Specificity of a back muscle exercise machine in healthy and low back pain subjects

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Christian Larivière, Ph.D.\textsuperscript{1,2}, Rubens A. da Silva, Ph.D.\textsuperscript{2}, A. Bertrand Arsenault, Ph.D.\textsuperscript{2,3}, Sylvie Nadeau, Ph.D.\textsuperscript{2,3}, André Plamondon, Ph.D.\textsuperscript{1}, Roger Vadeboncoeur, MD\textsuperscript{2}

Affiliation
2. Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR), Montreal Rehabilitation Institute, 6300 Darlington, Montreal, Quebec, Canada, H3S 2J4.
3. School of Rehabilitation, Faculty of Medicine, University of Montreal, C.P. 6128, Succursale Centre-Ville, Montreal, Quebec, Canada H3C 3J7.

Correspondence to
Christian Larivière, Ph.D.,
Occupational Health and Safety Research Institute Robert-Sauvé
505 boul. De Maisonneuve Ouest, Montreal, Quebec, Canada, H3A 3C2.
Tel: (514) 288-1551 ext: 217; Fax: (514) 288-6097
Email: lariviere.christian@irsst.qc.ca

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ABSTRACT

Purpose: To determine whether dynamic back muscle endurance exercises in a semi-sitting position induce more fatigue in back muscles than in hip extensors in healthy controls as well as in patients with non-specific chronic low back pain. Methods: Sixteen healthy and 18 volunteers with non-specific chronic low back pain performed trunk flexion-extension cycles until exhaustion, at 60% of their strength, in a machine designed for back exercise in a semi-sitting position with knees’ angle at 135°. The number of cycles and perceived muscle fatigue (Borg CR-10 scale) at five areas (upper and lower back, gluteus, hamstrings, quadriceps) were used as fatigue criteria. Electromyographic (EMG) signals were recorded bilaterally on four back muscles, two hip extensors (gluteus maximus, biceps femoris) and the vastus medialis. The slope values of the instantaneous median frequency values computed over time were retained as EMG indices of fatigue. Results: The number of cycles was equivalent in healthy controls (n = 23 ± 13) and patients with back pain (n = 27 ± 16). EMG indices of fatigue disclosed evidence of muscle fatigue in all back muscles and the vastus medialis, contrary to hip extensors. EMG revealed significantly more muscle fatigue of lower back muscles, which was further corroborated by the Borg scale assessment. No between-group difference was obtained in any EMG comparison. Conclusion: These results showed that this type exercise machine can specifically train the back muscles, and this as much in subjects with non-specific chronic low back pain as in healthy controls. This has implications for the training of back muscle endurance, especially in patients with back pain for whom poor back muscle endurance is sometimes of concern.

Key words: rehabilitation, muscular endurance, pain, EMG, stabilization, hamstrings
INTRODUCTION

Excessive fatigability of lumbar paraspinal muscles is a predictor of a first episode of low back pain (LBP) [3] and also is a predictor of long-term back-related disability [13]. In patients with chronic LBP (CLBP), poor back muscle endurance could be attributed to a higher proportion of type II fatigable fibers [26] and to the atrophy of lumbar muscles [17]. It is hypothesized that back muscle fatigue would increase the risk of neuromuscular errors that would cause brief uncontrolled intervertebral movements and subsequent tissue strain injury, as proposed by the spinal stability hypothesis [15]. As concluded in a recent review, progressive resistance exercises (PRE) targeting the back muscles has been successful for increasing strength and/or endurance as well as for decreasing pain and/or disability among patients with LBP [27].

PRE for back muscles can be categorized by the equipment used [27]: (1) machines, (2) benches and roman chair, (3) free weights and (4) floor and stability balls. While each subcategory has advantages and disadvantages, only machines, while relatively expensive, provide the load ranges and progression necessary for patients [27]. However, hip extensors are synergistically recruited during all types of back extension exercises, which could hamper the specificity of these exercises to isolate, overload and train the muscles of interest, namely the back muscles. In line with this reasoning, hip extensors have been shown, using surface electromyography (EMG), to fatigue faster than back muscles in some studies investigating prone back extension exercises [7;19;28;30]. However, while back muscle fatigue has been repetitively observed in exercise machines [9;21;24;33], only two studies contrasted EMG indices of fatigue from back and hip extensors [9;21]. Both studies showed lower fatigue of gluteus maximus relative to back muscles in healthy controls [9;21] but only one investigated the biceps femoris [9], showing no significant difference with back muscles. Interestingly, patients with CLBP showed higher gluteus maximus fatigue than healthy controls so that no muscle fatigue difference was obtained between this muscle group and the back muscles [21]. The authors also suggest that gluteus maximus was the limiting factor in this exercise that was performed until exhaustion, which points the possible lack of specificity of the machine used. However, these results apply for a machine providing at least some pelvis stabilization (cushion on the lower lumbar vertebrae in [21] and posterior to the pelvis in [9]) and with the knees at 90°, which apparently does not represent an optimal exercise modality in terms of specificity [10].

In a previous study, we have tested various combinations of pelvic stabilization (three levels: no stabilization, posterior stabilization, anterior + posterior stabilization) and lower-limb configurations [two levels of hip extensors length: knees at 90° (sitting) or 135° (semi-sitting)] to determine which one would maximize the specificity of back extension exercises in a machine [10]. These exercise modalities represented machines promoted on the market or used in research settings. Posterior pelvic stabilization combined with knees at 135° (semi-sitting position) allowed, respectively, to increase the activation of back muscles and to decrease the activation of hip extensors. However, to minimize the confounding effect of muscle fatigue on the EMG activation estimates, only five cycles were performed in each experimental condition, thus preventing an EMG analysis of muscle fatigue. Also, only
healthy subjects were tested, thus precluding to generalize these findings to patients with CLBP. Patients with CLBP are known to produce various abnormal trunk muscles activation patterns [39]. Even though these exercise modalities impose a highly standardized motion pattern and thus decreased the likelihood of producing abnormal EMG patterns, the generalization of findings to patients with CLBP is still mandatory.

The main purpose of the present study was to examine whether a dynamic back muscle endurance exercise performed in a semi-sitting position induces more fatigue in back muscles than in hip extensors in healthy subjects as well as in patients with CLBP. We hypothesized that (1) more fatigue would be induced in back muscles relative to hip extensors and (2) that these results would be applicable as much in patients with CLBP as in healthy controls.

**METHODS**

**Subjects.** Eighteen healthy volunteers (8 men) and 18 patients with non-specific CLBP (9 men) aged between 20 and 55 years were recruited (from October 2006 to May 2007) on a voluntary basis. This is a sample of convenience and the 20-55 years range was selected to target subjects potentially at work (requirement of the funding agency). The basic demographic and anthropometric characteristics were comparable between these groups (Table 1). Healthy controls were recruited from words of mouth and newspaper ads in Montreal (Quebec) while patients with CLBP were recruited through the Montreal Rehabilitation Institute (referral from one of the authors, RV) and newspaper ads. Considering that exercises are considered safe in subjects with non-specific CLBP [32], relatively broad inclusion and exclusion criteria were used. Consequently, no pain history (mechanism, onset, duration), no investigation of co-morbidities and no systematic physical exam were used to select or to further describe the patients. Inclusion criteria for the patients with CLBP were as follows: lumbar or lumbosacral pain with or without proximal radicular pain (limited distally to the knees); and presence of chronic pain defined as a daily or almost daily pain for at least three months. One specific exclusion criteria was applied to healthy controls: back pain exceeding one week in the preceding year. General exclusion criteria were as follows: surgery of the pelvis or spinal column; known congenital malformation of the spine or scoliosis; body mass index (BMI) > 30 kg/m²; systemic-neurological-degenerative disease; one positive response to the Physical Activity Readiness Questionnaire; pregnancy. The pre-enrollment screening and laboratory assessments were carried out by the same research assistant while the data analysis and interpretation was carried out by the authors. The subjects were informed about the experimental protocol and the potential risks of the study and gave written consent prior to their participation. The protocol and consent form had been previously approved by the ethics committee of the Centre for Interdisciplinary Research in Rehabilitation of Greater Montreal (CRIR).
Table 1. Demographic, physical and clinical characteristics of the subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>Healthy controls (n = 16)</th>
<th>Patients with CLBP (n =18)</th>
<th>T-test</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean</td>
<td>SD</td>
<td>Mean</td>
</tr>
<tr>
<td>Age (yrs)</td>
<td>43</td>
<td>8</td>
<td>40</td>
</tr>
<tr>
<td>Mass (kg)</td>
<td>70</td>
<td>14</td>
<td>69</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>168</td>
<td>10</td>
<td>167</td>
</tr>
<tr>
<td>BMI (kg/m^2)</td>
<td>25</td>
<td>3</td>
<td>26</td>
</tr>
<tr>
<td>% body fat</td>
<td>26</td>
<td>5</td>
<td>26</td>
</tr>
<tr>
<td>Phys. activity level</td>
<td>8.6</td>
<td>1.5</td>
<td>8.8</td>
</tr>
<tr>
<td>VAS pain (cm)</td>
<td>/</td>
<td>/</td>
<td>3.8</td>
</tr>
<tr>
<td>RDQ (%)</td>
<td>/</td>
<td>/</td>
<td>38</td>
</tr>
<tr>
<td>TSK (score/68)</td>
<td>/</td>
<td>/</td>
<td>45</td>
</tr>
<tr>
<td>PCS (score/52)</td>
<td>/</td>
<td>/</td>
<td>25</td>
</tr>
<tr>
<td>Strength (Nm)</td>
<td>264</td>
<td>103</td>
<td>231</td>
</tr>
<tr>
<td>NbRep</td>
<td>23</td>
<td>13</td>
<td>27</td>
</tr>
</tbody>
</table>

SD: standard deviation; BMI: Body Mass Index; % body fat: percentage of fat; VAS: Visual Analog Scale of pain intensity; RDQ: Rolland-Morris Disability Questionnaire; TSK: Tampa Scale of Kinesiophobia; PCS: Pain Catastrophizing Scale. A higher score for VAS, RDQ, TSK and PCS reflects a worse condition.

The sample size was estimated using the best data available, namely from a study [20] showing the effect of endurance exercises on an EMG fatigue index comparable to what has been used in the present study (using a similar dynamic fatigue test), namely NIMFslp (details below). The pre-post results were simply considered as independent (from two groups) to comply with the present statistical analyses (between-group factor, as further outlined below). Using the means (-21.5 and –13.9 Hz/min) and a similar standard deviation (7.2 Hz/min), a 1.05 effect size was calculated. Using a statistical power table corresponding to t-tests (bilateral testing) and considering an effect size of 1.00 (a little more conservative) and a power of 0.80, 17 subjects were required in each group. Eighteen subjects were assessed in each group but two healthy subjects were rejected due to the poor quality of their EMG signals.

**Procedures.** The basic steps of the assessment were as follows: (1) questionnaires and basic anthropometric measures (details below), (2) surface electrode positioning, (3) submaximal contractions in the Biodex for warming-up and to get familiarized with the dynamic task [range of motion (ROM) and pace] using the metronome, (4) three isometric maximal voluntary contractions (MVC), separated by a minimum of 2 min rest (actually ranged between 2 and 3 minutes), (5) 10 min rest during which the subjective rating of muscle fatigue (details below) was explained to the subject, (6) dynamic back endurance exercise performed until exhaustion, (7) subjective assessment of muscle fatigue.

**Questionnaires and basic anthropometric measures.** In order to describe the subjects, in addition to basic anthropometric measurements, including four skinfold measures to estimate
the percentage of body fat (\% body fat) [12], five self-administered questionnaires were used. First, the physical activity level was assessed in all subjects [1]. Then, four clinical and pain-related psychological variables were assessed in CLBP subjects: (1) pain intensity on the day of testing with a visual analog scale (VAS), (2) perception of disability with the Rolland-Morris disability questionnaire (RDQ) [34], (3) fear of movement or injury with the Tampa scale of kinesiophobia (TSK) [14] and (4) pain catastrophizing with the Pain catastrophizing scale (PCS) [38].

**Surface electromyography.** EMG signals were collected from 14 pre-amplified (gain: 1000) active surface electrodes (Model DE-2.3, Delsys Inc., Wellesley, MA) consisting of 2 silver bars (10-mm long, 1-mm wide) spaced 10 mm apart. EMG signals from the recording sites were band-pass filtered between 20 and 450 Hz, analog-to-digital converted at a sampling rate of 2048 Hz, and stored on a PC hard disk for later analyses.

After the skin at the electrode sites was shaved and abraded with alcohol, the electrodes were positioned bilaterally on the multifidus at the L4 level (MU-L4-Left and MU-L4-Right), on the iliocostalis lumburum at the L3 level (IL-L3-L and IL-L3-R), and on the longissimus at L1 (LO-L1-L and LO-L1-R) and T10 (LO-T10L and LO-T10-R) considering their muscle fiber directions [23]. We acknowledge the difficulty of capturing the multifidus with surface electrodes and therefore assigned validity of the EMG signal to the landmark location rather than to the multifidus muscle itself. Six additional electrodes were positioned over the belly of the gluteus maximus (GM-L and GM-R), the biceps femoris (BF-L and BF-R) [19] and the vastus medialis (VM-L and VM-R) [4]. VM was also considered because the semi-sitting position requires the participation of the quadriceps to stabilize the body during the exercise. To avoid movement artifacts related to direct contact of electrodes on the seat, holes were pierced into a cushion (thickness: 2.5 cm), which covered the whole seat, so as to allow GM and BF electrodes to be free from contact. A reference silver-silver chloride electrode was positioned over the T8 spinous process.

**Tasks and exercise machine.** The three isometric MVCs and the dynamic back endurance exercise were performed in a specialized dynamometer (Biodex dynamometer Medical Systems III, Inc., New York, USA), combined with a chair designed for trunk muscle exercises, because it can simulate machines having a pin loaded weight stack as available on the market, in the isotonic mode. For instance, it allows posterior stabilization of the pelvis, a slightly forward tilting of the seat (15º), the positioning of lower-limbs with knees at 135º and the feet pressing against a footboard, which make the femurs to be driven toward the pelvis and thus securing the pelvis against the sacral pad (Figure 1). However, instead of using the sacral pad or the pelvic-femur strap from the original system, a custom-designed sacral pad that is more alike the ones on the market machines [relatively rigid foam (depth: 5 cm; height: 10 cm; width: 33 cm) glued on a plywood] was positioned on the sacrum to prevent the posterior motion of the pelvis. This pad was adjusted both horizontally (to generate a straight lumbar spine) and vertically (upper edge just covering the posterior superior iliac spines) so that the arm axis of the machine could be aligned with the L5/S1 joint. In all tasks, the thighs were firmly stabilized against the seat with a belt available with the system, the resistance scapular pad was positioned in the middle of the scapulas and the hands were crossed on the opposite shoulders.
Figure 1. Experimental setup showing the subject’s position and stabilization in the Biodex dynamometer. A custom device designed to stabilize the pelvis anteriorly is also shown but was used only during maximal voluntary contractions (not during the back endurance exercise). Please note that this picture was obtained during pilot testing, explaining why no EMG electrodes are shown. This picture has also been modified (elements eliminated in the background) to improve its clarity.

Three isometric MVCs were performed with the trunk flexed at an angle of 5° in relation to vertical, which represents the middle of the range of motion (ROM) covered during the dynamic exercise. All MVCs were performed progressively (3 s to reach the maximal, 1 s to maintain and relax). Only for MVCs (not the dynamic endurance exercise), a custom-designed stabilization device (two adjusted pads mounted on a metallic armature) was positioned against the anterior superior iliac spines to prevent the anterior motion of the pelvis (Figure 1). To maximize performance at each contraction, the measured L5/S1 extension moment was displayed in real time as visual feedback (on a monitor) and standardised verbal encouragements were given. Back strength (Strength) was defined as the peak L5/S1 extension moment among the three MVCs.

The dynamic back endurance exercise consisted of extending the trunk from a forward flexion posture of 25° to a -15° extension posture (dynamometer settings), for a 40° total ROM. Each flexion/extension cycle lasted four seconds (2 s of flexion and 2 s of extension) and was paced with a metronome (60 beats/min). The subjects generated efforts constantly during the concentric (extension) and eccentric (flexion) phases of each cycle using the isotonic mode of the system. The load corresponded to 60% of Strength, as used in previous training studies in patients with CLBP [11;37]. This should approximately lead to 15-25 repetitions maximal but a limit of 60 repetitions was fixed, which was reached in only one case (healthy woman).
Exhaustion was defined as the inability to reach the target angles in due time for three consecutive cycles or the inability to generate the required torque. Then, the number of successful cycles (repetitions) was recorded ($NbRep$).

**Subjective rating of muscle fatigue.** Immediately after exhaustion, the subjects were asked to rate the fatigue of each muscle group using a Borg CR-10 scale [6] combined with a drawing of the body representing five broad areas corresponding approximately to the positioning of the EMG electrodes: upper and lower back, buttocks, hamstrings, quadriceps.

**Signal processing.** All data processing was performed using Matlab sub-routines (Version 7.0; the MathWorks Inc., Natick, MA, release 14). From the EMG signals corresponding to the trunk range of motion lying between $15^\circ$ and $-5^\circ$ (to avoid the acceleration and deceleration portions of the concentric exertions during extension) and from all flexion-extension cycles, two EMG parameters were computed to assess muscle fatigue: the root mean square (RMS) amplitude and the instantaneous median frequency (IMF). A continuous wavelet transform (continuous Morlet, as described elsewhere [22]), was used to compute IMF values at each cycle, following the formulation of Bonato et al. [5], using successive (50% overlapped) 250-ms time-windows (512 point). The corresponding values were afterward averaged to obtain one IMF value per cycle. Then, linear regression was applied to each of these time-series (RMS and IMF values across cycles) to calculate the rate of decline in MF over time (MF/time slope: $IMF_{slp}$) and the rate of increase in RMS over time (RMS/time slope: $RMS_{slp}$), rates that were indicative of muscle fatigue. $RMS_{slp}$ and $IMF_{slp}$ were divided by their corresponding intercept value (obtained from the linear regression analysis) and multiplied by 100 to get normalized EMG indices of muscle fatigue ($NIMF_{slp}$, $NRMS_{slp}$), which account for subcutaneous tissue thickness differences between subjects. Finally, since no between side differences were obtained (T-test), $NIMF_{slp}$ and $NRMS_{slp}$ scores were averaged bilaterally to reduce data to seven muscle groups (4 back muscles, 2 hip extensors, 1 VM) and to increase their reliability [23].

**Interpretation of EMG indices of muscle fatigue.** Generally speaking, even though $NIMF_{slp}$ is a more reliable index of muscle fatigue than $NRMS_{slp}$ [23], evidence of muscle fatigue is more obvious when $NIMF_{slp}$ is negative and $NRMS_{slp}$ positive concomitantly [25], except when motor unit (MU) recruitment is not possible such as at higher force levels (> 80% MVC), which is not the case here. In this case, the positive $NRMS_{slp}$ is indicative of MU recruitment without an increase of the muscle mechanical contribution. When only a negative $NIMF_{slp}$ is obtained, more subtle muscle fatigue is present, with an approximately zero $NRMS_{slp}$ value indicating that no noticeable motor unit recruitment is required. On the other hand, when only a positive $NRMS_{slp}$ is obtained, motor unit recruitment is confirmed and a zero $NIMF_{slp}$ value indicates that this is not elicited by muscle fatigue, thus suggesting an increase of the muscle mechanical contribution. Obviously, these indications are valid only when the external net joint loading is constant during the exercise, which is the case in the present study.
**Statistical Analyses.** All statistical analyses were done with NCSS statistical software (version 6.0 for Windows) with an alpha of .05 as the level of statistical significance. Some of the variables (especially EMG indices of fatigue) were not normally distributed and thus were transformed to get normal distribution as verified with the Wilk-Shapiro test. However, the values reported in tables and figures are untransformed values. Even though this study was not designed, in terms of sample size, to carry out gender comparisons, no gender differences were observed in any of the different fatigue criterion (Borg, NbRep, NIMF_{slp}, NRMS_{slp}). Therefore, men and women were pooled to simplify all statistical analyses.

T-tests were used to assess between-group (healthy vs CLBP) differences in anthropometric measures, *Strength* and *NbRep*. To determine which muscle groups showed evidence of muscle fatigue, non-transformed NIMF_{slp} and NRMS_{slp} slope values were tested (Wilcoxon ranked test) to determine whether they were significantly different from zero. To further assess which muscle group was more associated with the end of the endurance exercise, Spearman correlations were carried out between these EMG indices of muscle fatigue (non-transformed values) and *NbRep*. To assess group and muscle differences in muscle fatigue using EMG indices (NIMF_{slp}, NRMS_{slp}), two-way ANOVAs (2 GROUP × 7 MUSCLE) with repeated measures on the MUSCLE factor were carried out. Likewise, a two-way ANOVA (2 GROUP × 5 MUSCLE-AREA) with repeated measures on the MUSCLE-AREA factor was used to analyze Borg ratings. Post hoc analyses were performed, when necessary, using the Tukey test.

**RESULTS**

*Strength* and *NbRep* were not significantly different between healthy controls and patients with CLBP (Table 1). The non-transformed NIMF_{slp} slope values were significantly lower than zero at all back muscle sites and for the VM, while NRMS_{slp} slope values were significantly higher than zero in all cases (Table 2, Figure 2). The highest significant correlations between the EMG indices of fatigue (NIMF_{slp} and NRMS_{slp}) and *NbRep* were obtained at L4 (NIMF_{slp} : 0.68 ; NRMS_{slp} : -0.65) and L3 (NIMF_{slp} : 0.51), as detailed in Table 2.

The ANOVA results showed no GROUP × MUSCLE interaction, neither for the EMG indices of fatigue, nor for the Borg ratings (Table 3). Even though a significant GROUP main effect was observed for the Borg ratings (Healthy < CLBP subjects), no GROUP main effect was obtained with the EMG indices of fatigue. In fact, the effect sizes corresponding to NIMF_{slp} were all (n = 7 muscles) below 0.31, which is relatively small. The Borg ratings showed a MUSCLE main effect (Table 3), the corresponding post-hoc analyses revealing more muscle fatigue at the lower back than at the four other areas (upper back, buttocks, hamstrings, quadriceps). Only the NIMF_{slp} EMG parameter showed a MUSCLE main effect (Table 3), the post-hoc analyses showing more fatigue at L4 than at T10, GM, BF and VM.
### Table 2. Statistic results on the physiological significance of the EMG indices of fatigue

<table>
<thead>
<tr>
<th>Muscle sites (^a)</th>
<th>Different than zero? (^b)</th>
<th>Correlation with (NbRep) (^c)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(NIMF_{slp})</td>
<td>(NRMS_{slp})</td>
</tr>
<tr>
<td>L4</td>
<td>0.000 (&lt;)</td>
<td>0.000 (&gt;)</td>
</tr>
<tr>
<td>L3</td>
<td>0.001 (&lt;)</td>
<td>0.000 (&gt;)</td>
</tr>
<tr>
<td>L1</td>
<td>0.001 (&lt;)</td>
<td>0.003 (&gt;)</td>
</tr>
<tr>
<td>T10</td>
<td>0.015 (&lt;)</td>
<td>0.000 (&gt;)</td>
</tr>
<tr>
<td>GM</td>
<td>0.946</td>
<td>0.000 (&gt;)</td>
</tr>
<tr>
<td>BF</td>
<td>0.893</td>
<td>0.000 (&gt;)</td>
</tr>
<tr>
<td>VM</td>
<td>0.027 (&lt;)</td>
<td>0.000 (&gt;)</td>
</tr>
</tbody>
</table>

\(^a\) Electrodes were positioned on the skin overlying the back muscles at different levels of the spine (L4, L3, L1 and T10 vertebral levels) as well as on the gluteus maximus (GM), the biceps femoris (BF) and vastus medialis (VM) muscles.

\(^b\) To determine whether the \(NIMF_{slp}\) and \(NRMS_{slp}\) slope values (EMG indices of muscle fatigue) were significantly different from zero. The corresponding \(P\) values are presented, the bold characters identifying statistical significance (\(P < 0.05\)), and the < (lower than zero) and > (higher than zero) symbols in parentheses indicate the direction of the difference.

\(^c\) To determine the relationship between \(NIMF_{slp}\) or \(NRMS_{slp}\) and \(NbRep\). The statistically significant Pearson correlation values (\(P < 0.05\)) are identified in bold characters.

---

**Figure 2.** Boxplot representation corresponding to \(NIMF_{slp}\) and \(NRMS_{slp}\) results (untransformed values) for each group and each muscle site.
Table 3. ANOVA results (P values) corresponding to the comparisons between healthy and CLBP subjects (GROUP factor) and between muscle sites (MUSCLE factor) for the EMG indices ($NIMF_{slp}$, $NRMS_{slp}$) and subjective perception (Borg) of muscle fatigue

<table>
<thead>
<tr>
<th>Variable</th>
<th>ANOVA P Values</th>
<th>Direction of the effects</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>GROUP (G)</td>
<td>MUSCLE (M)</td>
</tr>
<tr>
<td>$NIMF_{slp}$</td>
<td>0.781</td>
<td>0.000</td>
</tr>
<tr>
<td>$NRMS_{slp}$</td>
<td>0.371</td>
<td>0.129</td>
</tr>
<tr>
<td>Borg‡</td>
<td>0.003</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Direction of the effect when the GROUP factor was significant. H < C (Healthy < CLBP subjects). † Direction of the effect when the MUSCLE factor was significant. For the EMG indices of muscle fatigue ($NIMF_{slp}$ and $NRMS_{slp}$), the MUSCLE factor (7 electrode sites) was represented by electrodes positioned bilaterally on the skin overlying the back muscles at different levels of the spine (L4, L3, L1 and T10 vertebral levels) as well as on the gluteus maximus (GM), the biceps femoris (BF) and vastus medialis (VM) muscles. For the Borg variable, the MUSCLE factor was represented the five muscle areas as follows: upper back (UPP), lower back (LOW), buttocks (BU), hamstrings (HA), quadriceps (QU). ‡ P values were similar when NbRep (number of repetitions) was entered as a covariate, to correct for the time when muscle fatigue was rated that was inherently different across subjects.

DISCUSSION

The main findings of the present study were that EMG revealed significantly more muscle fatigue of lower back muscles (L4 electrode sites) than at the other electrode sites, which was further corroborated by the subjective Borg-scale assessment. Concerning the between-group differences, although the Borg assessment suggests that patients with CLBP were more fatigued, NbRep and EMG fatigue indices did not. However, no GROUP × MUSCLE interaction was disclosed for the Borg rating or for both EMG parameters.

MUSCLE main effect. All back muscles, as well as VM, showed clear evidence of muscle fatigue (significantly negative $NIMF_{slp}$ and positive $NRMS_{slp}$) while hip extensors showed evidence of MU recruitment without fatigue. However, between-muscle comparisons revealed more negative $NIMF_{slp}$ values at L4 than at T10, GM, BF and VM and the highest correlations between EMG indices of fatigue and NbRep were obtained at L4 (for $NIMF_{slp}$ and $NRMS_{slp}$) and L3 (for $NIMF_{slp}$ only). Furthermore, these findings were corroborated by the subjective Borg-scale assessment showing more muscle fatigue at the lower back than at the four other muscle areas (upper back, buttocks, hamstrings, quadriceps). All these results point in the same direction, highlighting the specificity of this back endurance machine modality (posterior pelvic stabilization combined with semi-sitting position) to induce fatigue at the lower back. As mentioned earlier, $NRMS_{slp}$ is a less reliable EMG fatigue index [23] so that the between-muscle differences were not large enough to be detected with this parameter. This means that more subjects would probably be required to disclose significant differences using $NRMS_{slp}$ and also to disclose more subtle differences between the other muscle sites (e.g. between L4, L3 and L1) using the $NIMF_{slp}$ parameter.
The specific fatigue of lower back muscles can partly be explained by the increased back muscle activation with pelvic stabilization, as recently substantiated [10;36]. This is also associated with the specific training of back muscles [16]. However, lower-limb configuration is apparently also of importance. Previous findings in the same apparatus (Biodex), but with the knees at 90º (using a tibial pad), also showed clear low back muscle fatigue but also, contrary to the GM, a comparable fatigue level of the BF [9]. In the present study, the fatigue level of the BF was apparently eliminated by positioning the knees at 135º. This position lengthens hamstrings [29], which increases their strength according to the length-tension relationship. Considering that the net moment at the hip theoretically remains the same, this in turn decreases the relative contribution (relative to their higher maximal strength) of these muscles [10]. On the other hand, the EMG analyses of GM and BF muscle groups showed evidence of MU recruitment (without fatigue) that would most likely be attributable to an increase mechanical contribution of hip extensors. These muscles have the potential to extend the knee in this machine and to contribute, with the VM, to stabilize the body by pushing against the footboard. It is also possible that hip extensors try to compensate for lower back muscle fatigue by tensioning the passive tissues (sacro-tuberous ligament, thoracolumbar fascia) linking hip extensors to lower back muscles [31].

The presence of VM fatigue was not unexpected with this exercise modality because the subjects have to push against the footboard to stabilize the body, which in turn facilitates the generation of extension torque at the lower back. However, according to ANOVA results ($NIMF_{slp}$ parameter), the level of fatigue is not as important as at the lower back and the corresponding $NIMF_{slp}/NbRep$ correlation ($r = 0.43$) was not as high as at L4 ($r = 0.68$) and L3 ($r = 0.51$), thus suggesting that VM fatigue are less likely to limit the number of repetitions required to specifically overload the back muscles.

**GROUP main effect.** A statistically significant group difference was obtained with the subjective fatigue criterion (Borg) while the more objective mechanical ($NbRep$) and electromyographic ($NIMF_{slp}$ and $NRMS_{slp}$) fatigue criteria did not. This suggests that the increased perception of fatigue in patients with CLBP, and this independently of muscle groups (GROUP × MUSCLE interaction), could be explained by the difficulty to disconnect discomforts due to pain nociception emerging from lower back passive tissues from discomforts due to muscle fatigue per se.

Taking into account an equivalent strength between groups (CLBP executed “true” MVCs regardless of their fears or pain), the 60% relative load was also likely equivalent, thus confirming that the patients with CLBP did not show abnormal back muscle fatigue. The sole study where similar conditions are reunited [equivalent strength, trunk at vertical (though the contraction was isometric), 80% MVC], or in other words the sole study where most confounding effects were apparently avoided, showed a higher fatigability of back muscles as assessed with similar $NIMF_{slp}$ indices [35]. We believe that these conflicting findings might be attributable to the lack of abnormal muscle composition in our patients because heterogeneous findings are reported relative to back muscle composition of patients with CLBP [8;26]. Crossman et al. [8] suggest that not all patients may present abnormal back histomorphometric findings and the associated back muscle weakness and fatigability, depending if they are “avoiders” or “confronters”, as proposed in the fear-avoidance model.
Maybe our CLBP sample was mostly composed of confronters, as suggest the Strength and physical activity level results (Table 1). In line with this explanation, avoiders have been shown to fatigue faster than confronters which were comparable to healthy controls, again as assessed with similar $NIMF_{slp}$ indices (muscle sites at L4/L5 level) during an isometric extension contraction [2].

Two other comparable EMG studies, examining dynamic contractions in a machine with a pin loaded stack, but with the weight adjusted according to physical characteristics, did not obtain a group difference as long as back muscles are concerned [18;21]. However, in one of these studies, patients with CLBP showed higher gluteus maximus fatigue than healthy controls so that no muscle fatigue difference was obtained when compared to back muscles [21]. However, they used a sitting position (knees at 90°) and the stabilization pad was positioned at the lower back (at L3) making it difficult to ascertain whether or not the pelvis was posteriorly stabilized as in the present study. They suggested that patients with CLBP used the above mentioned mechanisms linking GM and back muscles through the thoracolumbar fascia, which might be possible in these exercise conditions. Nevertheless, the main finding of the present study regarding differences between groups is that no GROUP × MUSCLE interaction was disclosed for Borg or for the EMG parameters, suggesting that the present findings with regards to the specificity of this back muscle endurance exercise apply as much in patients with CLBP as in healthy controls.

Limitations. As outlined above, it appears always possible to find different findings in other CLBP subgroups and the sample of subjects was not large enough to well represent the heterogeneity of patients with non-specific CLBP. The fact that the present patients with CLBP were not significantly different from healthy controls according to Strength and NbRep results might represent a limitation in this respect. Also, although age and anthropometric characteristics of the patients and controls were similar (Table 1), patients were not perfectly matched to healthy controls (not a case-control study). These results cannot necessarily be generalized to obese subjects for whom the use of stabilization devices could be difficult. No direct comparisons with other exercise modalities (e.g. 90° knee angle) were carried out with the use of the same subjects. Finally, no deep back muscles were investigated using intra-muscular EMG and a specialized dynamometer was used instead of a real machine with a pin loaded stack.

Perspective. Because back muscle endurance is an important clinical outcome as suggested by prospective studies [3;13], therapists and trainers in clinical or fitness centres should pay attention to design more specific exercise programs for the endurance training of back muscles, specially for patients with LBP [27]. The results of this study should help in this respect. This does not mean that the training of other muscle groups is not of importance, but to plan, during the rehabilitation process, a specific exercise to target the muscles that often show histomorphometric alterations [26] as well as atrophy [17], namely the back muscles. Of course, whether or not such muscle atrophy is the consequence of reflex inhibition could possibly influence the effectiveness of this specific exercise. Further studies are required to verify whether this exercise modality is specific enough to reverse this situation and ultimately, to determine whether increasing back muscle endurance would help to further improve clinical outcomes and protect against recurrences.
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