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# Age- and low back pain-related differences in trunk muscle activation during one-legged stance balance task

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ABSTRACT

*Background:* Postural control declines with age and can be affected by low back pain. Poor balance has been reported in people with chronic low back pain (CLBP), which in turn could be explained by the changes in trunk muscle activation.

*Research Question:* Are there differences between younger and older adults with and without chronic low back pain (CLBP) on trunk muscle activity during one-legged stance task?

*Methods:* Twenty (20) with, and 20 subjects without nonspecific CLBP participated in the study. Each group was comprised of 10 younger (50% males; mean age: 31 years) and 10 older adults (50% males; mean age: 71 years). Subjects performed 3 × 30-second trials of one-legged stance, with eyes open, on a force platform, while surface electromyography (EMG) measurements were obtained bilaterally on the multifidus at L5, iliocostalis lumborum at L3, rectus abdominis and biceps femoris muscles.EMG amplitude analysis was processed by the Root Mean Square (250 ms window epochs) and normalized by the peak of activation during the balance tasks, to determine the muscular activity of each muscle.

*Results:* Participants with CLBP presented 15% lower lumbar muscle activation ($p < 0.05$), and 23% higher co-activation (ratio between rectus adominis by multifidus) than participants without CLBP, regardless of age. Significant differences ($p < 0.05$) between older and young groups were observed only for lower lumbar muscles (mean 24% lower in older than younger adults) and rectus adominis muscles (mean 17% lower in older than younger adults).

*Significance:* CLBP individuals have different trunk muscle activity than those without CLBP, and older adults exhibit lower trunk activation during one-legged stance balance task. The use of the EMG in evaluation of trunk neuromuscular function during one-legged stance may thus be a valuable tool when assessing balance in CLBP and older people.

## 1. Introduction

Postural control declines with age due to biological changes (e.g. decreased strength, mobility, and motor control) and physical inactivity, which in turn can lead to falls [1]. Chronic degenerative musculoskeletal disorders are also common among older adults. The prevalence of chronic low back pain (CLBP) can be as high as 84% in this segment of the population [2].

Stabilizing muscle function and coordination are often impaired in CLBP [3–6]. Decreased back endurance has been shown to be a predictor of first-time CLBP occurrence [3] and of long-term back-related disability [4]. Trunk muscle fatigue can increase neuromuscular

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deficits, resulting in brief uncontrolled intervertebral movements, lumbar spine instability and back pain [5]. In addition, poor lumbar proprioception has been reported in some individuals with CLBP [6–8]. Balance performance is also decreased in individuals with CLBP during bipedal standing [9–12] and one-legged stance conditions [13,14]. In fact, in a recently published study we found that participants with CLBP presented significantly poorer balance during a one-legged stance, as measured by centre of pressure (COP) variables, than participants without CLBP (effect size of $d = 1.44$ for younger adults and $d = 0.40$ for older individuals) [14]. In addition, older adults with CLBP presented poorer balance than younger adults with CLBP (large effect size, $d = 1.24$), which further underscores the age-dependent effect of CLBP on postural control.

Some theories (biomechanical model, pain adaptation model, reflex-spam pain model) based on the interpretation of changes in trunk muscle activation, may help to better explain these negative results on postural control measures in CLBP. In fact, people with CLBP have been shown to have different trunk activation patterns depending on the task (hyperactive or hypoactive) compared to those without CLBP [15]. Increased trunk activation was found in healthy older adults (n = 12, mean 69 years) during lumbar flexion-extension, lateral bending, and rotation tasks, compared to younger subjects [16]. Changes in trunk muscle activation were also observed in older adults with CLBP compared to control groups during extreme flexion and extension movements [17,18]. None of these studies, however, included the evaluation of trunk muscular activity during a specific balance task and this, in older adults with CLBP.

The main purpose of this study was to compare for the first time the trunk muscle activation of younger and older subjects, with and without CLBP, during one-legged stance balance task. A second purpose was to determine if age can mediate the results. Our hypothesis was that both CLBP status and age would affect the trunk activation pattern during a one-legged stance.

## 2. Methods

### 2.1. Participants

Twenty (20) individuals with, and 20 without nonspecific CLBP (10 > and 10 < 60 years in each group) were recruited on a voluntary basis from the university and local community. Both groups were matched by age and sex (50% males and 50% females). This study was performed between July 2016 to January 2017. We used data from our recent study of postural control [14] to determine the sample size required to identify the differences in trunk muscular activation between young and older subjects with and without CLBP. Using the moderate to large effect size ($d = 0.40$–$1.60$) attained in the prior study [14] and a desired power of 0.80, a minimum of 11 participants per group was calculated (i.e. to run independent t test) to be the sample size needed to detect between groups differences.

All participants signed informed consent before their participation. The protocol and consent form were approved by the local ethics committee (#PP/0004/14). During the initial evaluation, participants were questioned by a trained physiotherapist about medical history, symptoms, and CLBP history. The inclusion criteria for the CLBP group were: history of lumbar or lumbosacral pain, with or without proximal radicular pain, and presence of chronic pain defined as daily or almost daily pain for a minimum of 3 months. The inclusion criteria for individuals without CLBP were: no history of back pain for the past year, being defined as an episode that required treatment or led to missed work or school days. The exclusion criteria were: sensory or neurological disorders, previous back surgery, lower limb musculoskeletal pathology, use of medications that affect balance, history of falls in the past year, Mini-Mental State Examination score < 21 [19] and taking part in structured physical activities ( > 3 days a week) or rehabilitation programs at the time of the study period.

### 2.2. Procedures

Data collection was completed in one session of approximately 2 h duration. A single investigator performed all the procedures. CLBP participants completed 3 questionnaires: (1) The Rolland–Morris disability questionnaire (RDQ) [20]; (2) The Fear-Avoidance Beliefs Questionnaire for physical activities (FABQp) and work activities (FABQw) [21]; (3) a 10-cm visual analog scale (VAS) for pain intensity measurement [11]. Because the FABQw was administered to retired older adults, the term "work" was changed for "social or home activities."

### 2.3. One-legged balance task protocol

After familiarization, all participants performed 3 trials of one-legged stance on the individual's self-selected leg for 30 s maximum on a force platform, with a rest period of approximately 30 s between each trial [14,22]. A standardized protocol regarding feet, trunk, arms and eye positioning was used, as previously detailed by da Silva et al. [14,22]. The same COP parameters and time-limit performance as those described in da Silva et al. [14] were computed for each participant.

### 2.4. Electromyography (EMG) signal processing

EMG signals were collected with a Bagnoli-8 EMG System (Delsys Inc., Wellesley, MA, USA). We used 8 active surface electrodes, with a gain of 1000 and a sampling rate of 2000 Hz. All EMG signals were subsequently bandpass filtered in 20 and 450 Hz ($8^{th}$ order zero-lag Butterworth, Infinite Impulse Response: IIR filter) to remove high frequency noise, as well as low-frequency movement and electrocardiogram (ECG) artifacts. A notch filter was also used for the EMG signals for removing of frequencies at 60 Hz and their harmonics. The ECG is dominant in torso EMG signals, which mandated the use of a high-pass cut-off frequency (at least from 20 Hz); as pointed out by Redfern et al., which is above what is recommended (10 Hz) to remove movement artefacts from the procedure in the standard of the Journal of Electromyography and Kinesiology [23,24].

After the skin at the electrode sites was shaved and abraded with alcohol, the electrodes were positioned bilaterally on the multifidus at the L5 level (MU-L5-Left and MU-L5-Right), and on the iliocostalis lumborum at the L3 level (IL-L3-Left and IL-L3-Right), following the recommendations of Defoa et al. [25]; with regard to muscle fiber direction (details in da Silva et al.) [24,26]. Four (4) additional electrodes were positioned, bilaterally, over the biceps femoris (BF-Left and BF-Right) and rectus abdominis (RA-Left and RA-Right). A reference (ground) silver-silver chloride electrode was positioned over the T8 spinous process [24,26].

All EMG data processing was performed using both EMG work analysis from Delsys system (Version 4.0, Delsys, MA, USA) and MATLAB sub-routines (Version 8.0; The MathWorks Inc., Natick, MA, USA, release 14). From the EMG signals, a moving Root Mean Square (RMS) processing method was executed on successive 250-ms (512 points) time-windows [26]. For each muscle, the peak RMS value calculated across 5 to 25 s time-series balance tasks represented the maximal EMG activity ($RMS_{PEAK}$). This portion of time was used to avoid acceleration and deceleration or fatigue phase in the end of the test from 0 to 30 s [26]. $RMS_{PEAK}$ was used then to compute the muscle activation level, which is determined by the percentage of EMG amplitude relative to the maximal EMG obtained during a submaximal activation contraction reference from balance task in our study, as supported by Burden [27]. Normalization of the EMG signal procedure from the peak of EMG amplitude calculated during a submaximal contraction contributes to reduce the inter-individual variability of data in each muscle group, mainly from a pathological sample where pain and fear-avoidance of movement can be present as confounding variables associated with EMG measurement [27]. This procedure also increases the reliability of the data [28,29].

Thus, the average of the RMS values (250 ms, 50% overlapped) from this same time-series portion was also computed for each muscle, which represented the mean RMS activity during one-legged balance task ($RMS_{TASK}$). Both $RMS_{PEAK}$ and $RMS_{TASK}$ values were averaged across the 3 balance trials to increase reliability and to give a single value [29]. Finally, the trunk muscle activation (in %) was computed for each muscle using the equations below:

$$\% \text{ RMS EMG} = [(RMS_{TASK} / RMS_{PEAK}) \times 100\%]$$

Because no between-side differences (right and left side) were obtained ($p < 0.05$: *t*-test results) for each group (with and without CLBP) and age, the RMS EMG% values were averaged bilaterally to reduce the data to 2 back muscle groups (MU-L5 and IL-L3). This averaging procedure has been shown to increase the reliability of EMG estimates [29]. A complementary analysis for trunk coordination muscles was also applied to determine the ratio between abdominal and lumbar muscles during the task, namely co-activation based on the reference of a lumbar muscle (MU-L5) as follows [30]:

$$\text{Co-activation (\%)} = (\text{RA - MU-L5}) / \text{MU-L5} \times 100\%$$

Ex: rectus abdominis activity was subtracted by the reference (EMG activity of muscle lumbar: MU-L5) and afterward, divided by the same reference (MU-L5) to better determine the ratio between anterior and posterior trunk activity.

### 2.5. Statistical analysis

Shapiro-Wilk and Leven's test revealed that the EMG variables were normally distributed. A MANOVA factorial analysis was performed, including all the anthropometric variables (age, height, mass and BMI) on PATHOLOGY and AGE comparisons. For back-pain related questionnaires, independent t-tests were performed to compare younger and older adults with CLBP.

The postural balance performance, from COP parameters and time-limit measure, was previously analyzed and compared between-group in Da Silva et al. [14]. Hence, only trunk muscular activity was analyzed and interpreted in this study. For EMG variables, a two-way ANOVA (PATHOLOGY and AGE) was performed to determine the effects between: (1) with CLBP and without CLBP, (2) younger and older, and (3) Interaction (PATHOLOGY × AGE) for the % RMS EMG values in each muscle evaluated. To determine the magnitude of differences between the main effects, the effect size (ES) based on Cohen's *d* values was also reported [31]. Thus, Cohen's d effect size was used to indicate the standardized difference between two means from ANOVA results for the main effects found [31]. All statistical analyses were performed with SPSS statistical software (version 20.0 for Windows) with an alpha level of 0.05.

## 3. Results

### 3.1. Description of subjects

There were no significant differences between participants, with and without CLBP, on demographics ($F = .048–.399$; $p = 0.513$ to 0.828; cf. Table 1). There were no significant differences between younger and older adults with CLBP on the back pain related questionnaires ($t = -0.125$ to 1.190, $p = 250$ to 0.902). On the other hand, there were significant differences between younger and older adults in BMI ($p < 0.01$; mean 23 ± 2.5 versus 26 ± 3.5, respectively, Table 1).

### 3.2. Trunk muscle activation

Trunk muscle activation results from ANOVA are presented in Table 2; and mean % values are reported in Fig. 1 for each muscle evaluated. The ANOVA results revealed non-significant interaction effects (PATHOLOGY × AGE) for any of the muscles investigated (Table 2).

Significant differences between individuals, with and without CLBP, in both AGE groups were observed for MU-L5 ($F = 7.612$; $p < 0.01$; ES $d = .21$), IL-L3 ($F = 9.405$; $p < 0.01$; ES $d = .23$), and for co-activation [*(RA-MU-L5)/ MU-L5]* variable ($F = 7.672$; $p < 0.01$; ES $d = .17$). Regardless of AGE, participants with CLBP presented with 15% lower lumbar muscle activation and 23% higher co-activation than participants without CLBP. The mean descriptive data for co-activation levels were 10% in younger and 7% in older for individuals without CLBP, while of 25% in younger and 35% in older with CLBP.

Significant AGE effects ($p < 0.01$; Table 2) were found for both the lumbar (MU-L5: ES $d = .27$ and IL-L3: ES $d = .22$) and rectus abdominis muscles (ES $d = .24$) (also illustrated in Fig. 1). Lower activation was found more in older than in younger adults for both groups, with and without CLBP, (mean 20% lower in older than younger, Fig. 1). For the biceps femoris, there were no significant differences between participants, with and without CLBP, or between younger and older participants (Fig. 1C).

**Table 1**
The characteristics of subjects.

| Variables | Younger adults[b] | | Older[b] | |
|---|---|---|---|---|
| | Without CLBP | With CLBP[a] | Without CLBP | With CLBP[a] |
| Age (yrs) | 30 (4) | 33 (8) | 73 (7) | 70 (8) |
| Mass (kg) | 64 (8) | 67 (9) | 67 (10) | 66 (9) |
| Height (m) | 1.65 (0.12) | 1.70 (0.06) | 1.60 (0.10) | 1.58 (0.08) |
| BMI ($kg/m^2$) | 23 (2) | 23 (3) | 26 (4) | 26 (3) |
| VAS pain (cm) | / | 5 (2) | / | 4 (2) |
| RDQ score | / | 8 (4) | / | 9 (6) |
| FABQp score | / | 16 (9) | / | 14 (5) |
| FABQw score | / | 18 (6) | / | 23 (12) |

*Note*: mean values with Standard Deviation in parenthesis (SD). BMI: body mass index; VAS: Back pain intensity; RDQ: Roland-Morris Disability Questionnaire; FABQp: Fear-Avoidance Beliefs related to physical activity; FABQw: Fear-Avoidance Beliefs related to work (or social activities for older people). CLBP: chronic low back pain.

[a] No significant differences (PATHOLOGICAL effect) were reported in all variables between younger adults with and without CLBP as well as for older adults with and without CLBP ($p > 0.05$).

[b] Significant differences (Age effect) were found between younger and older adults, in both with and without CLBP, for age, height and BMI variables (From MANOVA results; $p < 0.01$). Clinical back condition between younger and older with CLBP was similar (no significant differences from independent t-tests; $p > 0.05$).

## 4. Discussion

Overall, people with CLBP presented different trunk muscle activation patterns during a one-legged stance, which supported our hypothesis on the effect of pathology. Second, low lumbar activation and higher abdominal activation were found more in older than in younger adults, regardless of pathology, which also supported our second hypothesis. To the authors' knowledge, this is the first study to compare trunk muscle activation patterns in young and older adults, with and without CLBP, during a one-legged stance task. Our results from COP parameters between groups were presented recently in da Silva et al. [14] and helped us to interpret and explain these new findings related to trunk muscular activation during balance performance.

Da Silva et al. [14] showed that balance measures during one-leg stance tasks were sensitive for differentiating between subjects with and without CLBP (pathology effects), but with a larger effect size in younger adult comparisons (mean $d = 1.60$ across centre of pressure parameters) than in older adults, where the effect sizes were small (mean Cohen's $d = 0.40$). Second, the authors reported that these

**Table 2**
Trunk neuromuscular activation pattern during one-legged balance stance (ANOVA results).

| Muscles | Two-way ANOVA results (*P* values) | | | Direction of effects[a] |
|---|---|---|---|---|
| | PATHOLOGY *p* (effect size) | AGE *p* (effect size) | PATHOLOGY × AGE *p* (effect size) | |
| Multifidus (MU-L5) | 0.010 (0.21)* | 0.002 (0.27) * | 0.488 (0.15) | CLBP < Activation than WCLBP<br>Older < Activation than younger |
| Iliocostalis (IL-L3) | 0.004 (0.23)* | 0.005 (0.22) * | 0.427 (0.20) | CLBP < Activation than WCLBP<br>Older < Activation than younger |
| Biceps femoris (BF) | 0.969 (0.01) | 0.132 (0.07) | 0.970 (0.01) | |
| Rectus abdominis (RA) | 0.504 (0.02) | 0.003 (0.24) * | 0.220 (0.04) | Older > Activation than younger |
| Co-activation (*RA-MU-L5/MU-L5*) | 0.009 (0.17)* | 0.410 (0.01) | 0.864 (0.01) | CLBP > Activation than WCLBP |

* Significant differences on PATHOLOGY effect ($p < 0.01$): people with chronic low back pain (CLBP) ≠ people without CLBP for both lumbar muscles (MU-L5: multifidus at the L5 level and IL-L3: iliocostalis at the L3 level) and in Co-activation variable (a complementary analyses). Significant AGE effect ($p < 0.01$) for both lumbar muscles and rectus abdominis.

[a] Direction of the effect when the PATHOLOGY or AGE effect was significant in the % root mean square electromyography (%RMS EMG) (> = higher activation; < = lesser activation).

measures were efficient in differentiating between younger and older adults (age effects). Significant differences for COP measures and in time-limit variable during one-legged stance were also found between AGE groups. For example, the mean time-limit ability of older individuals is 20.5 s (with CLBP = 20 s and without CLBP = 21 s) while the mean time-limit ability of younger adults is 28 s (with CLBP = 26 s and without CLBP = 30).

For the muscular activation results, one past study investigating muscular strategies for balance postures was reported by Horak and Nashner in the mid-1980s [32]. Horak and Nashner's observations highlighted the importance of trunk muscles compared to lower-limb muscles to control the body during both ankle and hip postural strategies under normal and short surface sway perturbations [32]. In their review article, Helbostaed et al. supported the notion that trunk muscles play a determining role in balance and functional activities, particularly in older adults and in turn, in fall prevention when associated to balance [33]. This interpretation is coherent with the results from a recent study published by our research team revealing that conditioned

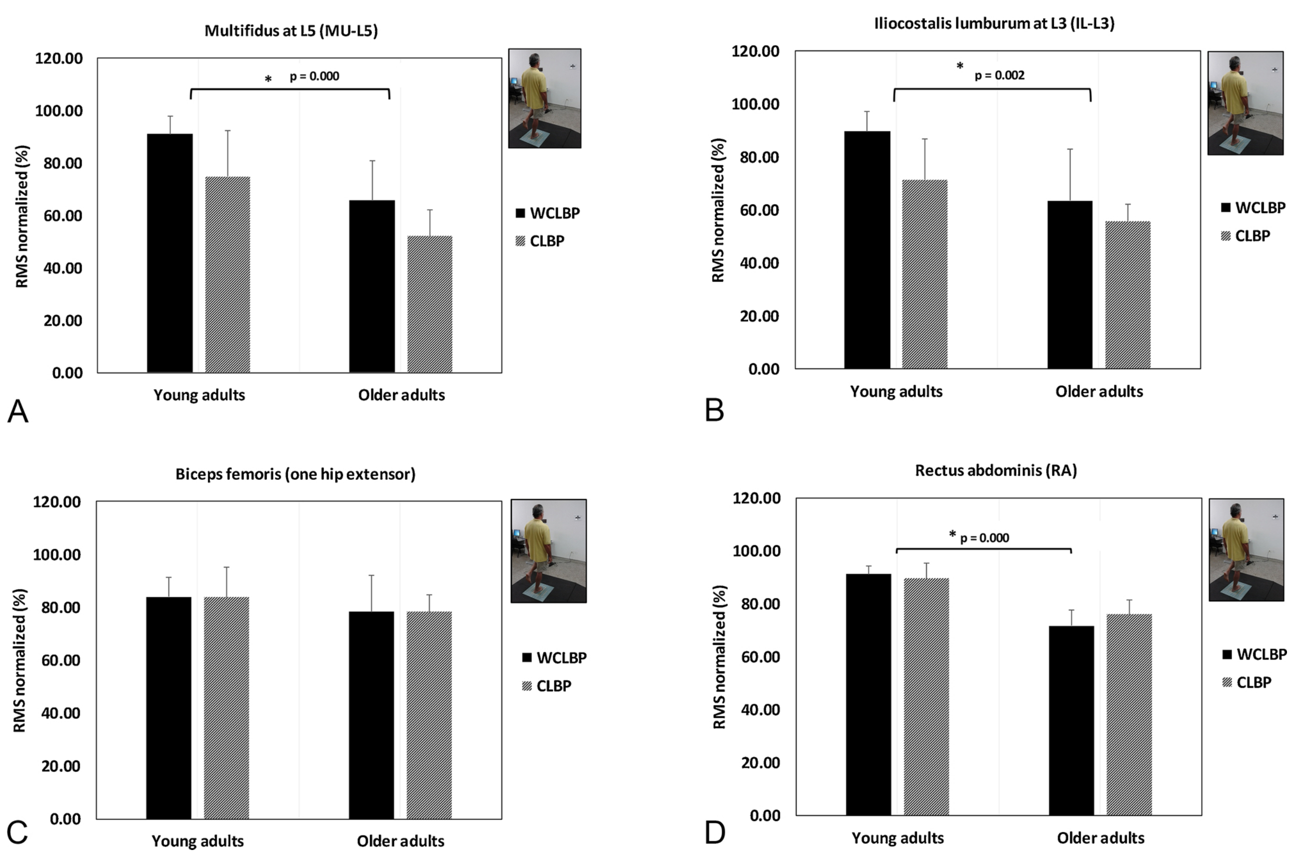


**Fig. 1.** Neuromuscular trunk activation values (error bars = standard deviations) from one-legged stance analysis (30 s time-series). (A) the multifidus (MU-L5), (B) the iliocostalis lumborum (IL-L3), (C) the biceps femoris (BF), and (D) the rectus abdominis (RA). *Significant differences ($p < 0.05$) between individuals without chronic low back pain (WCLBP) and with CLBP, independent of age (younger and older) for lumbar muscles (MU-L5 and IL-L3). *-Significant differences ($p < 0.05$) between younger and older subjects, mainly on WCLBP (*t*-test results intra-group), for the lumbar (MU-L5 and IL-L3) and abdominal (RA) muscles.

trunk extensor muscles contribute to good postural control in both young and older healthy subjects [34].

Some studies also showed impaired lumbosacral proprioception and trunk instability in individuals with CLBP [6–8]. In addition, Taimela et al. showed that, in a state of fatigue, trunk extensor muscles lose their ability to perceive changes in the position of the lumbar spine [35]. Moreover, the authors observed that decreased proprioceptive impulses can result in larger movements of the lumbar spine and, consequently, greater postural sway responses for balance control.

Given the findings of the aforementioned studies, it is possible that a decline in proprioception could contribute to decreased muscle activation when generating the appropriate postural corrections during trunk movements [6–9]. This could explain, at least in part, the results of the present study showing that our participants with CLBP presented 15% lower lumbar muscle activation (Fig. 1), and 23% higher co-activation than participants without CLBP, regardless of AGE. This supports that back disorders like CLBP can lead to an altered synergism of back muscle activity when accomplishing a specific balance task requiring one-legged stance [36]. In addition, the ability to stay in one-legged posture (measured by time-limit in seconds) between groups (with and without CLBP) for this condition was comparable, which supports the motor control mechanisms associated to pathology and balance performance more than the mechanical or physical capacity of individual.

The present results are similar to the biomechanical model, where low trunk muscle activity can be associated with poor posture control and guarding, which can develop in response to an original back injury [37–40]. A decreased paraspinal muscle activity during different flexion-extension movements was recently reported, and the authors suggested that persons with CLBP who are highly fearful not only guard when in flexion and extension movements, but also significantly limit their range of motion [38]. A limited mobility (rigid protection control based on pain adaptation) and excessive back fatigability can explain why some individuals with CLBP tend to use a more rigid control system, and limit ankle strategies to maintain stability [7], while individuals without CLBP tend to use a multi-segmental spine control strategy, without restriction of movement and muscular function [8,9]. This condition was also observed in our results and could explain the differences the muscular activity between groups (individuals with CLBP exhibited less muscle activity than individuals without CLBP).

Regarding the effects of aging, some studies found differences in trunk activation between older individuals with and without CLBP in other tasks than the one-legged stance, such as during full trunk flexion and extension movements (flexion-relaxation ratio phenomenon) [17,18]. In these past studies, older adults with CLBP showed higher lumbar extensor activity during an upright standing position (mainly the female group), and decreased muscular activity changes from a dynamic flexion-extension movement compared to young patients with CLBP (< 60 years) [18]. This higher back extensor activity in standing presented by these authors is in complete contrast with the results of the present study, where older adults presented decreased lumbar activation compared to younger adults during one-legged stance. The nature of each study's task may explain these discrepancies. Also, Kienbacher et al. suggested two explanations for their results: (1) increased excitability of the motor neuron pool in older individuals to promote co-contraction of the trunk antagonist muscles during the task; and (2) a fear related inhibition model or pain-spam-pain model that promote higher back extensor activity in older adults with CLBP compared to young adults with CLBP [18]. Thus, it is possible that age differences based on back disorders or on trunk muscle activity are task-dependent, and sometimes related to two models of purposed low back pain for sub-groups of patients (biomechanical stability model and reflex-spam pain model) [15].

On the other hand, aging is associated with neuromusculoskeletal alterations and decreased physiological functions, which in turn can lead to problems such as weakness, mobility issues, sensory-motor deficits, and consequent changed trunk muscle activity and impaired balance and falls [41]. We thus believe that the observed differences can be due to age-related functional decline, and in part to back disorders, as opposed to other anthropometric differences between groups, such as BMI (26 $kg/m^2$ for older vs. 23 $kg/m^2$ for the younger adults) as pointed out in the Table 1. In addition, we assumed that it is unlikely that the slightly higher BMI observed for the older adults could affect balance, and consequently trunk neuromuscular responses [42].

As a perspective from this work, use of the EMG for evaluation of trunk neuromuscular function may thus be a valuable tool when assessing balance in CLBP and older people. Our results could contribute to clinical decision-making in rehabilitation and preventive programs for younger as well as older people with CLBP. It must be remembered that advancing age is accompanied by a pronounced decrease in muscle mass and trunk function [41,43–46]. Such structural and functional changes when associated with back disorders can result in an impaired ability to perform daily activities and may ultimately cause dependence and disability in older adults. Health professionals should thus consider preventive measures focusing on strengthening trunk muscles through physical therapy. Pathology and aging can adversely affect balance, but improving the endurance of trunk muscles could minimize the negative impact on balance in these individuals.

Finally, a limitation of the present study was that we used non-random sampling based on individuals who volunteered to participate. Therefore, the sample may not be generalizable to the general population with CLBP or to older adults. Kinematic measures from the hip, knee and ankle joints, as well as strength measurement (not quantified here) could also help explain these results. Our individuals with CLBP presented moderate pain and minimal disability, which supports the biomechanical model notion. However, a new study including a more severe sample of low back pain patients (VAS > 7; RMQ > 12) would be more suitable to generalize the results.

## 5. Conclusion

Both younger and older adult CLBP individuals investigated in this study show decreased activation of the lumbar muscles and more co-activation between rectus adominis and multifidus muscles than healthy control groups during one-legged balance stance. Older subjects also reported decreased activation of the lumbar and abdominal muscles than younger subjects, regardless of any pathology.

## Conflict of interest statement

None declared.

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