing may need reappraisal.

Positional information also demonstrated to be derived from motor command and effort associated with movement (Gandevia et al., 2006; Smith et al., 2009; Walsh et al., 2004; Weerakkody et al., 2003). For example, a change in joint position is perceived when an effort is made to move a joint even though the muscles that cross that joint are paralysed, anaesthesised or undergo muscle vibration (Brooks et al., 2013; Luu et al., 2011; Monjo et al., 2018). Studies indicate that when movements are produced volitionally, centrally generated signals of motor command and sense of effort are a source of kinaesthetic information (Proske and Allen, 2019).

The ability to actively replicate target positions of the trunk is most commonly used to study proprioception in LBP (Tong et al., 2017). Considering the active nature and the revealed contribution of motor commands and sense of effort to kinaesthesia, it is impossible to determine whether the deficits in proprioception demonstrated in these repositioning tasks could be explained by altered receptor afference and its central processing as previously suggested (Brumagne et al., 2000). An alternative hypothesis is that proprioception is altered in cLBP due to altered motor commands or sense of effort that would contribute to repositioning errors as the person moves the back to the target position. The aim of this study was to examine whether sense of effort is altered in people with cLBP. We hypothesised that sense of effort is affected in cLBP, but because no other studies have investigated this, we are unable to reason whether there would be a consistent overestimation or underestimation of the generated force, or whether the error would be fluctuating (Pranata et al., 2017). revealed that the ability to control lumbar extensor force output is impaired in people with cLBP. However, their research focused on the ability to generate isometric muscle force, and not on sense of effort. The participants in that study had real-time visual feedback about their force production throughout the experiment and could rely on visual rather than proprioceptive feedback.

2. Materials and methods

2.1. Participants

Twenty-eight volunteers participated in this study. The participants' characteristics are listed in Table 1. Participants were aged between 18 and 50 years of age, without neurological or respiratory disorders. Fourteen participants had cLBP and 14 volunteers served as control participants. Inclusion criteria for the cLBP group were the presence of LBP for at least 6 months, which had limited activities of daily living and for which some form of treatment, such as medication, medical consultation, or physiotherapy, had been sought. In agreement with previous motor control studies in cLBP (e.g., Pranata et al., 2017; van den Hoorn et al., 2012), people with mild cLBP were recruited (i.e., a pain intensity between 0.5 and 4.4 cm on a 10-cm visual analogue scale (Jensen et al., 2003), ranging from 0 (no pain) to 10 (worst possible pain imaginable)). Exclusion criteria included a history of spinal surgery, spinal deformities, such as scoliosis, or a moderate or severe pain intensity score (more than 4.4 cm on a visual analogue scale (Jensen et al., 2003)). Control participants could not have had a significant episode of LBP in the preceding two years. Written consent was obtained from all participants prior to the commencement of the study. The study was carried out in accordance with The Code of Ethics of the World Medical Association (Declaration of Helsinki) for experiments involving humans and was approved by the Institutional Ethics Committee.

Table 1
Characteristics (mean (SD)) for the participants with and without low back pain.

	Low back pain group	Asymptomatic group	Statistical comparison
Sex (female n (%))	8 (57%)	7 (50%)	
Age (years)	25 (7)	24 (6)	$p = 0.81$
Height (cm)	170 (7)	172 (8)	$p = 0.48$
Weight (kg)	61.4 (11.5)	65.9 (10.7)	$p = 0.30$
BMI (kg/m^2)	21.5 (3.4)	22.3 (2.7)	$p = 0.50$
Baecke Physical Activity Questionnaire			
- Work (1–5)	2.6 (0.6)	2.3 (0.4)	$p = 0.15$
- Sport (1–5)	2.6 (1.4)	2.6 (0.9)	$p = 0.90$
- Leisure (1–5)	2.9 (0.3)	3.0 (0.4)	$p = 0.26$
Oswestry LBP Disability Index (0–100)	27.6 (10.4%)	0.3 (0.9%)	$p < 0.0001$
Roland-Morris Low Back Pain and Disability Questionnaire (0–24)	5.1 (4.2)	0.1 (0.3)	$p < 0.0001$
Pain intensity (day of testing; VAS 0–10)	2.6 (1.8)	0.0 (0.1)	$p < 0.0001$
Pain intensity (worst last week; VAS 0–10)	5.5 (2.0)	0.1 (0.2)	$p < 0.0001$
Duration of symptoms (years)	5 years (4)		

Abbreviations; BMI: body mass index; VAS: visual analogue scale.

2.2. Pain and function scales

Participants completed the Oswestry Low Back Pain Disability Index and the Roland-Morris Low Back Pain and Disability Questionnaire prior to the testing session. They rated their current and worst pain level during the last week on a 10-cm visual analogue scale (ranging from 0 (no pain) to 10 (worst possible pain imaginable)). These instruments have been shown to be adequately valid and reliable for use in this population, and recommended tools for research in LBP (Chiarotto et al., 2018). Participants also completed the Baecke Physical Activity Questionnaire, which is reliable (Carvalho et al., 2017) and valid (Pols et al., 1995).

2.3. Force matching task

Participants were semi-seated in an aluminium frame (Fig. 1A). To minimise pelvic motion, the pelvis was fixated with supports behind the sacrum and in front of the left and right anterior superior iliac spine. Participants performed an isometric trunk extension effort against resistance provided via a steel cable, to match a varying target force for 120 s. The target force varied pseudo-randomly between 3% and 10% of a force estimated to represent the average maximum isometric trunk extension force of healthy individuals using our experimental set-up. To determine the average maximum voluntary contraction (MVC), a preparatory experiment with nine males (mean (SD) age: 25.8 (5.3)) and seven females (age: 23.0 (2.2)) was conducted. The participants were positioned in the same semi-seated position in the same experimental set-up as the actual experiment. The peak trunk extension force of three isometric 3s MVC attempts was determined for each participant (mean (SD) extension force males: 70.3 (12.3) kg; females: 39.5 (18.2) kg). Based on the findings of this preparatory experiment, the target force was varied between 2.5 kg (3%) and 7.5 kg (10%) for males and between 1.5 kg (3%) and 7.5 kg (10%) for females. We opted for low %MVC to avoid possible exacerbation of cLBP, to reflect activity levels still performed by both people with cLBP and healthy participants, and to minimise the impact of possible functional and structural changes in the trunk extensor muscles (Hodges and Danneels, 2019). Each 120-s trial started at a force level midway between these two limits, i.e. at 6.5% of MVC. Before each trial, the force level of 6.5% of MVC was displayed for 15s to allow the participants to generate the required starting force.

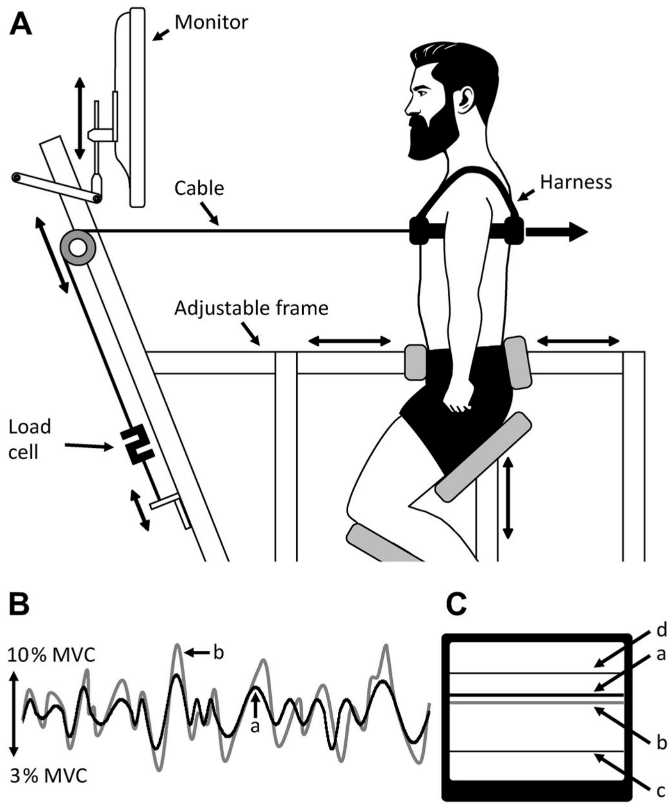

Fig. 1. (A) The experimental set-up showing a participant in the semi-seated position in an aluminium frame with the pelvis fixed bilaterally over the anterior superior iliac spines and the sacrum. A harness was connected via a cable and pulley to a load cell. (B) The pseudo-random target waveform (black line) and an illustration of a generated trunk extension force (grey line). (C) The monitor displayed the target force as a horizontal line (a) which moved up and down semi-randomly. In trials with visual feedback, a second horizontal line (b) displayed the generated trunk extension force. The boundaries between which the target force varied (c: 3% MVC; d: 10%MVC) were displayed throughout all trials.

The force-matching task was performed in two different conditions. In one condition, the participant received visual feedback about the target and the generated force. Both forces were displayed on a computer monitor as horizontal lines of different colours (Fig. 1C). In the other condition, visual feedback of the generated force was removed to eliminate exteroceptive input (vision). In this condition, the target force and the lower (3%) and upper (10%) limits were displayed. Visual feedback about their force generation was removed once the participant had maintained the starting force level of 6.5% of MVC for 2–3 s. The conditions were offered in random order and each condition was performed once with 2 min rest between trials. One practice trial with visual feedback was performed prior to commencement of the study to familiarise the participants with the experimental set-up, tasks and the required force level.

Spike 2 software and a Micro 1401 data acquisition system (Cambridge Electronic Design, Cambridge, UK) were used to generate the waveform of the target force and to collect the data. The extension force produced by the participant was measured with a load cell (Model L235, Futek, Irvine, CA) connected to the cable that provided resistance to trunk extension. Signals from the load cell were amplified (SG71, Valydine, Northridge, CA) and sampled at 100 Hz.

2.4. Data analysis

Data files were imported into Matlab for analysis (The Mathworks, Natick, MA). Fig. 1B shows the target force waveform and an example of a waveform of the generated trunk extension force. Based on the waveforms, three outcome measures were calculated (see below for further details): (1) accuracy (error area, mean absolute error and % MVC), (2) undershooting or overshooting (%MVC), and (3) drift (trendline slope).

Accuracy: The area between the two waveforms was calculated as a measure of task accuracy (i.e., error area). A larger error area represents larger discrepancies between the target force and generated force, and reflects lower accuracy. In these calculations, absolute differences between the waveforms were used, i.e., the direction of the error (overshooting or undershooting) was not considered. Accuracy was also expressed as the mean absolute error by dividing the error area by the trial duration (i.e., the number of data points) and expressed as %MVC.

Undershooting or overshooting: To identify whether the participants undershot or overshot the waveform of the target force, the mean error (difference between the target and generated force) was calculated. This yielded either a positive or negative mean value. The mean error across the entire trial was expressed in %MVC. Positive values indicate that, on average, the generated force exceeded (overshot) the target, that is, the participant underestimated the trunk extension force they were generating. Negative values represent undershooting, consistent with overestimation of the force that was generated. Both errors were interpreted as a distorted sense of effort.

Drift: The overall drift of the generated trunk extension force away from the target over the course of the trial was calculated by fitting a linear trendline through the generated extension force. A trendline sloping upward (positive slope) would represent a trend of a progressive increase in force generated by the participant (i.e., progressive increase in underestimation of the generated trunk extension force). A downward sloping trendline (negative slope) would represent a trend of a progressive decrease in force generated by the participant.

2.5. Statistical analysis

A two-way mixed-design analysis of variance (ANOVA) with one group factor (GROUP: cLBP vs. control) and one repeated-measures factor (CONDITION: visual feedback vs. no visual feedback) evaluated differences in the area between the waveforms, overall undershooting or overshooting of the target force, and differences in the slope of the trendline between participants with and without cLBP (Statistica, StatSoft, Tulsa, OK). Characteristics of the participant groups were compared with unpaired t-tests. The level of significance was set at $p < 0.05$.

3. Results

3.1. Participants

There were no significant differences between the participants with and without cLBP for age, height, body weight, body mass index and level of physical activity during work, sport or leisure (Table 1). For the cLBP group, the mean level of pain was mild on the day of testing and moderate when at its worst (Jensen et al., 2003). People with cLBP reported a mild to moderate level of disability (Table 1).

3.2. Sense of effort

3.2.1. Accuracy

Absence of visual feedback had a different effect on error area for participants with cLBP compared to pain-free controls (Group × Condition interaction: $p = 0.023$; Fig. 2A). There was no difference in error area between the cLBP group and the control group when visual feedback was available ($p = 0.38$). Although removal of visual feedback increased the error area for both groups ($p < 0.0001$), the increase in error area was significantly larger for the cLBP group compared to the control group ($p = 0.023$).

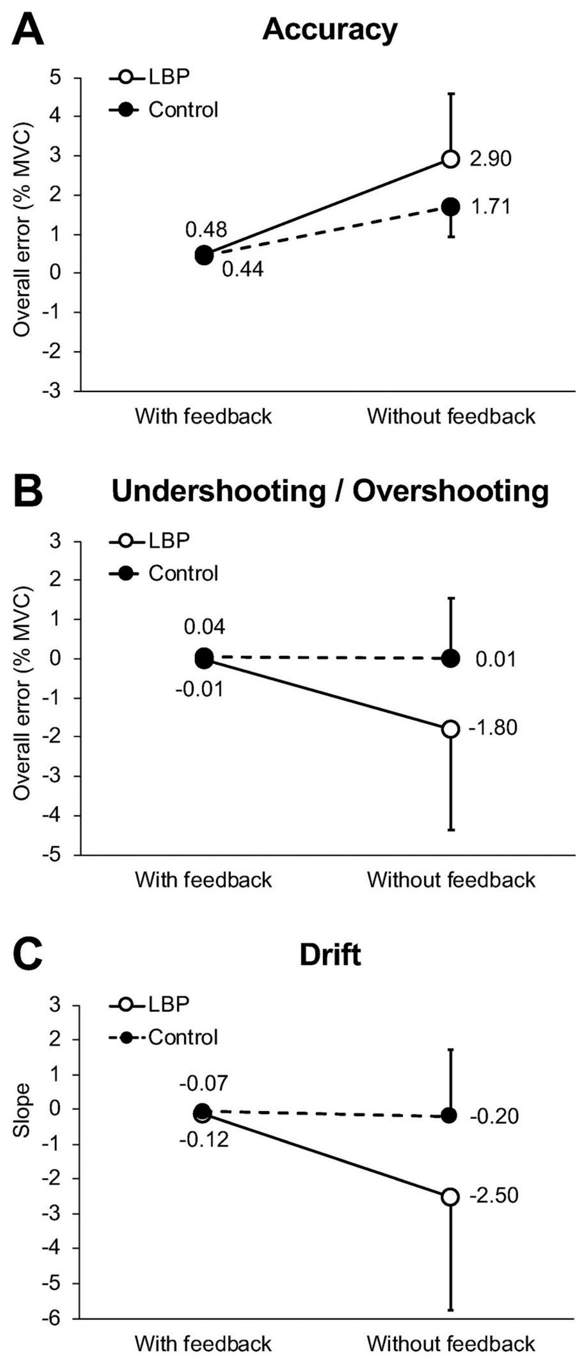

Fig. 2. (A) *Accuracy*: Without visual feedback, the error was significantly larger for both groups, but the increase in error was significantly larger for the LBP group compared to the control group. (B) *Undershooting or overshooting*: In contrast to the control group which showed no difference, when visual feedback was removed, the LBP group significantly undershot the target force, indicating that they overestimated their actual trunk extension force. (C) *Drift*: Without visual feedback, the slope of the trendline decreased significantly for the LBP group, whereas it remained largely unchanged for the control group. Please note, all slope values are multiplied by 10^4. Results from statistical analyses are reported in the text. Error bars represent one standard deviation.

3.2.2. *Undershooting or overshooting*

There was no consistent undershoot or overshoot of the target when visual feedback was available. Removal of visual feedback had a different effect for people with and without cLBP (Group × Condition interaction $p = 0.036$; Fig. 2B). For the control participants, removal of visual feedback did not lead to a consistent undershooting or overshooting of the target force ($p = 0.93$). In contrast, cLBP participants significantly undershot the target force in the absence of visual feedback relative to trials with feedback ($p = 0.020$). That is, participants with cLBP overestimated their generated trunk extension force during the force-matching task.

3.2.3. *Drift*

Fig. 3 illustrates the mean trunk extension force and the trendlines fitted through this extension force for the cLBP and control group. The corresponding slope values are shown in Fig. 2C. In the presence of visual feedback, the trendline was nearly horizontal for both control (slope (mean (SD)): 0.00001 (0.00001)) and cLBP (slope: 0.00001 (0.00001)) participants. Removal of visual feedback had a different effect for healthy participants and people with cLBP (Group × Condition interaction: $p = 0.034$). Whereas the slope of the trendline remained largely unchanged when visual feedback was removed for controls (slope: 0.00002 (0.00019); $p = 0.80$), the slope of the trendline decreased significantly in the absence of visual feedback for those with cLBP (slope: 0.00025 (0.00033); $p = 0.016$). That is the cLBP participants overestimated the generated trunk extension with a progressively greater amount over time.

4. Discussion

The results of this study support the hypothesis that sense of effort is altered in people with cLBP. Trials with visual feedback demonstrated that participants with and without cLBP could perform the task accurately. Yet, when visual feedback was removed, participants with cLBP matched the force less accurately than control participants, and undershot the target force. This can be interpreted as overestimation of the force generated by their extensor muscles. The discrepancy between the target and generated force increased over the duration of the task.

Deficits in proprioception in LBP have generally been attributed to impaired afference from paraspinal muscle spindles or changes to its central processing (Brumagne et al., 2000; Parkhurst and Burnett, 1994). Although kinaesthesia has been considered to depend on peripheral afferent signals from cutaneous and joint receptors (Skoglund, 1973) and that muscle spindles play a key role in sense of position and movement (Goodwin et al., 1972), muscle spindles have several drawbacks as position sensors. The most important is that sensitivity of muscle spindles is influenced by fusimotor control (Gandevia et al., 2006). This means that spindles provide potentially ambiguous information and discharge can be modulated by intrafusal muscle contractions or result of muscle stretch (Proske, 2005). If muscle spindles are not optimal for position sense, the current common interpretation of proprioceptive deficits in LBP may require revision. Compelling evidence that motor commands and effort contribute to position sense was previously revealed (Gandevia et al., 2006; Smith et al., 2009). Gandevia et al., (2006) showed that with the forearm and hand paralysed (anaesthesised by ischaemic block), the perceived wrist angle changed by ~20° in the direction of effort during attempted wrist flexion or extension. Further, Smith et al., (2009) showed that the amplitude of the illusion depends on the level of effort. Similar results but of a smaller magnitude were found when the arm was paralysed but with afferent signals intact.

It is plausible that distorted sense of effort can, at least in part, explain deficits in repositioning error in LBP. Most paradigms used to investigate position sense in LBP have involved active reproduction of target positions of the trunk (Brumagne et al., 2000; Field et al., 1997; Gill and Callaghan, 1998; Koumantakis et al., 2002; Lam et al., 1999; Newcomer et al., 2000a; Newcomer et al., 2000b; O'Sullivan et al., 2003; Parkhurst and Burnett, 1994). Although this has been interpreted to rely on muscle spindle feedback, participants may also use reproduction/matching sense of effort to reproduce the target position. As the tasks involve movement, it is difficult to disentangle whether the observed deficits are explained by altered input from

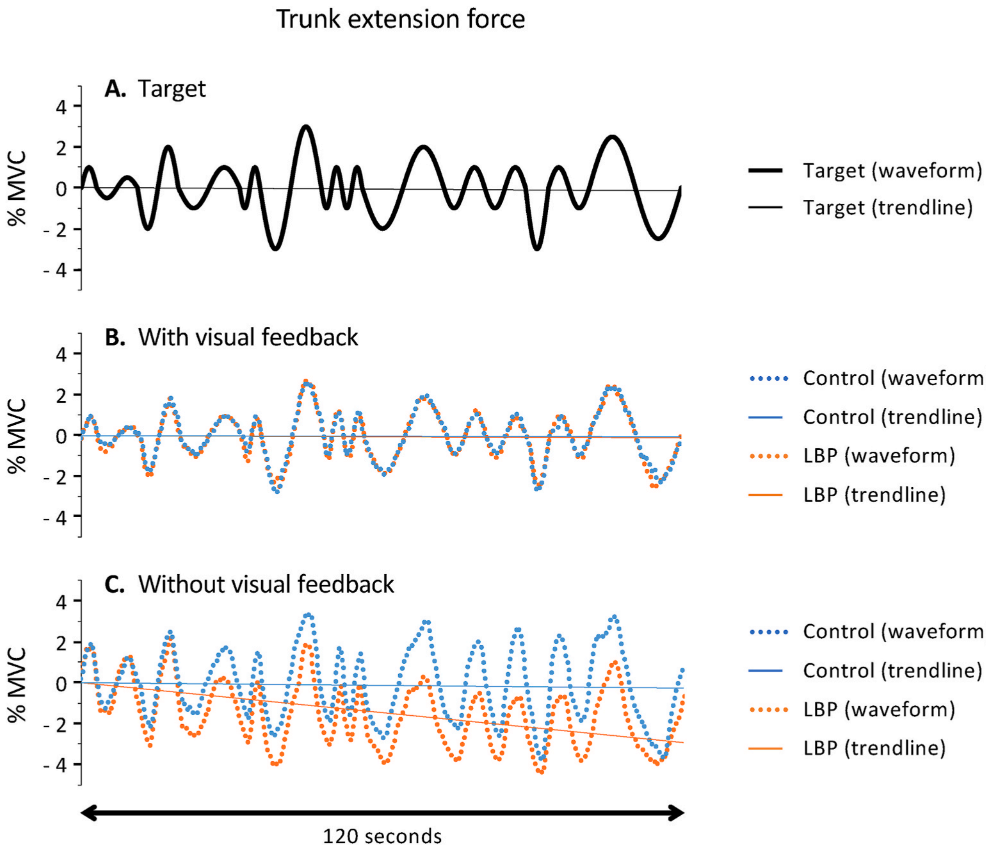

Fig. 3. The mean trunk extension forces for the LBP group and control participants during the trials with visual feedback (B) and without visual feedback (C). With visual feedback, the slope of the trendlines was horizontal and the trendline of both groups overlapped. Without visual feedback, the trendline for the control participants remained horizontal, but the slope of the trendline for the LBP group became negative, indicating that participants in the LBP group progressively overestimated their trunk extension force. Panel (A) shows the target force. %MVC: Percentage of maximum voluntary contraction.

position/movement sensors, their central processing, sense of effort, or a combination. To minimise the contribution of position/movement sensors and more specifically assess sense of effort, we designed a static force-matching paradigm. Using this paradigm, we showed consistent undershooting of target forces in cLBP participants. Our interpretation of these results is that people with cLBP perceived that the back muscles were generating more force than actual. This implies overestimation of force in people with cLBP. Our observations do not exclude a concurrent contribution of muscle spindles to position sense. Previous work has shown that vibration of contracting muscles during a force matching task increases the error (Boucher et al., 2015), demonstrating a peripheral component to force/position sensation (Cafarelli and Kostka, 1981; McCloskey et al., 1974). It is unlikely that our results can be explained by pain interference (Moseley and Hodges, 2005) or changes in muscle morphology or muscle function (Hodges and Danneels, 2019) in the cLBP group as there was no difference in performance when feedback was provided.

Several studies have evaluated the perception of muscle tension in LBP (Flor et al. 1992, 1999). Individuals with and without LBP differ in their ability to discriminate levels of muscle tension (Flor et al., 1999). Because the patient group had difficulty estimating muscle tension in both the affected area (erector spinae) and an unaffected region (frontalis muscle), it was argued that the sensory deficit might not be due to dysfunction of local muscle receptors, but might be related to a central perceptual deficit (Flor et al., 1999).

A limitation of the current study is that matching the target force depended on memory of the relationship between sense of effort and target forces in trials with visual feedback. Although memory may be affected in cLBP (Ling et al., 2007; Lourenco Jorge et al., 2009), this would be expected to lead to error characterised by both overshooting and undershooting of force, rather than a predominantly undershooting of the target force. A future challenge will be to further investigate the interaction between centrally derived sense of effort and peripherally derived afferent information for provision of proprioceptive information (Proske, 2005) and how the mechanisms underpinning this distortion in LBP. This will depend on greater understanding of the brain mechanisms involved in the sensation of effort. Experiments that have used transcranial magnetic stimulation have demonstrated that a motor response elicited via stimulation of the motor cortex is not accompanied by any sensation of effort (Ellaway et al., 2004; Gandevia et al., 1993). Thus, it is assumed that the effort signal is not simply derived from a copy of the output of the motor cortex but arises somewhere upstream of the motor cortex (Carson et al., 2002; Proske et al., 2004). Further investigation of this problem will aid interpretation of how this sense cooperates with motor output, how this changes in pain, and whether this can be rectified with rehabilitation.

We conclude that the most plausible interpretation of the results of this study is that sense of effort is altered in people with cLBP compared to pain-free controls. If confirmed in other studies, assessment and management of deficits in sense of effort in people with cLBP may be included in multimodal interventions in future clinical efficacy trials.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declaration of competing interest

Declarations of interest: none. The authors have no competing interests.

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