Flexion-Relaxation Phenomenon in Children and Adolescents With and Without Nonspecific Chronic Low Back Pain: An Electromyographic and Kinematic Cross-Sectional Comparative Study

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Abstract
A cross-sectional comparative study. OBJECTIVE: This study aimed to investigate the flexion-relaxation phenomenon (FRP), in standing trunk flexion and slumped sitting tasks, by comparing children and adolescents suffering from nonspecific chronic low back pain (NSCLBP) with controls (CTRL).

Reference


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Flexion-relaxation phenomenon in children and adolescents with and without non-specific chronic low back pain: an electromyographic and kinematic cross-sectional comparative study

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Abstract

Study Design: Cross-sectional comparative study

Objective: This study aimed to investigate the flexion-relaxation phenomenon (FRP) in standing trunk flexion and slumped sitting tasks, by comparing children and adolescents suffering from non-specific chronic low back pain (NSCLBP) with controls (CTRL).

Summary of Background Data: The absence of the FRP can accurately discriminate adults with NSCLBP from those without during standing trunk flexion and slumped sitting tasks. Even if the FRP has been extensively studied in adults with NSCLBP, only one study has evaluated the FRP in adolescents, during a slumped sitting task, and this suggested that the FRP was also present in adolescents with NSCLBP.

Methods: Thirty-seven children and adolescents with NSCLBP and 23 CTRL performed standing trunk flexion and slumped sitting tasks. All participants were equipped with surface electromyography (EMG) electrodes on the erector spinae (ESL) and multifidus (M) muscles and reflective markers on the spinous processes of C7, L1 and S1. Global (C7-S1), thoracic (C7-L1) and lumbar (L1-S1) trunk flexion absolute angle were measured. The FRP was reported using visual inspection and a flexion-relaxation ratio (FRR). A self-reference threshold was used to identify the time of FRP onset. Repeated measures ANOVA was used to determine the main and interaction effects of task, group and muscle on FRR and the relative maximal angle at FRP onset of the global trunk (C7-S1).

Results: Results showed three main findings: (1) the FRP’s low sensitivity in discriminating between NSCLBP and CTRL participants in either groups, tasks or muscles; (2) similar observed
maximal flexion angles in both groups during flexion tasks; and (3) similar observed relative maximal global trunk flexion angles at FRP onset in groups, tasks and muscles.

**Conclusion:** These results are not consistent with the literature on adults and could lead to modified therapeutic management of NSCLBP in children and adolescents.

**Key Words:** Low back pain, children and adolescents, electromyography, flexion-relaxation phenomenon

**Level of Evidence:** 3
1. Introduction

Standing trunk flexion is characterised by a sudden myoelectric silence of extensor muscles at full flexion. Floyd and Silver described this phenomenon—present in 82%–100% of asymptomatic adults—as the flexion-relaxation phenomenon (FRP). FRP has also been documented during slumped sitting, although with inconsistent occurrence due to studies’ non-standardised sitting postures. The relative angle at which FRP occurred (onset angle) varied from 62%–90% of maximal trunk flexion during standing flexion and tended to be earlier (around 50%) during slumped sitting.

Absent or diminished FRP during standing trunk flexion has frequently been observed in adult patients with chronic low back pain (CLBP) in comparison with healthy age-matched participants. Evaluating FRP is a clinically relevant means of discriminating CLBP patients from asymptomatic adults, showing good specificity and sensitivity.

LBP was recently identified as the third most frequent cause of paediatric pain disorders among children and adolescents, with prevalence comparable to adults. However, although FRP has been extensively studied in adults with LBP, there is a lack of electromyography (EMG) data on children and adolescents with LBP. To the best of our knowledge, only one study has evaluated FRP in adolescents during a slumped sitting task. It reported that 14–16 years old adolescents suffering non-specific chronic LBP (NSCLBP) showed a significant reduction in the activity of their thoracic erector spinae muscles during slumped sitting in comparison with usual sitting, suggesting the presence of an FRP. They also reported no significant reduction in activity in the multifidus muscles between slumped and usual sitting.
The present study aimed to investigate the FRP in children and adolescents suffering from NSCLBP during both standing trunk flexion and slumped sitting tasks in comparison with age-matched controls.

The working hypotheses were:

- (1) FRP occurs less frequently in children and adolescents with NSCLBP and can be used to discriminate between NSCLBP and control groups with high sensitivity and specificity.
- (2) Children and adolescents with NSCLBPHave a lower maximal trunk flexion angle and a higher EMG amplitude than controls.
- (3) Children and adolescents with NSCLBP exhibiting FRP have a higher relative maximal onset of FRP than controls.

2. Methods

2.1. Participants

Patients with NSCLBP were recruited in the paediatric orthopaedics department of a tertiary university hospital between November 2014 and December 2016. Age-matched healthy volunteers (CTRL) were invited to participate using a hospital advertising poster. The local ethics committee approved this prospective study (CER no.14-126), and all participants and their respective legal guardians gave written informed consent. NSCLBP group inclusion criteria were: aged from 10–18 years old; suffering from NSCLBP with a pain level ≥ 3/10 on a visual analogue scale; and in pain >3 months. CTRL group inclusion criteria were: aged from 10–18 years old and no history of LBP during the last year. Intensity of pain was evaluated using a visual analogue scale; functional disability was evaluated using the Oswestry questionnaire. To
limit any age bias that this paediatric population might have on body mass index (BMI) evaluation, BMI-for-age was computed as a z-score \( z \) \(^{25} \) and weight status categories were defined using World Health Organization recommended cut-offs \(^{26} \).

2.2. Task and procedure

Experiments were conducted in the tertiary university hospital’s Laboratory of Kinesiology. First, participants lying in an prone position, with arms along their trunk and outstretched legs, were asked to raise their trunk and umbilicus off the table (Figure 1a). EMG of the low back erector spinae longissimus (ESL) and multifidus (M) muscles, recorded during this isometric manual muscle testing against gravity (isoMMT3), was used to normalise the EMG amplitude for the subject’s next tasks \(^{27} \).

Second, participants were asked to perform two distinct trunk flexion tasks in the sagittal plane (Figure 1b): (1) moving from upright standing to full trunk flexion \(^{7} \) and (2) moving from upright sitting to slumped sitting \(^{9} \). Task was repeated and measured three times in the same order (standing then sitting); mean values were computed. Task analyses were divided into three successive phases (Figure 1b): dynamic flexion, static full flexion and dynamic extension \(^{2} \).

2.3. Instrumentation

Participants were equipped with surface EMG electrodes placed bilaterally on ESL and M muscles and reflective markers placed on the C7, L1 and S1 spinous processes.

Active EMG surface electrodes (model Trigno, Delsys Inc., Boston, MA, USA), recording at a 1000 Hz sampling frequency, were located directly on shaved, alcohol-cleaned skin according to SENIAM recommendations \(^{28} \), as described below:
• ESL: two fingers-width lateral from the processus spinae of vertebra L1
• M: on and aligned with a line from caudal tip posterior spinailiaca superior to the interspace between L1 and L2 at the L5 spinous process (2–3 cm from the midline)

A twelve-camera motion analysis system (ViconMX3+, Vicon Peak, Oxford, UK, and Qualisys Oqus7+, Göteborg, Sweden) set at a 100 Hz sampling frequency recorded marker trajectories and EMG recordings were synchronised.

2.4. Dataprocessing

a. EMG parameters

Firstly, the quality of the raw EMG data was visually evaluated to exclude muscles with noise in their data due to poor skin-electrode contact during movement. After checking that there were no statistical differences between left and right sides, one randomly picked side was reported (left)\(^{11}\). When left-side EMG was excluded, the right side was reported; when both sides were excluded the participant was excluded from analysis. Next, raw EMG data were band-pass filtered between 20 Hz and 500 Hz using a fourth-order Butterworth filter to attenuate low-frequency noise due to any skin movement artefacts. The filtered EMG signal was full-wave rectified and low-pass filtered using a fourth-order filter (cut-off frequency: 3 Hz) to compute the normalised EMG linear envelopes (NEMG_LE) by dividing by the mean value from the normalisation task (Figure 1a)\(^ {27}\).

The FRP was identified as a sudden significant reduction in motor activity on NEMG_LE (ESL and M) during the standing trunk flexion and slumped sitting tasks\(^ {6}\). Each muscle’s flexion-relaxation ratio (FRR) was computed during each task by dividing the averaged NEMG_LE recorded during standing and sitting by the averaged NEMG_LE recorded during
maximal standing flexion and slumped sitting, respectively. A self-reference threshold “3 frp” (3 times the average NEMG LE during full flexion) was used to identify time of FRP onset. The first point followed by 50 data points continuously meeting threshold (50 ms) was defined as the FRP onset (Figure 2).

b. Trunk kinematics

Trunk kinematic parameters were computed using MATLAB R2012b (MathWorks, Natick, MA, USA) during the standing and seated trials. The spine was partitioned into three regions: global from plates C7-S1, thoracic from plates C7-L1 and lumbar from plates L1-S1. Angles were measured as absolute angle (°) which was taken with respect to the vertical. For each trial with the presence of aFRP, the angle (expressed as a percentage of the maximal angle at full flexion) was determined at the time of FRP onset (Figure 2).

2.5. Statistical analysis

Analyses used R software, v.3.1.3, and the RStudio interface (Rstudio Team 2016). Normality of data distribution was confirmed using the Shapiro–Wilk test. Differences between NSCLBP and CTRL groups were examined using unpaired Student t-tests for continuous outcomes and Pearson’s χ² tests for dichotomous outcomes. The level of significance was set at p<0.05. Cohen’s effect size (ES) and 95% confidence intervals (95% CI) were also reported. Repeated measures analysis of variance (ANOVA) was used to determine the main effect and interaction effects of each task (standing, sitting), group (NSCLBP, CTRL) and muscle (ESL, M) on the outcome measures: FRR and relative maximal angle at FRP onset of global trunk (C7-S1).
3. Results

3.1. Participants

Thirty-eight NSCLBP patients and 24 healthy age-matched subjects performed standing trunk flexion and slumped sitting tasks. Due to technical problems with the EMG electrodes (not sticking to skin), one NSCLBP participant and one CTRL participant were excluded from the analysis of both standing and sitting tasks. Furthermore, two CTRL group participants were excluded from the sitting task due to a misunderstanding of the instructions. After these exclusions, CTRL and NSCLBP groups remained comparable in terms of age, proportion of females, height, weight and body weight status (Table 1). NSCLBP participants described pain intensities ranging from 3.0–8.0 (mean 3.9), indicating intermediate pain intensities (<5/10), Oswestry disability levels ranging from 0.0%–35.6% (mean 18.5%), indicating minimal disability (<21%) \(^{30}\), and mean pain duration of 16.3 +/- 15.1 months.

3.2. Occurrence of FRP

We observed no significant differences in the proportion of NSCLBP and CTRL group participants who did not exhibit an FRP in standing trunk flexion and slumped sitting tasks (see Table 2). Furthermore, FRP showed low sensitivity (<50%) and high-to-moderate specificity (from 75%–84%) in distinguishing NSCLBP from CTRL participants for all muscles during standing trunk flexion (sensitivity: ESL=13%, M=17%; specificity: ESL=81%, M=78%) and for ESL during slumped sitting (sensitivity: ESL=14%; specificity: ESL=73%); its sensitivity and specificity were low (<50%) for M during slumped sitting (sensitivity: M=42%; specificity: ESL=38%).

3.3. Normalised EMG amplitude
In the standing trunk flexion task, normalised EMG amplitudes of ESL and M muscles were similar in both groups (see Figure 3). However, in the slumped sitting task, ESL muscle activity was significantly lower ($p<0.05$) in the NSCLBP group than in the CTRL group during dynamic flexion and extension, but M muscle activity was significantly higher in NSCLBP group during static full flexion. In both standing trunk flexion and slumped sitting tasks, normalised EMG amplitudes for ESL and M muscles during static full flexion were significantly lower ($p<0.05$) than in dynamic flexion and extension in both groups.

3.4. Maximal flexion angle and relative maximal flexion angle at FRP onset

In the standing full flexion task, there were no significant differences between NSCLBP and CTRL groups in either maximal flexion angle or relative maximal flexion angle at FRP onset for both the ESL and M muscles and all trunk regions (Table 2).

In slumped sitting task, there was no significant difference between NSCLBP and CTRL groups for both maximal flexion angle and % maximal flexion angle at FRP onset of every evaluated region for M muscle. A significantly earlier onset angle in NSCLBP in comparison with CTRL was reported in thoracic (NSCLBP: 63.3 (25.7)%; CTRL: 83.8 (17.9)%; $p=0.020^*$) and lumbar (NSCLBP: 56.7 (25.8)%; CTRL: 77.6 (14.0)%; $p=0.024^*$) flexion angle and similar for the global trunk angle (NSCLBP: 77.2 (17.9)%; CTRL: 80.9 (11.2)%; $p=0.312$) for ESL muscle (Table 2).

3.5. Task, muscle and group effects on FRR and relative maximal flexion angle at FRP onset

As Table 3 reports, task (df=1, $F=51.617$, $p<0.001$) and muscle (df=1, $F=6.384$, $p=0.010$) had significant effects on the FRR. Calculating an ANOVA of the FRR revealed no statistically
significant group effect (df=1, F=2.798, p=0.096). There were no significant interaction effects on the FRR (p>0.05).

Although the main group (df=1,F=1.382, p=0.242), task (df=1, F=0.148, p=0.701) and muscle (df=1, F=0.182, p=0.670) effects on the relative maximal flexion angle at FRP onset of global trunk (C7-S1) were not significant, the muscle x group interaction effect was (F=4.681, p=0.032). No significant interaction effects on the relative maximal flexion angle at FRP onset of global trunk (C7-S1) were found for task x group, muscle x task, and task x group x muscle (p>0.05).

4. Discussion

The present study aimed to evaluate the flexion-relaxation phenomenon (FRP) in children and adolescents with and without non-specific chronic low back pain (NSCLBP) during standing trunk flexion and slumped sitting tasks. Taken together, its results rejected the three hypotheses originally formulated, namely: (1) FRP occurs less frequently in children and adolescents with NSCLBP and can discriminate between NSCLBP and control groups with high sensitivity and specificity; (2) Children and adolescents have lower maximal trunk flexion angle and a higher EMG amplitude than controls; (3) Children and adolescents with NSCLBP exhibiting FRP have a higher maximal flexion angle at FRP onset than controls.

Results concerning the occurrence of FRP in the majority (>75%) of CTRL group participants, during both standing and sitting tasks, were consistent with literature on asymptomatic adults populations, which reports occurrence from 82%–100%2–5. However, NSCLBP participants had similar results to the CTRL group for the occurrence of FRP in both standing (ESL: NCLBP=81%, CTRL=91%, p=0.758; M:NCLBP=78%, CTRL=87%,...
and slumped sitting tasks (ESL: NCLBP=76%, CTRL=83%, \( p=0.366; \) M:NCLBP=41%, CTRL=46%, \( p=0.725 \)). These results contrast with adults with NSCLBP, of whom only 30%–60% exhibited FRP\(^{4,31–33} \). The FRP’s low sensitivity and specificity in distinguishing between NSCLBP and CTRL children and adolescents in this study was inconsistent with its high combined sensitivity (88.8%) and specificity (83.1%) when evaluating adult populations\(^{10,12,34} \).

Presence of the FRP in the majority of children and adolescents, both with and without NSCLBP, was confirmed by both groups having similar FRRs and significantly lower normalised EMG amplitudes during static full flexion than in dynamic flexion or extension. However, this supports the only other published study evaluating FRP during slumped sitting in adolescents with NSCLBP and controls\(^{22} \). Astfalck et al.\(^{22} \) showed that multifidus muscle activation levels could not discriminate between these groups, in contradiction to results with adults suffering from LBP\(^{35} \). We speculate that differences between adolescents’ and adults’ results can be explained by the undamaged muscular fibres in younger populations, associated with the immaturity and greater plasticity in the trunk motor systems of adolescents with NSCLBP, as Astfalck et al. proposed\(^{22} \). One other hypothesis could be less laxity in the osteoligamentous spine of the children and adolescents (less damage), suggesting that the younger population could use passive structures to support themselves.

Our analysis of range of trunk motion during flexion showed similar results in NSCLBP and CTRL groups for both standing and sitting tasks for every evaluated trunk region. These results were consistent with those reported by Astfalck et al.\(^{22} \) in adolescents. They did not support those of Kaigle et al.\(^{36} \), who reported that participants with CLBP were significantly limited in their ability to flex and extend their trunks compared to an asymptomatic group. During seated
task, Dankaerts et al.\textsuperscript{35} reported a limited ability to change lumbo-pelvic posture from usual sitting in adults suffering of NSCLBP.

Relative maximal flexion angles at FRP onset in the standing task were superior to 70\% in the ESL and M muscles of both groups, matching values reported in asymptomatic adults\textsuperscript{6,8}. However, slumped sitting task results were different, with higher values in the CTRL group (>70\%) than in the existing literature (around 50\%)\textsuperscript{6,8}. Subdividing the spine into two sections added knowledge in ESL muscles during slumped sitting task. FRP onset was significantly earlier in NSCLBP group in thoracic (63.3 (25.7) \%) and lumbar (56.7 (25.8) \%) flexion angle during slumped sitting in comparison with CTRL (thoracic flexion: 83.8 (17.9) \%, lumbar flexion: 77.6 (14.0) \%). Values in NSCLBP are similar to results in asymptomatic adults (around 50\%)\textsuperscript{6,8} but these in CTRL are higher. Results in CTRL did not support the fact that child thorax is more flexible\textsuperscript{37} where lower values were expected. It should be of interest to evaluate the lumbar and thoracic relative maximal flexion angles at FRP onset in thoracic level of ES muscles to confirm/reject lower angles during slumped sitting task in comparison with upright trunk flexion as reported in asymptomatic adults\textsuperscript{38}.

O'Sullivan et al.\textsuperscript{6} explained the FRP’s earlier onset in a slumped sitting task than in a standing one as being due to slumped sitting involving transfer of the extensor moment from the local lumbar musculature (M) to other muscles and its contribution to midrange thoracolumbar movements (e.g., thoracic erector spinae). However, this proposition remains unverified in children and adolescents.

Furthermore, FRP’s occurrence during slumped sitting was dependent on the muscle investigated, being observed in fewer than half of participants’ M muscles but >75\% of their
ESL muscles. These results are consistent with those of asymptomatic adults. This could be explained by Nairn et al.’s observation that in slumped sitting the mid- and lower-thoracic regions achieved almost a full-range of movement, whereas upper-thoracic and lumbar regions achieved only a half-range.

Overall, the present results for children and adolescents differed from those for adults with LBP. More investigations in a larger cohort would be needed to confirm these results, to improve understanding of paediatric NSCLBP and to define specific therapeutic strategies. It would be interesting for further studies to evaluate whether paediatric patients suffering NSCLBP go on to have LBP in adulthood, when the FRP ceases to occur and which factors are associated with an absence of FRP.

In perspective, it should be interesting to evaluate the role of other extensor in FRP as iliocostalis and thoracic erector spinae (TES). Astfalck et al. reported no significant differences between adolescents with NSCLBP and no-LBP in iliocostalis and TES muscles during slumped sitting. These authors also reported significant reduction in EMG for iliocostalis ($t=-2.132$, $p=0.042$) and TES ($t=-2.128$, $p=0.038$) between usual and slump sitting suggesting presence of FRP in NSCLBP group. These results are consistent with healthy adults with similar occurrence of FRP in both standing and sitting position in TES. These results should be confirmed on a larger cohort of children and adolescents and relationship with higher thoracic flexibility in this young population and presence of FRP should be evaluated. Furthermore, evaluating presence/absence of FRP in thoracic ES level in a population of adults with NSCLBP could confirm/reject differences with children and adolescents with NSCLBP.
It should also be interesting to evaluate the role of deep muscles as spinalis and semispinalis muscles. However, such evaluation is only possible with intramuscular EMG, invasive electrodes that complicates the evaluation especially in young patients.

Finally, in the literature, children and adolescents with LBP presented a lower performance time of trunk extensor muscles endurance test from no-LBP subjects. In future work, it could be of interest to compare in the same cohort performance time and muscular fatigue (slope of median frequency during test) of ESL and M muscles during trunk extensor muscles endurance test between children and adolescents with NSCLBP and CTRL. ESL muscle fatigue after trunk extensor muscles endurance test in asymptomatic adults has been reported to modulate the FRP with earlier FRP onset during upright trunk flexion. Interactions between chronic pain and muscular fatigue and their effect on the FRP need to be studied in both adults and children/adolescents with NSCLBP.

Limitations

The present study has some limitations. Because all the participants recruited with NSCLBP came from a single university hospital paediatric orthopaedic clinic, results should not be generalised to all paediatric populations with NSCLBP. Some participants had to be excluded from the analysis due to EMG electrodes detachment (1/38 NSCLBP, 1/24 CTRL) and misunderstandings about slumped sitting task instructions (2/24 CTRL). Another limitation concerns using surface EMG to record M muscles. Stokes et al. showed that accurate measurement of M muscle activity requires intra-muscular electrodes. However, the present study followed the SENIAM recommendations for electrodeplacement, and surface EMG data for ESL and M muscles have been evaluated as highly correlated with intra-muscular EMG data. Finally, the present study
evaluated moderately affected patients (pain intensity<5/10; Oswestry scores<21%); results might be different in a group more severely affected by pain.

5. Conclusion

The present study highlighted:(1) FRP’s slow sensitivity in discriminating between children and adolescents with NSCLBP and controls, as the FRP was present in both groups and in both tasks (standing and slumped sitting); (2) a similar maximal flexion angle during flexion tasks in children and adolescents with NSCLBP and controls; (3) a similar relative maximal flexion angle at FRP onset in both the NSCLBP and CTRL groups, in both tasks and in both muscles (ESL and M) and earlier relative maximal flexion angle at FRP onset in lumbar and thoracic regions during slumped sitting in ESL muscle. The present results are inconsistent with existing literature on adults and could lead to modifications in the therapeutic management of children and adolescents with NSCLBP.
References


Figure captions

Figure 1: A. An EMG normalisation task based on manual muscle testing against gravity (isoMMT3); B. Description of the tasks evaluated: standing trunk flexion and slumped sitting. Grey circles represent reflective markers placed on the C7, L1 and S1 spinous processes. Black squares represent surface electromyographic electrodes placed bilaterally on back muscles (ESL and M).

**A - EMG normalisation task**
- Based on manual muscle testing against gravity
- 5 s hold on, mean value

**B - Trunk flexion tasks**

Standing trunk flexion

1 (5 s) 2 (10 s) 3 (5 s)

Slumped sitting

1 (5 s) 2 (10 s) 3 (5 s)

1 - Dynamic flexion; 2 - Static full flexion; 3 - Dynamic extension
Figure 2: Illustration of angle (expressed as a percentage of the maximal trunk angle at full flexion) at the time of onset of the FRP for a representative control subject. FRP is the self-reference threshold (3 times the average of normalised linear envelope EMG during full flexion) and FRP onset represent the first time followed by 50 ms continuously below threshold.
Figure 3: Comparison by group of mean normalised EMG amplitudes (%isoMMT3) computed during the dynamic flexion, static full flexion and dynamic extension stages of the standing trunk flexion and slumped sitting tasks, for both the erector spinae longissimus (ESL) and multifidus (M) muscles. CTRL=control group; LBP=non-specific chronic low back pain group; * is significant group difference evaluated with $p<0.05$ using unpaired Student t-test.
Table 1: Anthropometric and pain-related characteristics

<table>
<thead>
<tr>
<th>Groups</th>
<th>LBP (n = 37)</th>
<th>CTRL (n = 23)</th>
<th>p-value</th>
<th>95% CI</th>
<th>ES</th>
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<tr>
<td><strong>Anthropometric characteristics</strong></td>
<td></td>
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</tr>
<tr>
<td>Female, n (%)</td>
<td>30 (81%)</td>
<td>16 (67%)</td>
<td>0.331</td>
<td>-12 to 41</td>
<td>0.193</td>
</tr>
<tr>
<td>Age, years, mean (SD)</td>
<td>14.1 (1.9)</td>
<td>13.9 (2.3)</td>
<td>0.649</td>
<td>-0.9 to 1.4</td>
<td>0.128</td>
</tr>
<tr>
<td>Height, m, mean (SD)</td>
<td>1.60 (0.11)</td>
<td>1.64 (0.13)</td>
<td>0.246</td>
<td>-0.10 to 0.26</td>
<td>0.322</td>
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<tr>
<td>Body mass, kg, mean (SD)</td>
<td>53.9 (11.4)</td>
<td>50.5 (13.6)</td>
<td>0.323</td>
<td>-3.4 to 10.1</td>
<td>0.277</td>
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<tr>
<td><strong>Body weight status</strong></td>
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<tr>
<td>Underweight (z &lt; -2SD), n (%)</td>
<td>1 (5%)</td>
<td>2 (8%)</td>
<td>0.698</td>
<td>-21 to 10</td>
<td>0.019</td>
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<tr>
<td>Healthy weight (-2SD ≤ z ≤ 1SD), n (%)</td>
<td>24 (65%)</td>
<td>19 (83%)</td>
<td>0.201</td>
<td>-43 to 6</td>
<td>0.210</td>
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<tr>
<td>Overweight (1SD &lt; z ≤ 2SD), n (%)</td>
<td>10 (27%)</td>
<td>2 (8%)</td>
<td>0.143</td>
<td>-3 to 40</td>
<td>0.275</td>
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<tr>
<td>Obese (z &gt; 2SD), n (%)</td>
<td>2 (5%)</td>
<td>0 (0%)</td>
<td>0.673</td>
<td>-5 to 16</td>
<td>0.023</td>
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<td><strong>Pain-related characteristics</strong></td>
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<tr>
<td>Last 24 h pain, /10, mean (SD)</td>
<td>3.9 (1.8)</td>
<td>-</td>
<td>-</td>
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<td>Pain duration, months, mean (SD)</td>
<td>16.3 (15.1)</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Disability Oswestry score, n (%)</td>
<td>18.2 (8.0)</td>
<td>0.6 (1.3)</td>
<td>&lt; 0.001</td>
<td>14.9 to 20.3</td>
<td>2.856</td>
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</table>

LBP is non-specific chronic low back pain group; CTRL is control group. Pain intensity was evaluated using a visual analogue scale (Jensen, Karoly, and Braver 1986), functional disability was evaluated using the Oswestry questionnaire (Vogler et al. 2008). BMI-for-age was computed as a z-score (z) (Mercedes de Onis et al. 2007) and weight status categories were defined using World Health Organization recommended cut-offs (M. de Onis and Lobstein 2010).

Mean (Standard deviation) or n (%); * Unpaired Student-t or Khi2 test P-value < 0.05
Table 2: Results of task, muscle and group effects

<table>
<thead>
<tr>
<th></th>
<th>Standing trunk flexion</th>
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<th>Slumped sitting</th>
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<tr>
<td></td>
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<td>Group effect</td>
<td>LBP (n = 37)</td>
<td>CTRL (n = 23)</td>
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<td></td>
<td></td>
<td></td>
<td>LBP (n = 37)</td>
<td>CTRL (n = 21)</td>
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<tr>
<td>FRP occurrence</td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Visual inspection, n (%)</td>
<td></td>
<td></td>
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<tr>
<td>ESL muscle</td>
<td>30 (81%)</td>
<td>21 (91%)</td>
<td>0.758</td>
<td>28 (76%)</td>
</tr>
<tr>
<td>M muscle</td>
<td>29 (78%)</td>
<td>20 (87%)</td>
<td>0.623</td>
<td>15 (41%)</td>
</tr>
<tr>
<td></td>
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</tr>
<tr>
<td>FRR ratio, mean (SD)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>ESL muscle</td>
<td>0.31 (0.22)</td>
<td>0.32 (0.27)</td>
<td>0.882</td>
<td>0.54 (0.25)</td>
</tr>
<tr>
<td>M muscle</td>
<td>0.36 (0.26)</td>
<td>0.32 (0.26)</td>
<td>0.528</td>
<td>0.68 (0.27)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Trunk range of motion</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Global trunk flexion (F), °, mean (SD)</td>
<td>102.0 (16.3)</td>
<td>104.7 (17.9)</td>
<td>0.552</td>
<td>18.9 (8.6)</td>
</tr>
<tr>
<td>Onset angle, % F, mean (SD)</td>
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<td></td>
<td></td>
</tr>
<tr>
<td>ESL muscle</td>
<td>76.5 (7.8)</td>
<td>81.7 (12.7)</td>
<td>0.062</td>
<td>77.2 (17.9)</td>
</tr>
<tr>
<td>M muscle</td>
<td>79.8 (13.0)</td>
<td>79.8 (12.0)</td>
<td>0.996</td>
<td>81.9 (20.6)</td>
</tr>
<tr>
<td>Thoracic flexion (TF), °, mean (SD)</td>
<td>120.8 (14.9)</td>
<td>125.8 (16.1)</td>
<td>0.230</td>
<td>34.6 (10.6)</td>
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<tr>
<td>Onset angle, % TF, mean (SD)</td>
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</tr>
<tr>
<td>ESL muscle</td>
<td>74.3 (10.1)</td>
<td>81.2 (16.4)</td>
<td>0.120</td>
<td>63.3 (25.7)</td>
</tr>
<tr>
<td>M muscle</td>
<td>81.6 (11.7)</td>
<td>80.4 (15.7)</td>
<td>0.779</td>
<td>70.7 (28.4)</td>
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<tr>
<td>Lumbar flexion (LF), °, mean (SD)</td>
<td>77.7 (15.0)</td>
<td>79.7 (18.3)</td>
<td>0.657</td>
<td>7.9 (6.2)</td>
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<tr>
<td>Onset angle, % LF, mean (SD)</td>
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</tr>
<tr>
<td>ESL muscle</td>
<td>72.2 (11.9)</td>
<td>79.4 (15.3)</td>
<td>0.101</td>
<td>56.7 (25.8)</td>
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<tr>
<td>M muscle</td>
<td>80.9 (12.8)</td>
<td>77.5 (14.7)</td>
<td>0.428</td>
<td>70.3 (17.7)</td>
</tr>
</tbody>
</table>

Mean (Standard deviation) or n (%); * Unpaired Student-t or χ² test P-value < 0.05; ESL is erector spinae longissimus and M is superficial lumbar multifidus; Flexion angle represent maximal flexion values.

Onset angle was only evaluated on participants with FRP and/or without a noisy EMG signal. Corresponding numbers of included participants were reported as a: n = 28, b: n = 24, c: n = 18, d: n = 19, e: n = 25, f: n = 13, g: n = 15, h: n = 8, respectively.
Table 3: Results of task, muscle and group effects and interaction effects.

<table>
<thead>
<tr>
<th>Effect</th>
<th>df</th>
<th>F-statistic</th>
<th>p-value</th>
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<tbody>
<tr>
<td>Flexion relaxation ratio</td>
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<tr>
<td>Group</td>
<td>1</td>
<td>2.798</td>
<td>0.096.</td>
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<tr>
<td>Task</td>
<td>1</td>
<td>51.617</td>
<td>&lt; 0.001*</td>
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<tr>
<td>Muscle</td>
<td>1</td>
<td>6.834</td>
<td>0.010*</td>
</tr>
<tr>
<td>Task x Group</td>
<td>1</td>
<td>1.492</td>
<td>0.223</td>
</tr>
<tr>
<td>Muscle x Group</td>
<td>1</td>
<td>0.027</td>
<td>0.869</td>
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<tr>
<td>Task x Muscle</td>
<td>1</td>
<td>3.356</td>
<td>0.069.</td>
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<tr>
<td>Task x Muscle x Group</td>
<td>1</td>
<td>0.373</td>
<td>0.542</td>
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<tr>
<td>Relative maximal flexion angle at FRP onset of the global trunk (C7-S1)</td>
<td></td>
<td></td>
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<tr>
<td>Group</td>
<td>1</td>
<td>1.382</td>
<td>0.242</td>
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<tr>
<td>Task</td>
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<td>0.148</td>
<td>0.701</td>
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<tr>
<td>Muscle</td>
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<td>0.182</td>
<td>0.670</td>
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<tr>
<td>Task x Muscle</td>
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<td>1.337</td>
<td>0.250</td>
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<tr>
<td>Muscle x Group</td>
<td>1</td>
<td>4.395</td>
<td>0.038*</td>
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<tr>
<td>Task x Muscle</td>
<td>1</td>
<td>1.237</td>
<td>0.268</td>
</tr>
<tr>
<td>Task x Muscle x Group</td>
<td>1</td>
<td>0.679</td>
<td>0.411</td>
</tr>
</tbody>
</table>

Repeated measures ANOVA was used to determine effects and interaction effects of group (low back pain, controls), task (standing trunk flexion, slumped sitting) and muscle (erector spinae longissimus, lumbar multifidus) at a significance level $p \leq 0.05*$. df is degree of freedom, FRP is flexion-relaxation phenomenon.