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Published in:
European Journal of Pain

DOI (link to publication from Publisher):
10.1002/ejp.993

Publication date:
2017

Document Version
Accepted author manuscript, peer reviewed version

PAIN-EVOKED TRUNK MUSCE ACTIVITY CHANGES DURING FATIGUE AND DOMS

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Original article for: European Journal of Pain

Running title: Trunk muscles and fatigue, DOMS and experimental back pain
Keywords: Movement, lumbar spine, experimental pain, motor control, electromyography
Conflict of interest: None declared

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Significance

What's already known about this topic?

- Low back pain, soreness and fatigue will impact the trunk muscle control
- Trunk-muscle response to surface perturbation known to decrease after unilateral and increase after bilateral pain

What does this study add?

- Back muscle activity decreased during unilateral and increased during bilateral pain after unpredictable surface perturbations during muscle fatigue and DOMS
- Accumulation effects of DOMS on pain intensity and spreading and trunk muscle activity after pain-induction

ABSTRACT

Background: Muscle pain may reorganise trunk muscle activity but interactions with exercise-related muscle fatigue and delayed onset muscle soreness (DOMS) is to be clarified.

Methods: In 19 healthy participants, the trunk muscle activity during 20 multi-directional unpredictable surface perturbations were recorded after bilateral isotonic saline injections (control) and during unilateral and bilateral hypertonic saline-induced low back pain (LBP) in conditions of back muscle fatigue (Day-1) and DOMS (Day-2). Pain intensity and distribution were assessed by visual analogue scale (VAS) scores and pain drawings. The degree of fatigue and DOMS were assessed by Likert scale scores. Root-mean-square electromyographic (RMS-EMG) signals were recorded post-perturbation from 6 bilateral trunk muscles and the difference from baseline conditions (Delta-RMS-EMG) was extracted and averaged across abdominal and back muscles.

Results: In DOMS, peak VAS scores were higher during bilateral control and bilateral saline-induced pain than fatigue ($P<0.001$) and during bilateral compared with unilateral pain ($P<0.001$). The saline-induced pain areas were larger during DOMS than fatigue ($P<0.01$). In response to surface perturbations during fatigue and DOMS, the back muscle Delta-RMS-EMG increased during bilateral compared with unilateral pain and control injections ($P<0.001$) and decreased during unilateral pain compared with control injections ($P<0.04$). In DOMS compared with fatigue, the post-perturbation Delta-RMS-EMG in back muscles was higher during bilateral pain and lower during unilateral pain ($P<0.001$). The abdominal Delta-RMS-EMG was not significantly affected.

Conclusion: Facilitated and attenuated back muscle responses to surface perturbations in bilateral and unilateral LBP, respectively, was more expressed during exercise-induced back muscle soreness compared with fatigue.

INTRODUCTION

Low back pain (LBP) is among the most challenging conditions regarding socioeconomic expenses (Dagenais et al., 2008), quality of life, and diagnostics (Vibe Fersum et al., 2013). Although changes in trunk muscle activity in LBP patients are evident (Hodges and Tucker, 2011) trunk-muscle retraining has no superior long-term effects (Smith et al., 2014) and the role of trunk muscle activity in LBP remains unclear.

Unpredictable surface perturbation induced trunk muscle co-contraction in pain-free recurrent LBP patients (Jones et al., 2012a) and decreased variability of trunk muscle activity in persistent LBP patients (Jacobs et al., 2009). In healthy subjects, the trunk muscle activity decreased after unpredictable surface perturbation during experimental unilateral LBP (Boudreau et al., 2011), while increased activity was found during experimental bilateral LBP (Larsen et al., 2016). Spatial and temporal differences in experimental and clinical pain conditions (Reddy et al., 2012) combined with psychosocial parameters found in LBP patients (O'Sullivan, 2012) may explain the different patterns of trunk muscle activation in patients and experimental conditions.

Higher pain intensity has been reported in persistent compared with subacute LBP patients (Chanda et al., 2011) and experimentally induced muscle pain additionally felt more intense with larger pain areas and higher pain intensity in LBP patients compared with asymptomatic controls (O'Neill et al., 2007). Similar manifestations of enlarged pain areas and increased pain intensity were observed in healthy subjects after bilateral compared with unilateral experimental saline-induced pain in the back muscles (Larsen et al., 2016) and when comparing saline-induced pain in the wrist extensor muscles before and during a condition of delayed onset muscle soreness (DOMS) (Slater et al., 2003). Long-lasting experimental LBP by exercise-induced back muscle fatigue (Boucher et al., 2012) and delayed onset muscle soreness (DOMS) (Bishop et al., 2011)

have been suggested as relevant LBP models. Fatigue and DOMS decreased trunk repositioning sense in healthy participants during fatigue (Boucher et al., 2012) and decreased lumbar stability during gait (Olson, 2010) and trunk extension exercises (Descarreaux et al., 2008) during DOMS. However, it is unknown how experimental LBP combined with muscle fatigue and subsequent DOMS will impact the trunk muscle control.

The aim of the present study was to compare the effects of unilateral and bilateral experimental LBP in conditions of muscle fatigue and subsequent DOMS on the trunk muscle activity after unpredictable surface perturbation in healthy participants. It was hypothesised that (1) during DOMS compared with the muscle fatigue condition, saline-induced pain results in higher pain intensity and larger pain areas. Moreover, (2) unilateral saline-induced LBP will decrease and (3) bilateral saline-induced LBP will increase the trunk muscle activity after unpredictable surface perturbation during muscle fatigue and DOMS conditions, respectively, and (4) the difference between unilateral and bilateral pain-induced changes in the trunk muscle activity following unpredictable surface perturbation will be more pronounced during DOMS compared with the muscle fatigue condition.

METHODS

Participants

Nineteen healthy participants [4 females; mean age 26 years (19-39 years); mean height 180 cm (160-200 cm), mean body mass index 23.7 kg/m^2 (20.4-29.2 kg/m^2)] without lower extremity or back related pain or dysfunction participated in the study. The study was approved by the local

ethics committee (N-20090053) and conducted in accordance with the Helsinki Declaration. Informed consent was obtained from participants prior to the study.

Protocol

On two consecutive days (Day-1, Day-2) trunk muscle activity during unpredictable surface perturbations were assessed at baseline and during sessions with bilateral saline-induced LBP, bilateral control, and unilateral saline-induced LBP. Fifteen minutes interval was kept between the experimental sessions. Between the baseline session and bilateral pain session at Day-1, the participants completed a series of back muscle exercise until exhaustion to induce back extensor muscles fatigue at Day-1 and DOMS in the back extensor muscles at Day-2 (24-48 hours after Day-1). In each perturbation session, the participant was standing in a self-selected position on a moveable platform during a series of 20 randomised multi-directional surface perturbations delivered after an auditory warning signal. During the surface perturbations the muscle activity from 6 bilateral trunk muscles were recorded by surface electromyography (EMG). Between sessions the participants were allowed to sit on a chair. Pressure pain thresholds (PPTs) were recorded on baseline sessions at Day-1 and Day-2 to study the effect of exercise-induced soreness on the low back sensitivity, as well as one Day preceding the experiment (Day-0). Day-0 baseline data on surface perturbation combined with experimental pain has been reported elsewhere (Larsen et al., 2016).

Surface perturbations

The foot position was marked on the platform to ensure that the position from the baseline condition (Day-1) was used during all sessions. Ten perturbations in different randomised

directions were conducted on each test day as acclimatisation. Surface perturbations in series of 20 consecutive perturbations trials were performed by a computer-controlled moveable platform (van Doornik and Sinkjaer, 2007). The participant stood on the platform in a relaxed position with the feet in approximately shoulder-width distance, the arms along the body, and instructed to look straight forward at a 5 cm diameter marker on the wall, 4m from the standing position.

The perturbation protocol aimed to challenge the postural stability during quiet standing, while still allowing the participants to not move their feet during recovery from the perturbation (Henry et al., 2006). Trials including stepping strategies after perturbation were excluded. Each series of perturbation consisted of 20 multi-directional surface perturbations applied randomly with 4-8 s intervals in-between and minimum 3 repetitions of each perturbation type in each series. The individual perturbation was initiated by an auditory cue and the perturbation was conducted after 0.2 – 5.0 s at random, in randomized order, and consisted of 6 different perturbations: Anterior and posterior tilt (range of movement: 3°, velocity: 30°/s, peak acceleration: 200°/s^2), left and right tilt (10°, 40°/s, 140°/s^2), left and right displacement (100 mm, 0.4 m/s, 140 m/s^2).

Electromyography

Surface EMG signals were recorded from 6 trunk muscles bilaterally by pairs of electrodes (Ambu Neuroline 720, Denmark). After shaving of the skin and cleaning with alcohol electrodes were placed bilaterally on the 3 back muscles according to previous recommendations (Hermens et al., 2000): (1) m. iliocostalis (one finger width medial from a line from posterior superior iliac spine (PSIS) to lowest point of lower rib at L2 level, (2) m. longissimus (2 fingers width lateral from L1 spinal process), and (3) m. multifidus (line from caudal tip of PSIS to L1-L2 interspace at L5

process). Likewise electrode pairs were attached above the 3 abdominal muscles: (1) m. obliquus internus (along horizontal line between left and right anterior superior iliac spine, medial from inguinal ligament (Anders et al., 2005), (2) m. rectus abdominis (3 to 4 cm lateral to the navel (Olson, 2010)), (3) m. obliquus externus (upper electrode directly below most inferior point of costal margin of PSIS (Anders et al., 2007)). A ground electrode (Blue sensor P 34mm, Ambu Neuroline, Denmark) was mounted on the skin over the most prominent spinal process at C6, C7 or Th1.

The EMG signals were synchronised with the onset of perturbation and recorded with a 16-channel surface EMG-USB amplifier (LISiN-OT Bioelettronica, Torino, Italy) and the signals were band-pass filtered (10–500 Hz), sampled at 2048 Hz with a gain of 2000, and converted to digital form by a 12-bit analogue-to-digital converter.

Electromyographic analysis

A 500 ms time window after the perturbation onset was visually inspected to verify the data quality. Root-mean-square (RMS) values were derived from the EMG signals in 10 non-overlapping signal epochs of 50 ms and the average value across all epochs (defined as RMS-EMG) was extracted for each perturbation and subsequently averaged across all perturbations (Shiozawa et al., 2015). In addition, average RMS-EMG values across respectively left and right back (m. iliocostalis, m. longissimus, and m. multifidus) and abdominal (m. obliquus internus, m. rectus abdominis, and m. obliquus externus) muscle groups were extracted. The RMS-EMG during the experimental pain and control sessions was expressed as a percentage of the baseline RMS-EMG values recorded on the respective day (Delta-RMS-EMG; baseline defined as 100%).

Saline-induced low back pain

The Th12 segment was located while the participants were prone lying and L2 located by counting down from Th12 and verified by palpation of L4 at the line between the iliac crest bilaterally where L2 was estimated. At the L2 level, the most bulky part of m. longissimus on both sides were palpated and marked (typically 3-5 cm from the midline). The injection sites were cleaned with alcohol and sterile isotonic (1.0 ml, 0.9%) or hypertonic (1.0 ml, 5.8%) saline were injected bilaterally perpendicular to the skin surface with a 25G × 19 mm needle. The participants were informed about the repeated injection procedure but blinded to the type of saline injected. The two injections were performed manually over approximately 5 s each and with 15-25 s interval while the participants were seated on a chair in a relaxed position during 3 sessions: (1) bilateral pain condition (bilateral hypertonic saline), (2) bilateral control condition (bilateral isotonic saline), and (3) unilateral pain condition (one hypertonic saline injection in the dominant side immediately followed by an injection of isotonic saline in the contralateral side). In the bilateral conditions, the injection in the dominant side was performed first and followed immediately after by injection in the contralateral side. After completion of both injections the participant was assisted to the individually marked standing position on the surface perturbation platform and started scoring the pain intensity on the 10-cm electronic visual analogue scale (VAS) anchored with 'no pain' and 'maximum pain' at 0 cm and 10 cm, respectively. The signal from the VAS was sampled by 20 Hz until the pain vanished. The participants controlled the VAS score with an external handheld slider in the breaks between perturbations, when they had recovered their balance.

The VAS score was extracted in the time window from perturbation onset to the next perturbation, for all perturbations and the peak VAS scores were extracted for each of the conditions bilateral control and unilateral and bilateral experimental pain. After each session the

participants were asked to draw the pain distribution on a body chart and the pain area was extracted in arbitrary units (a.u.) from the drawings (ImageJ 1.47V, Rasband, NIH, USA).

Low back exercise and DOMS

The starting position was prone lying with the upper body unsupported over the end of a plinth while the lower extremity was fixed with straps around the ankles and knees, and a pillow under the ankle. This position allowed the participants to slowly lower themselves into flexion and be assisted back into neutral position (Fig. 1). The arms were crossed in front of the chest and participants completed repeated exercises unsupported during flexion (eccentric back extensor muscle work) and manually supported by the researchers during extensions (Lo Vecchio et al., 2015). The participants were asked to complete as many repetitions from 0 to 45 degrees of flexion as possible and were encouraged by verbal feedback. The procedure was stopped when the participants were unable to control the active flexion motion of the upper body or stopped due to discomfort or pain in the back extensor muscles. Fatigue was determined using a fatigue subset of the Profile of Mood States (McNair et al., 1992) consisting of a 5-point Likert scale (0 = *not at all*, 1 = *a little*, 2 = *moderately*, 3 = *quite a bit*, 4 = *extremely*) and exercise-induced pain was determined by a McGill pain questionnaire with indication of localisation and present pain intensity and quality (Melzack, 2005). Initially during Day-2 DOMS was assessed by a 7-point modified Likert Scale (Gibson et al., 2006) and verified by assessment of pressure pain sensitivity (PPT) and the participants were asked to indicate pain distribution on a body chart.

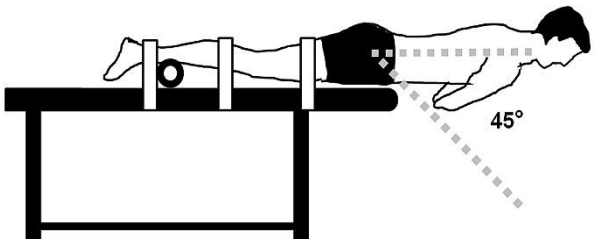

Figure 1. The staring position to induce experimental muscle fatigue was prone lying with the upper body unsupported and the lower extremity fixed to allow the participants to slowly lower themselves into approximately 45 degrees of flexion and be assisted back into neutral position.

Pressure pain sensitivity

PPT was recorded while the participants were prone lying on a plinth with both arms relaxed along the body. The algometer (Wagner FPX digital) pressure was applied perpendicularly to the most bulky part of the erector spinae muscle at lumbar levels L1, L3 and L5 (Farasyn and Meeusen, 2005) bilaterally with a rubber covered 1.0 cm^2 rounded probe. The pressure was increased with an approximate rate of 1 kg/s (Chesterton et al., 2007) and participants indicated verbally when the pressure changed from strong pressure to pain and this defined the PPT. The PPTs were assessed on each site in three series with 3 minutes break between.

PPT was recorded by the same researcher and averaged between 3 consecutive recordings for each day, side and site to reduce the inter-trial variability (Chesterton et al., 2007). Finally PPT was expressed as percentages of the corresponding Day-0 baseline (100%) value (delta-PPT).

Statistics

Data are presented as mean and standard error of the mean (SEM) except Likert scale scores where median and 25th and 75th percentiles are reported. Statistical analyses were performed in SPSS®23.0 (IBM) and statistical significance was accepted at $P < 0.05$.

VAS scores failed the Shapiro-Wilk test for normality ($P<0.01$) and was analysed with a Friedman Test between *conditions* (bilateral control, unilateral pain and bilateral pain) for fatigue and DOMS respectively and post-hoc tested by Bonferroni corrected Wilcoxon Signed Rank tests. Pain area, PPT and EMG data was normally distributed ($P > 0.05$) and were analysed with repeated measures analysis of variance (RM-ANOVA) with a Greenhouse-Geisser correction and post-hoc tested with Bonferroni adjusted pairwise t-tests. Pain areas were analysed with a 2-way RM-ANOVA with main factors *day* and *condition*. The PPTs were analysed with a 3-way RM-ANOVA with the main factors *day*, *side* (left and right), and *site* (L1, L3 and L5). The Delta-RMS-EMG was analysed with a 4-way RM-ANOVA with factors *day, condition, side* and *muscle group*.

RESULTS

Experimental low back pain

Injection of isotonic saline resulted in small pain areas around the injection site (Fig. 2A,D) during both days. Unilateral hypertonic saline injections resulted in pain primarily located in the low back area during both days (Fig. 2B,E). After bilateral hypertonic saline injections the pain areas involved the low back and gluteal areas during both days (Fig. 2C,F). DOMS compared with fatigue more frequently involved the gluteal areas after bilateral hypertonic saline injections and during DOMS spreading to the upper trunk and the groin also was included in few participants (Fig. 2C,F). A significant interaction between days and condition (RM-ANOVA: $F(2,36)=35.2$, $P<0.02$) showed larger pain areas during DOMS compared with fatigue for all conditions (Fig. 2G,H,I; Bonferroni: $P<0.01$). During both fatigue and DOMS, respectively, larger pain areas were observed after bilateral hypertonic saline injections compared with unilateral hypertonic saline injections

(Bonferroni: P<0.001) and bilateral isotonic saline injections (Bonferroni: P<0.001). Moreover, unilateral injection of hypertonic saline induced larger pain areas than after bilateral control injections during both days (Bonferroni: P<0.001).

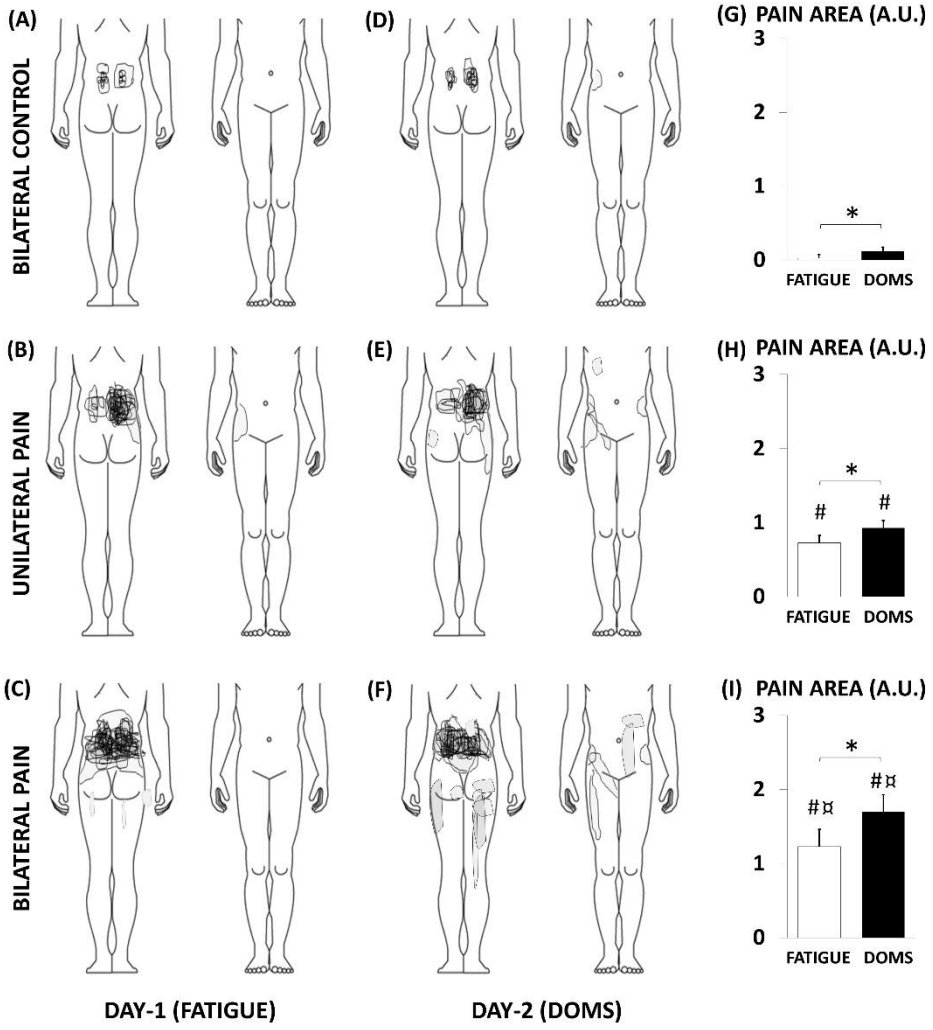

Figure 2. Superimposed perceived areas of self-reported pain (N=19) after control injections and unilateral and bilateral pain induction after back muscle extensor fatigue (A,B,C) and delayed onset muscle soreness (DOMS: D,E,F). Significantly larger pain areas were found following bilateral pain-induction compared with unilateral pain (¤, Bonferroni: P<0.01) and control conditions (#, Bonferroni: P<0.001) during fatigue and DOMS. Pain areas were significantly larger during DOMS than during fatigue (*, Bonferroni: P<0.01).

A Friedman test showed significant differences in peak VAS pain scores between *conditions* (Fig. 3; χ^2 (5) = 75.8, P<0.001). Wilcoxon signed Rank post-hoc tests showed significant higher peak VAS scores Day-1 (Fatigue) during unilateral (Z=-3.8, Bonferroni: P < 0.001) and bilateral pain (Z=-3.5, Bonferroni: P < 0.001) compared with control conditions. Likewise, increased VAS peak during Day-2 (DOMS) was found with bilateral pain compared with unilateral pain (Z=-3.8, Bonferroni: P < 0.001) and bilateral control conditions (Z=-3.8, Bonferroni: P < 0.001) and during unilateral pain compared with control conditions (Z=-3.6, Bonferroni: P < 0.001). Compared with the fatigue condition, the VAS peak was higher during DOMS for the bilateral control injections (Z=-2.6, Bonferroni: P < 0.03) and during bilateral pain (Z=-2.8, Bonferroni: P < 0.01).

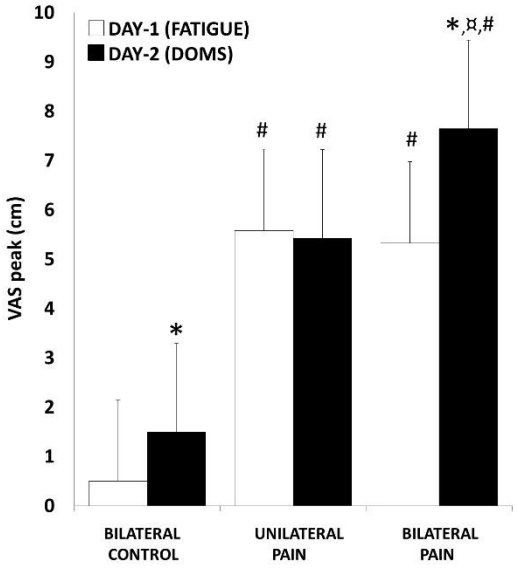

Figure 3. Mean (±SEM, N=19) peak visual analogue scale (VAS) scores. Compared with control injections Peak VAS increased after injections of unilateral and bilateral hypertonic saline during muscle fatigue and delayed onset muscle soreness (#, Bonferroni: P<0.001). During DOMS peak VAS was higher during bilateral pain compared with unilateral pain (¤, Bonferroni: P<0.001) and during bilateral control (*, Bonferroni: P<0.03) and bilateral pain (*, Bonferroni: P<0.01) compared with during fatigue.

Fatigue and DOMS

The participants completed 38.6 (range 22-63) exercises in average. After exercise-induced fatigue 2 participants indicated fatigue-related likert scores 2 (moderate) and the rest of the participants indicated 3 (quite a bit) or 4 (extremely fatigue) (median 3; 25th and 75th percentiles: 3 and 4). Additionally, all participants indicated mild soreness, 12 without pain and 7 participants indicated light pain in the back and 3 of these additionally indicated mild pain in the gluteal and hamstring areas. All pain disappeared while the participants were assisted from the exercise plinth to the perturbation plate.

All participants subjectively indicated light to moderate exercise-induced low back soreness at Day-2 with Likert scores ranging from 1 (light soreness by muscle palpation) to 4 (light soreness when walking on flat surface) (median 2; 25th and 75th percentiles: 1 and 3). A 3-way ANOVA of the PPTs showed main effect on days (RM-ANOVA: $F(1,18)=13.7$, $P<0.01$). Post-hoc analyses showed decreased PPTs at the three lumbar levels bilaterally during Day-2 compared with before exercise on Day-1 (Fig. 4; Bonferroni: $P<0.001$).

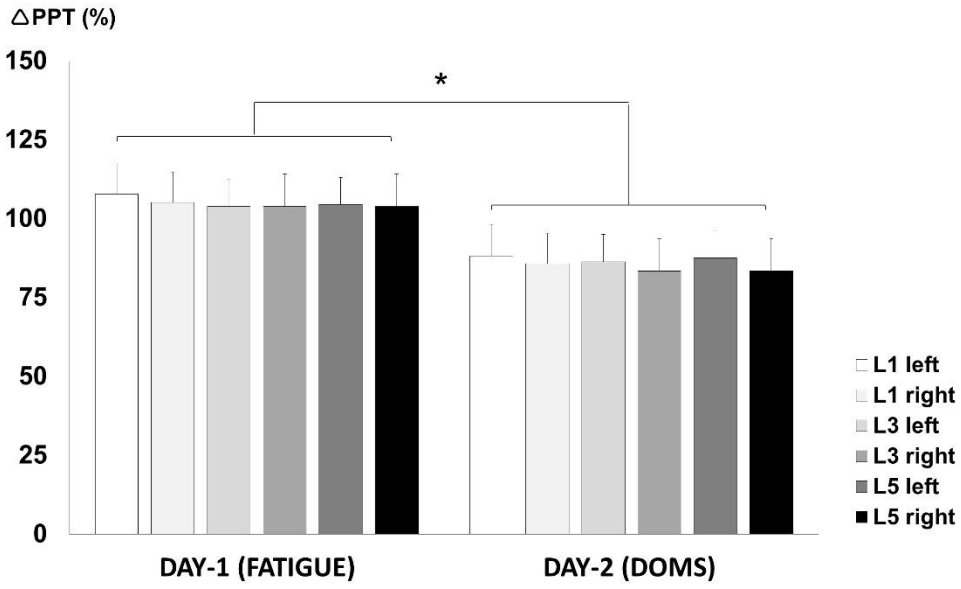

Figure 4. Mean (+/- SEM, N=19) pressure pain threshold (PPT) normalised to baseline values recorded before muscle fatigue and during delayed onset muscle soreness (DOMS), respectively. During DOMS PPTs were significantly decreased compared with the pre fatigue condition at all 3 sites (*, Bonferroni: $P<0.01$).

Muscle activity following surface perturbation during fatigue and DOMS

The Delta-RMS-EMG for the individual days, conditions, perturbations, sides and muscles are presented in Figures S1 and S2 for descriptive purposes. A 4-way RM-ANOVA of Delta-RMS-EMG across perturbation types showed significant interaction between days, side, muscle group, and condition (Fig. 5; RM-ANOVA: $F(2,36)=17.8$, $P<0.001$). Post-hoc analyses showed that on both Day-1 (Fatigue) and Day-2 (DOMS) unilateral pain induction resulted in lower Delta-RMS-EMG in the left and right back muscle group compared with bilateral control (Bonferroni: $P<0.04$) and bilateral pain induction resulted in higher Delta-RMS-EMG in the left and right back muscle group on both Day-1 and Day-2 compared with bilateral control (Bonferroni: $P<0.001$) and unilateral pain (Bonferroni: $P<0.001$).

During DOMS compared with Fatigue, Delta-RMS-EMG in the left and right back muscle group was lower during unilateral (Bonferroni: $P<0.03$) and higher during bilateral (Bonferroni: $P<0.04$) experimental pain.

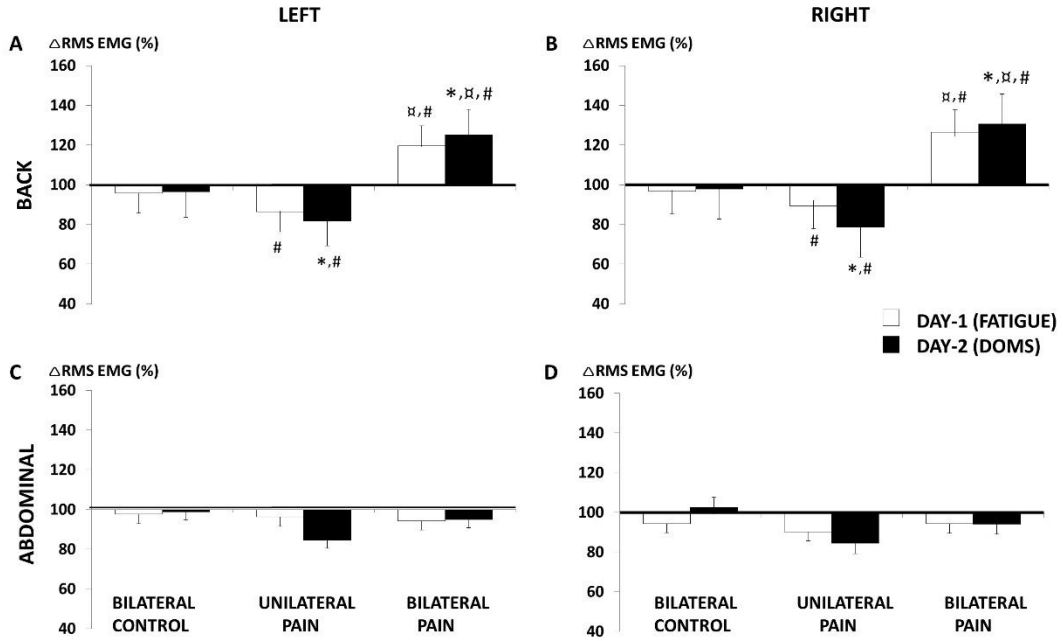

Figure 5. Mean (±SEM, N=19) Delta-RMS-EMG across all perturbation types following control injections and unilateral and bilateral pain at Day-1 and Day-2 in left (A) and right (B) back muscle groups and left (C) and right (D) abdominal muscle groups. Compared with control injections the back muscle group Delta-RMS-EMG bilaterally decreased during unilateral (*,Bonferroni: $P<0.04$) and increased during bilateral pain (*,Bonferroni: $P<0.01$) during Day-1 and further changes in same directions were observed during Day-2 (*,Bonferroni: $P<0.03$).

DISCUSSION

This is the first study comparing trunk muscle responses following surface perturbations in combinations of eccentric exercise-induced back extensor muscle fatigue, DOMS and experimental unilateral versus bilateral LBP and control conditions. In line with the hypotheses, bilateral compared with unilateral back muscle pain induction increased the pain intensity and pain areas and these effects were enhanced during DOMS. Likewise, perturbation-evoked increased back muscle activity response during bilateral pain and decreased back muscle activity response during unilateral experimental pain was further facilitated during DOMS compared with fatigue.

However, the effect of pain on the abdominal muscle activity was smaller than expected and not significantly changed.

The experimental low back pain model

The saline-induced LBP model attempted to mimic acute clinical pain and combining this model with fatigue and DOMS models aimed to link the effect of pain with the well-known characteristics in LBP patients by e.g. decreased muscle strength and endurance (Suuden et al., 2008). The immediate effect of exercise-induced fatigue to exhaustion in the back extensors at Day-1 was mild soreness and no participants indicated pain when the surface perturbation procedure commenced in spite of subjective indications of extensive fatigue immediately after completion of the series of exercises. In the fatigue condition, the pain intensity after bilateral control injections and unilateral and bilateral hypertonic saline injections, respectively, was consistent with previous reports after saline-induced pain without preceding induction of fatigue (Boudreau et al., 2011; van den Hoorn et al., 2014; Hirata et al., 2015; Larsen et al., 2016).

The presence of DOMS at Day-2 was confirmed by mild to moderate soreness during palpation or movement in accordance with recent findings (Lo Vecchio et al., 2015). Observation of increased pressure pain sensitivity at three bilateral lumbar levels at Day-2 compared with Day-1 verified the DOMS model. DOMS has been suggested to be triggered by a peripheral inflammatory reaction (Tegeder et al., 2002) related to microstructural damage in the contractile system. Recent evidence, however, indicate that neurotrophic factors are essential in DOMS (Mizumura and Taguchi, 2016). Although the underlying mechanisms are not well covered exercises will influence the somatosensory system resulting in sensitisation of peripheral and central mechanisms as previously observed with DOMS in e.g. the wrist extensors (Slater et al.,

2003) and m. infraspinatus (Domenech-Garcia et al., 2016). The DOMS model thereby evoked mechanical hyperalgesia (Gibson et al., 2006) as we observed in the decreased PPT values and a subsequent change in the pain quality and perception could be expected (Reddy et al., 2012). Interestingly, unilateral experimental pain intensity was not different between the fatigue and DOMS conditions but after bilateral injections of hypertonic or isotonic saline the facilitator effect of DOMS was more expressed than in the fatigue condition. DOMS was previously hypothesized to sensitise central pain processing (Hosseinzadeh et al., 2013). Likewise, this was indicated by observations of larger pain areas generated by experimentally induced unilateral and bilateral pain during DOMS compared with fatigue conditions, suggesting that DOMS might have sensitized the mechanisms for pain distribution and referred pain like observed in previous studies (Slater et al., 2005; Gibson et al., 2006). The higher impact of bilateral control injections on pain intensity during DOMS furthermore indicated that the pain effect of the skin penetration during injections possible is aggravated by hyperalgesia due to DOMS.

Observation of higher pain intensity and wider pain distribution after bilateral compared with unilateral hypertonic saline injections during fatigue and DOMS supported the hypothesized higher impact of bilateral pain observed in a previous study (Larsen et al., 2016). These observations are the first reports on bilateral experimental LBP and consistent with higher pain intensity during bilateral compared with unilateral experimental pain in m. masseter (Svensson et al., 1997) and m. trapezius (Ge et al., 2006), probably caused by spatial summation of converging inputs from nociceptors bilaterally (Greenspan et al., 1997).

Effect of fatigue, DOMS and experimental pain on trunk muscle activity

Decreased bilateral trunk muscle activity during unilateral pain is generally observed after surface perturbations in healthy participants (Boudreau et al., 2011; Hirata et al., 2015). The observed differences in back muscle activity between decreased muscle activity during unilateral and increased activity during bilateral pain, however, confirmed previous observations of unilateral and bilateral pain (Larsen et al., 2016). The obvious explanation of increased muscle activity during bilateral pain would be pain intensity related kinesiophobia that is associated with pain and disability in LBP patients (Picavet et al., 2002). In LBP patients, kinesiophobia is also correlated with increased trunk stiffness after anterior perturbation (Karayannis et al., 2013) and reduced peak trunk torque and trunk co-contraction have been found in pain-free recurrent LBP patients after multidirectional surface perturbation (Jones et al., 2012a). In contrast, recent aggravation of LBP in recurrent LBP patients showed no differences in trunk torque after multidirectional surface perturbation compared with healthy participants (Jones et al., 2012b) but simultaneously shorter latency of trunk responses in the patients could be an expression of changed postural strategies due to kinesiophobia.

The present findings of increased back muscle activity was accompanied by no change in the abdominal muscle activity during bilateral pain compared with control injections indicating changed postural strategies based on the back muscles as primary controllers of the trunk during bilateral pain. The abdominal muscle activity has gained much attention in LBP explanatory models (van der Hulst et al., 2010) and clinical practice (Davin and Callaghan, 2016) but the present data indicated that the abdominal muscles probably play a minor role in the changed motor strategies after unpredictable surface perturbation during acute pain. However, based on the current experimental design, analyses of co-contraction was not possible since EMG data was analysed by

differences from baseline conditions. This normalisation procedure was selected because the most used method in EMG by comparisons based on maximal voluntary contraction normalisation analyses (Burden, 2010) would be incorrect at Day-2 where the maximal back force exertion would expect to decrease during DOMS. DOMS in the knee extensor muscles decreased the knee muscle activity after surface perturbations (Hedayatpour et al., 2011) but the set-up in this study limited the insight in to the effect of exercise-induced DOMS in the back on the back muscle activity after perturbations. However, observation of no significant differences in Delta-RMS-EMG between Day-1 and Day-2 after bilateral control injections although indicated that exercise-induced DOMS in the back in healthy participants only impact the Delta-RMS-EMG when induced concurrently with experimental pain.

Clinical implications

Differential impact of the pain modalities in the present study suggest that central summation of bilateral converging painful stimuli and the facilitation by DOMS resulted in protective movement strategies previously observed in recurrent LBP patients (Jones et al., 2012b) and during bilateral pain in healthy participants (Larsen et al., 2016). Observation of decreased muscle activity during identical postural tasks during unilateral pain in line with previous reports (Boudreau et al., 2011; Hirata et al., 2012; Larsen et al., 2016) suggested that it is clinically important to support intervention strategies minimizing the reinforcing effects of central and peripheral processes on increased pain intensity and distribution and thereby reduce the sensory impact on the muscle activity.

Conclusion

Unpredictable perturbation-induced postural reactions in healthy participants resulted in decreased back muscle activity after experimental unilateral low back pain and increased back muscle activity after experimental bilateral low back pain while having back muscle fatigue and delayed onset muscle soreness, respectively. Delayed onset muscle soreness furthermore resulted in higher impact of acute pain on the sensory and motor system.

Acknowledgements

Center for Neuroplasticity and Pain (CNAP) is supported by the Danish National Research Foundation (DNRF121). The study was supported by University College North Denmark, Department of Physiotherapy, Aalborg, Denmark.

Conflict of interest statement

The authors have no conflict of interest regarding the contents of this paper.

Author contributions

Lars Henrik Larsen was main responsible for data collection, data analyses, and drafting of the paper. Rogerio Pessoto Hirata and Thomas Graven-Nielsen participated in planning of data collection, data analyses, and manuscript revision. Rogerio Pessoto Hirata additionally contributed substantially in developing the general set-up of the lab and data collection. All authors discussed the results and approved the final manuscript.

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