Pelvic stabilization and semi-sitting position increase the specificity of back exercises

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ABSTRACT

**Purpose:** To examine the effect of pelvic stabilization and two lower-limb configurations on the electromyographic (EMG) activity of back and hip extensor muscles during a dynamic back extension exercise on a machine and to compare them between sexes.

**Methods:** Twenty-two healthy volunteers (11 men, 11 women) performed five trunk flexion-extension cycles at 40% of their maximal voluntary contraction (MVC) in a machine designed for back exercise. Two different positions were used: I) seated position (seat horizontal, knees at 90°) and II) semi-sitting position (seat slightly tilted forward at 15°, knees at 45° of flexion). In each position, three pelvic stabilization conditions were tested: (1) unrestrained (control condition), (2) partially restrained (posteriorly) and (3) totally restrained (posteriorly and anteriorly). EMG signals were recorded bilaterally with 12 pairs of electrodes placed on back muscles, as well as on the gluteus maximus and biceps femoris. The muscular activation level, that is the percentage of EMG amplitude relative to the maximal EMG obtained from MVC, was used to assess the relative contribution of each muscle group across exercises.

**Results:** In both sexes, two main results were found: (1) pelvic stabilization (partially and totally restrained) significantly ($P < 0.05$) increased the activity of all back muscles (average of 12%) and (2) semi-sitting position significantly decreased (range: 8 to 27%) the activity of two hip extensors compared to the seated position. Sex differences were also observed relative to the activity of some back muscles as well as the biceps femoris.

**Conclusions:** Combining pelvic stabilisation and a semi-sitting position in back exercise machines might be a useful way to localise the effects of endurance training at the back muscles and this in both the sexes.

**Key words:** Electromyography, Back muscles, Endurance, Training, specificity
INTRODUCTION

Excessive fatigability of lumbar paraspinal muscles is a predictor of a first episode of low back pain (LBP) (3;10) and often associated with chronic LBP (15). In patients with chronic LBP, poor back muscle endurance could be attributed to a higher proportion of type II fatigable fibers and to the atrophy of lumbar muscles (14;19). Progressive resistance training involving the back muscles has been successful for increasing strength and/or endurance (20;23) as well as for decreasing pain and/or disability (13;29) among patients with LBP.

There are several exercises for improving the muscular function of the back. Regarding the use of exercise machines, the marketplace offers a variety of designs (knees positioned at 90°, 60° or 45° of flexion; with the pelvis stabilized or not) involving pulley systems, in which the subjects generate back force against a thoracic pad. However, because hip extensors are synergistically recruited during all types of back extension exercises, these muscles may fatigue faster than back muscles (4;17;22;27), which could limit the overload put on the muscles of interest, namely the back muscles.

Pelvic stabilization could be a solution to decrease the involvement of the hip extensors and better isolate the recruitment of lumbar extensors during trunk extension exercises (11;30). Graves et al. (11) showed that pelvic stabilization was mandatory to increase back strength during a 12-weeks progressive training of back muscles. Few studies have investigated the effect of pelvic stabilization on the electromyographic (EMG) activity of both muscle groups (back and hip) during trunk extension exercises in machines. San Juan et al. (28) demonstrated that the EMG activity of lumbar muscles was 51% higher when the pelvis was restrained than unrestrained in a lumbar extension machine, although no changes were observed for the biceps femoris. Contrary to San Juan et al. (28), Udermann et al. (32) reported no influence of pelvic stabilization on the activation of trunk extensors (back, gluteus and hamstrings). However, these two studies are not really comparable in a strict sense (i.e. relative load sustained, frequency of repetitions, EMG analysis). Furthermore, none of these studies investigated the effect of totally stabilizing the pelvis (using a sacral pad plus a pad on the anterior-superior iliac spines) during the exercise, as sometimes used in research settings (26;30).

Another approach that could be effective to decrease the relative contribution of the hip extensor muscles is the changing of the lower-limb configuration. Dedering et al. (7) proposed flexing the hips at an angle of 40° relative to the horizontal during a Roman chair exercise. This position increases the mechanical advantage (longer lever arms, lengthened muscles) of hamstrings (24) and consequently appear to increase the endurance time values during exercises in a Roman chair (7). However, the lengthening of hip extensors, through a change in knee flexion, has not been tested in exercise machines. So far, none of the above solution (pelvic stabilization, changing lower-limb configuration) have been shown to be better than other in maximizing the activity of back muscles while minimizing the activity of hip extensors with the use of machines (specificity principle). Perhaps combining both approaches would lead to an optimal solution. However, this warrants a more comprehensive EMG investigation of exercise machines. Also of importance, sex differences apparently exist relative to the activation patterns of back and hip extensor muscles during trunk extension...
exercise (2). It will thus be interesting to verify whether sex differences also exist for exercise machines.

The main purpose of the present study was to assess the effect of pelvic stabilization and two lower-limb configurations on the EMG activity of back and hip extensor muscles during back extension exercises in a machine. A second objective was to assess whether sex mediated the effects. We hypothesized that (1) pelvic stabilization would enhance the activation of back muscles and (2) changing lower-limb configuration (ex: lengthening of hip extensors) would decrease the contribution of hip extensors during a sub-maximal exercise. It was further hypothesized that these effects would be observable in both sexes.

METHODS

Subjects.

Twenty-two healthy volunteers (11 men and 11 women) aged between 20 and 55 years were recruited (from October 2005 to May 2006) on a voluntary basis (University of Montreal students and Montreal Rehabilitation Institute employees). The exclusion criteria were as follows: back pain in the previous year or back pain lasting longer than one week, surgery on the musculoskeletal system of the trunk and legs, known congenital malformation of the spine or scoliosis, body mass index (BMI) > 30 kg/m², systemic-neurological-degenerative disease, history of stroke, pregnancy, abnormal blood pressure, family history of heart attack, medication of cholesterol or triglyceride control and involvement in a new training program. All subjects completed the Physical Activity Readiness Questionnaire (PAR-Q) for a general understanding of their physical aptitude. 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).

Assessments.

Two sessions of approximately three hours and separated by a maximum of one week were required. The same investigator performed the procedures and the tasks with all subjects to ensure uniformity. The first session was to collect basic anthropometric measures (height, mass) and to familiarize the subject with the equipment and the different tasks. The second session was used to assess the flexibility as well as measures collected across six experimental conditions (Figure 1, details below), namely the range of motion of the lumbar area and the EMG activity of the back and hip extensor muscles. The six experimental conditions were balanced among subjects to control for possible carry-over effects.
FIGURE 1—Experimental conditions tested in a back extension machine.

Tasks

Lumbar flexibility assessment.

The accelerometer was used as an inclinometer to measure the lumbar flexibility as well as the lumbar motion of subjects during the exercises. Lumbar flexibility could be associated with the flexion-relaxation phenomenon during trunk flexion-extension movement (1) while lumbar kinematics could be affected by pelvic stabilization and/or lengthening of hip extensors (6,26). Two movements were used to determine the lumbar flexibility of each subject (9). The first movement was from erect standing (upright) to maximal lumbar flexion without flexing the legs. This first movement was also used for the calibration of the accelerometer at L1 so that to obtain the trunk angle measure in the sagittal plane (12). The second movement was extreme toe-touching from the sitting position. Each position was performed one time lasting at least 10 s and the range of motion (ROM) was then computed (ex: Table 1: lumbar flexibility measures from standing: ROM$_{ST}$ and sitting: ROM$_{S}$).
Table 1. Characteristics of subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>Men (n = 11)</th>
<th>Women (n = 11)</th>
<th>t-test</th>
<th>P</th>
<th>(values)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Age (yr)</td>
<td>25 (4)</td>
<td>26 (3)</td>
<td>0.710</td>
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<td></td>
</tr>
<tr>
<td>Height (m)</td>
<td>1.77 (5.95)</td>
<td>1.67 (7.41)</td>
<td>0.002</td>
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<tr>
<td>Mass (kg)</td>
<td>74 (10)</td>
<td>60 (6)</td>
<td>0.001</td>
<td></td>
<td></td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>23 (3)</td>
<td>21 (2)</td>
<td>0.156</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROMST (°) a</td>
<td>107 (6)</td>
<td>120 (21)</td>
<td>0.060</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ROMS (°) b</td>
<td>30 (7)</td>
<td>32 (11)</td>
<td>0.696</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MVC_{H90} (Nm) c</td>
<td>290 (33)</td>
<td>212 (42)</td>
<td>0.006</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MVC_{H45} (Nm)</td>
<td>331 (79)</td>
<td>236 (47)</td>
<td>0.002</td>
<td></td>
<td></td>
</tr>
<tr>
<td>MVC BACK (Nm)</td>
<td>351 (74)</td>
<td>232 (39)</td>
<td>0.000</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Mean values in the Standard Deviation (SD) in parentheses. The significant differences (P < 0.05) are identified with bold characters. Lumbar flexibility measures: a Lumbar range of motion from erect standing position (ROMST). b Lumbar range of motion from erect sitting position (ROMS). c Significant differences between MVC_{H90} and MVC_{H45} for both the sexes (t-test result, P < 0.05).

Dynamometric assessment.

A specialized dynamometer (Biodex dynamometer Medical Systems III, Inc., New York, USA), combined with a chair designed for trunk muscle exercises, was used to perform maximal voluntary contractions (MVC) as well as the exercise tasks (next section) because it allows, with some minor modifications (detailed below), to simulate the pelvis stabilization and lower-limb configuration conditions of interest.

Maximal voluntary contraction (MVC).

MVCs were performed for each muscle group to know their strength and their maximal EMG activation for normalization purpose. After familiarization with the dynamometer with sub-maximal contractions, MVCs were performed for each muscle group (back and hip extensors, see Figure 2) and each joint angle (muscle length) where EMG analysis was planned. This is to control for the confounding effect of muscle length on EMG measures during the dynamic contractions of the back muscles.

For the hip extensors, the axis of the dynamometer was aligned at the greater trochanter and two isometric MVCs were performed following two different positions of the lower-limb relative to horizontal (Figure 2, right pictures): (1) hip and knee at an angle of 90° (MVC_{H90}) and (2) hip at 90° and knee at an angle 45° of flexion (MVC_{H45}). Only the right hip extensor muscles were assessed, with the subject in the supine position. The trunk and left leg were strapped against the chair. A custom-designed stabilization device (two adjusted pads mounted on a metallic armature) was positioned on the anterior superior iliac spine to prevent the motion of the pelvis during maximal hip extension. The knee of the tested side was maintained by an in-house device designed to allow the control of the knee position and the resistance pad was fixed at the distal end of the thigh (Figure 2).
Figure 2. Illustration of the two main body configurations on the exercise (left pictures) and the corresponding maximal voluntary reference contractions (middle and right pictures) used to normalize the EMG signals. During the MVCs, the position (middle portion of the movement) of segments was the same (similar muscle lengths) as the position where the EMG was analyzed during the different exercise positions.

For the back muscles (MVC$_{BACK}$), the axis of the dynamometer was aligned at the L5-S1 level and the resistance scapular pad was positioned in the middle of the scapulas. Three isometric MVCs were performed with the trunk flexed at an angle of 5° in relation to vertical and the hands were crossed on the opposite shoulders (Figure 2, middle picture). The 5° angle has been chosen to normalize the EMG activity of back muscles extracted nearby the 5° angle during each exercise condition (details later). During all MVCs, the trunk and lower limbs were stabilized with the straps available with the system. The pelvis was totally restrained as detailed below in the exercise assessment section.

The MVCs of back and hip extensors were performed progressively (3 s to reach the maximal, 1 s to maintain and relax), allowing two minutes of rest between contractions. To maximize their performance at each contraction, the L5-S1 extension moment was displayed in real time as visual feedback (on a monitor) and standardised verbal encouragements were given. The largest value of the maximal contractions was retained as the MVC.

### Exercise assessment.

Ten minutes after the MVCs, the subjects performed six series of five dynamic back flexion-extension cycles in the dynamometer, simulating six different machine designs (Figure 1), hereafter called experimental conditions. Two different positions were evaluated: I) seated position [SP (seat horizontal, knees at 90°)] and II) semi-sitting position [SSP (seat...
slightly tilted forward at approximately 15º, knees at 45º of flexion). In each position, three pelvic stabilization conditions were tested (Figure 1): (1) Pelvis UnRestrained [PUR (control condition)], (2) Pelvis Partially Restrained [PPR (pad positioned on the sacrum level)] and (3) Pelvis Totally Restrained [PTR (same as (2) plus one pad positioned on the anterior-superior iliac spines)].

First, the subjects were placed into a neutral position (0º trunk flexion), with the axis of the machine aligned at the L5-S1 level and the resistance scapular pad positioned at the level of the scapular. In both pelvic conditions (PPR and PTR), a custom-designed pad was positioned on the sacrum to prevent the posterior motion of the pelvis instead of sacral pad or of pelvic-femur strap from original system. For the total pelvic stabilization, a second 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. These two pelvic-stabilization devices were adjusted both horizontally and vertically to reach a neutral position where the arm axis of machine is aligned with the L5-S1 joint. The use of two devices allowed the standardization of the pelvic conditions across both positions (SP and SSP) respectively. During the pelvis unrestrained condition, these two devices were completely removed of machine. Finally, in seated position (SP), the knees were restrained with a tibial pad from system while in the semi-sitting position (SSP), the feet was placed on the footboard, which caused femurs to be driven toward the pelvis and thus securing the pelvis against the sacral pad. For all experimental conditions, the thighs were firmly stabilized against the seat with a belt available with the system.

The load used during the exercises was at 40% of MVC from the peak MVC value during the maximal EMG activation of back muscles. At least three minutes of rest were allowed between each condition. For all conditions, the subjects extended their trunk from a forward flexion posture of 25º to a -15º extension posture (dynamometer settings), for a 40º 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 concentric (in extension) and eccentric (in flexion) contractions during the movement because the load was applied constantly on the two directions using the isotonic mode of system. During dynamic exercises, the motion of lumbar spine was measured with an inclinometer positioned at L1. We assumed that this motion corresponded to the effect of pelvic tilting on the lumbar lordosis because the flexion angle of the whole trunk (from hips to shoulders) was the same across all experimental conditions because it was controlled by system. This procedure was used because using an inclinometer directly on the pelvis (sacrum) could have interfered with the posterior stabilizing system and consequently biased the results.

**Electromyography.**

EMG signals were collected from 12 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 lumborum 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) following the recommendations of Defoa et al. (8) with regard to muscle fiber direction. 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. Four additional electrodes were positioned over the belly of the gluteus maximus (GM-L and GM-R) and biceps femoris (BF-L and BF-R) following the procedure of Kankaanpää et al. (16). To avoid movement artifacts related to direct contact of electrodes on hard surfaces (dynamometer chair), we placed pierced circular cushions around GM and BF electrodes. A reference silver-silver chloride electrode was positioned over the T8 spinous process.

**Kinematics.**

The angular position of the lumbar area (L1) was obtained from one accelerometer (Model ADXL105EM-3, Analog Devices Inc., Norwood, MA) at a sampling rate of 128 Hz. This accelerometer measures the angular position as an inclinometer following the calculation and calibration procedures of Hanson et al. (12). Briefly, the calibration of the accelerometer allows a plane of motion to be defined. This plan requires two vectors: one that ideally represents the initial position or ‘upright’, and the other the final position or ‘forward’, as determined using the first movement of the calibration tasks. The cross product of the two vectors defines a vector perpendicular to this plane. Subsequently, we transform the orientation given in the transducer coordinates (Xt,Yt,Zt) to a body-segment coordinate system (X,Y,Z). This ensures that wherever the sensor is positioned on a body segment, the new coordinate system is related to the ‘upright’ (v1) and ‘forward’ (v2) vectors.

**Signal processing.**

All data processing was performed using Matlab sub-routines (Version 7.0; the MathWorks Inc., Natick, MA, release 14). Angle signals from the inclinometer were low-pass filtered at 2 Hz, both ways, using a second order Butterworth filter. Force and angle signals from system were low-pass filtered, both ways, with a Butterworth filter using optimal cut-off frequency calculated with residual analysis. A notch-filter was used for all EMG signals, removing frequencies at 60 Hz and their harmonics.

From EMG signals corresponding to MVCs at 5° of trunk flexion, a moving Root Mean Square (RMS) processing method was executed on successive 250-ms (512 points) time-windows (50% overlapped). For each muscle, the peak RMS value across all MVC trials represented the maximal EMG activity (RMS\text{MAX}). RMS\text{MAX} was used to compute the muscle activation level, which is the percentage of EMG amplitude relative to the maximal EMG obtained from MVC, on each muscle group across the six experimental conditions. For each condition and each flexion/extension cycle (c) [c representing the cycle number], RMS values (250-ms, 50% overlapped) were computed using the EMG signals corresponding to the trunk
ROM from system between 15° and -5° to avoid the acceleration and deceleration portions of the concentric contractions during the extension phase of movement. For each muscle, the mean RMS(c) value was computed across the 20° ROM, which represented the mean RMS activity during the dynamic extension portion of exercise [RMSDYN(c), DYN = dynamic]. The RMSDYN(c) values were averaged across the three middle cycles of five to give a single value. Finally, the activation level (in %) were computed for each muscle using the equation below:

\[
\text{Activation level (\%)} = \left( \frac{\text{RMSDYN}}{\text{RMSMAX}} \times 100\% \right)
\]

**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. All variables were normally distributed, as verified with the Wilk-Shapiro test. Student \( t \) tests were used to assess between-group (men and women) differences in age, height, weight, body mass index (BMI), lumbar flexibility and MVC (back and hip muscles). All activation levels were averaged bilaterally because no significant differences were observed between left and right side muscles (ANOVAs, \( P \geq 0.05 \)). A three-way ANOVA (2 Sexes × 2 Positions × 3 Stabilizations) with repeated measures on both factors (Position and Stabilization) was performed to assess the differences in activation level and lumbar ROM during the exercises. Post hoc analyses were performed, when necessary, using the Tukey test.

**RESULTS**

The demographic characteristics (age, height, weight, BMI) as well as lumbar flexibility and strength of back and hip extensors of men and women are presented in Table 1. Only strength was significantly different between the sexes.

For activation level values, double and triple interactions from ANOVA results were not statistically significant (\( P > 0.05 \)) and thus were not reported in the table 2. The activation level of the back muscles ranged between 24 to 69% across the six experimental conditions, whereas it ranged between 17 to 57% for the hip extensor muscles and this across both sexes (Table 2). In both sexes, two main results were found: (1) regardless of the lower-limb position, partial and total pelvic conditions significantly increased the activity of all back muscles (12% on average) but did not change the hip extensors activity (Table 2); and (2) regardless of the stabilization conditions, the semi-sitting position significantly increased the activity of one back muscle (LO-T10) and significantly decreased (range of 8 to 27%) the activity of GM and BF muscles compared to the seated position (Table 2). Some of these results are further illustrated in Figure 3 where the data from both sexes were pooled.
Table 2. Activation level values of the back and hip extensor muscles. ANOVA results: main effects for both sexes, positions and pelvic conditions

<table>
<thead>
<tr>
<th>Variable</th>
<th>Muscle</th>
<th>Sexes</th>
<th>Positions</th>
<th>PUR</th>
<th>PPR</th>
<th>PTR</th>
<th>Sexes</th>
<th>Positions</th>
<th>Stabilizations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Activation level (%)</td>
<td>MU-L4 M</td>
<td>SP</td>
<td>48 (19)</td>
<td>61 (16)</td>
<td>65 (19)</td>
<td>0.104</td>
<td>0.864</td>
<td>0.003</td>
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</tr>
<tr>
<td></td>
<td>W SSP</td>
<td>51 (10)</td>
<td>56 (16)</td>
<td>65 (23)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>W SSP</td>
<td>52 (12)</td>
<td>69 (17)</td>
<td>65 (15)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>W SSP</td>
<td>52 (19)</td>
<td>64 (22)</td>
<td>60 (16)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>IL-L3 M SP</td>
<td>30 (12)</td>
<td>48 (19)</td>
<td>46 (14)</td>
<td>0.000</td>
<td>0.289</td>
<td>0.001</td>
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<tr>
<td></td>
<td>W SSP</td>
<td>34 (10)</td>
<td>38 (9)</td>
<td>41 (11)</td>
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<tr>
<td></td>
<td>W SSP</td>
<td>47 (15)</td>
<td>59 (12)</td>
<td>56 (16)</td>
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<tr>
<td></td>
<td>W SSP</td>
<td>47 (17)</td>
<td>55 (15)</td>
<td>56 (19)</td>
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<tr>
<td></td>
<td>LO-L1 M SP</td>
<td>38 (14)</td>
<td>55 (20)</td>
<td>59 (18)</td>
<td>0.000</td>
<td>0.336</td>
<td>0.000</td>
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<td>53 (8)</td>
<td>55 (13)</td>
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<td>LO-T10 M SP</td>
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<td>36 (10)</td>
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<td></td>
<td>W SSP</td>
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<td>42 (14)</td>
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<td>45 (14)</td>
<td>52 (15)</td>
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<td></td>
<td>GM M SP</td>
<td>42 (26)</td>
<td>35 (14)</td>
<td>30 (13)</td>
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<td>0.927</td>
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<tr>
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<td>W SSP</td>
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<td>17 (8)</td>
<td>22 (13)</td>
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<td></td>
</tr>
<tr>
<td></td>
<td>W SSP</td>
<td>35 (21)</td>
<td>38 (21)</td>
<td>38 (20)</td>
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<td></td>
<td>W SSP</td>
<td>20 (9)</td>
<td>22 (10)</td>
<td>25 (12)</td>
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<tr>
<td></td>
<td>BF M SP</td>
<td>57 (30)</td>
<td>53 (30)</td>
<td>51 (29)</td>
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<td>0.000</td>
<td>0.855</td>
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<td></td>
<td>W SSP</td>
<td>29 (10)</td>
<td>26 (8)</td>
<td>31 (11)</td>
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<td></td>
<td>W SSP</td>
<td>38 (18)</td>
<td>38 (19)</td>
<td>38 (14)</td>
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<tr>
<td></td>
<td>W SSP</td>
<td>25 (6)</td>
<td>24 (11)</td>
<td>26 (12)</td>
<td></td>
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</table>

Only main effects were presented because interactions were not statistically significant (P > 0.05).

Mean values with standard deviation (SD) in parentheses. The significant differences (P < 0.05) are identified with bold characters.

Sexes: M (men) and W (Women). Positions: Seated position (SP) and Semi-sitting position (SSP). Pelvic conditions: Unrestrained (PUR), partially restrained (PPR) and totally restrained (PTR).

Figure 3. Activation level values from three muscles (MU-L4, GM and BF) during the six experimental conditions. The data from both sexes were pooled.
**Activation level.**

For activation level values, double and triple interactions from ANOVA results were not statistically significant ($P > 0.05$) and thus were not reported in the table 2. The activation level of the back muscles ranged between 24 to 69% across the six experimental conditions, whereas it ranged between 17 to 57% for the hip extensor muscles and this across both sexes (Table 2). In both sexes, two main results were found: (1) regardless of the lower-limb position, partial and total pelvic conditions significantly increased the activity of all back muscles (12% on average) but did not change the hip extensors activity (Table 2); and (2) regardless of the stabilization conditions, the semi-sitting position significantly increased the activity of one back muscle (LO-T10) and significantly decreased (range of 8 to 27%) the activity of GM and BF muscles compared to the seated position (Table 2). Some of these results are further illustrated in Figure 3 where the data from both sexes were pooled.

Sex differences were found on the activation level values (Table 2). Women showed significantly higher activity (range of 6 to 17%) than men for three back muscles (IL-L3, LO-L1 and LO-T10). Women also showed significantly lower activation level values for the BF muscle compared to men (Table 2).

**Lumbar ROM.**

As for activation level values, the interactions from main effects (Stabilizations, Positions and Sexes) were not statistically significant (ANOVA results, $P > 0.05$) for lumbar ROM. No significant ($P = 0.225$) stabilization effect was observed for the lumbar ROM during the exercises. On the other hand, semi-sitting position significantly reduced (in average $4^\circ$; $P = 0.000$) the lumbar ROM relative to the seated position, and this for both sexes and in all stabilization conditions. Also, women showed significantly lower lumbar ROM values (in average $5^\circ$ across experimental conditions; $P = 0.000$) than men.

**DISCUSSION**

The main purpose of the present study was to assess the effect of pelvic stabilization and lower-limb configurations on the EMG activity of the back and hip extensor muscles during a dynamic back extension exercise in a machine. Our hypotheses were confirmed. Pelvic stabilization enhanced the activity of back muscles whereas using a semi-sitting position decreased the contribution of two principal hip extensors (GM and BF) during the exercise. Finally, these results were generalizable to both sexes.

**Effect of pelvic stabilization.**

The results of this study demonstrated that partial pelvic stabilization was sufficient to increase the recruitment of all back muscles during a dynamic sub-maximal exercise, which concurs with San Juan et al. (28) for the lumbar extensors. In other words, it is not necessary to use a more sophisticated stabilization device to achieve this goal. It is unknown whether a
12% increase of back muscles activation makes a physiologically (or clinically) meaningful difference relative to back endurance and/or strength gains. One study showed that pelvic stabilization was mandatory to increase back strength during a 12-weeks progressive training of back muscles (11). However, no EMG analysis was done to contrast the pelvic restrained and unrestrained conditions. Furthermore, Graves’s (11) findings may apply only to a back strength training program, not necessarily to an endurance training program using a lower load intensity. Definitely, more studies are needed to clarify this issue. We also demonstrated that both pelvic conditions (partially and totally restrained) did not affect the activity of the hip extensor muscles during the exercise, which also concurs with others (28;32) that obtained similar results, but with the partial pelvic condition only. Although this muscle group was not directly responsible for the work performed, it was activated even when the pelvis was well restrained during the dynamic exercise. This suggests that a well-established motor synergist pattern exists for familiar movements such as trunk flexion/extension cycles. Back and hip extensors act synergistically due the anatomic interaction between the muscles surrounding the spine and the pelvis allowing the load transfer from the lumbar spine to lower extremities (33). Effectively, GM muscle is tightly linked with the lower back muscles via the thoraco-lumbar fascia and with the BF muscle via the ligamentum sacrotuberale (33). It appears that only a changing of lower-limb configuration could be efficient to decrease their contribution during the exercise, as discussed in the next section.

Effect of lower-limb configuration.

To the authors’ knowledge, the effect of lower-limb configuration on the EMG activation of trunk extensors during exercise machines was investigated for the first time. The main finding of this study was that we identified a lower-limb position (semi-sitting position) that significantly decreased the activity of two main hip extensor muscles (GM and BF) while increasing the activity of one back muscle (LO-T10). This effect can be attributed to the increased mechanical advantage of the hip extensor muscles in this position, which in turn would decrease the relative contribution of these muscles. At this position, both hip muscles (gluteus and hamstrings) benefit from larger lever-arms as compared to the seated position (24). Hamstrings are also lengthened, which increase their strength according to the length-tension relationship. These explanations are further supported by the strength results of hip extensor muscles showing a higher strength in the semi-sitting position (Table 1). Although gluteus muscles are expected to slightly shorten in this position, it appears that the net mechanical effect (increased lever-arm but decreased length) was positive according to the activation level results. Consequently, as hypothesized in previous research (7), this position can help to fatigue more specifically the back muscles relative to hip extensors.

The difference in the activation of only one back muscle (LO-T10) associated to the effect of lower-limb configuration is difficult to explain. However, the different fiber type composition between the thoracic and lumbar back muscles (25) suggests functional differences between these two muscle groups. Back muscles are typically responsible to the postural control and are constituted of a greater percentage of type I fibers (25). Interestingly, the thoracic region has a higher percentage of type I fibers (slow twitch) as compared with the
lumbar region (31). Considering the postural function, the thoracic muscles could be more active than lumbar muscles in standing position as proposed by Ng et al. (25). The SSP is more alike the standing position and may consequently engage similar motor patterns. However, more studies are needed to clarify this issue.

Effect of sex.

Some studies assessed the effect of sex on the activation of the back (2;5;18;27) and hip extensor (2;5;27) muscles. One study (2) found an effect, pointing to a higher activation of lumbar muscles in women, while no effect was observed for GM. However, the exercise (prone back extension) was performed using a Roman chair in which the subject’s upper body is used as the load, thus not ensuring that the relative load, in percentage of the strength, was the same between men and women. Although we had accounted for back strength with the use of a relative load (40% MVC), our results do not concur with previous findings (5;18) where the same relative load was used but where no difference was detected. However, in these studies (5;18), the position of the hips was slightly flexed or neutral, which is considerably different than the hip position used in the present study. Consequently, we propose that sex differences in muscle activation patterns might be task dependent. On the other hand, the women showed a smaller lumbar motion than men as observed with the inclinometer at L1, which points to the maintenance of a more lordotic lumbar posture during the exercise. A more lordotic lumbar posture would be generated by tilting the pelvis anteriorly, which in turn is possible by shortening the back muscles and by lengthening the BF, thus explaining the activation level increase of back muscles and the activation level decrease of BF.

Perspective.

Because back muscle endurance is an important clinical outcome as suggested by prospective studies (3;10), therapists and trainers in clinical or fitness centres should pay attention to design more specific exercises programs for the endurance training of back muscles, specially for patients with chronic LBP (21). The results of this study should help in this respect. In addition, the relative contribution of individual muscle groups during compound trunk extension in a machine was not known so far, as stated in a recent review on this topic (21). From our results, the combination of two approaches (pelvic stabilization using a sacral pad and lengthening of hip extensors) was optimal to increase the specificity of back muscles exercises. Fortunately, some machine models on the marketplace already allows this combination, considering that only a sacral pad is required according to the present results (no full pelvis stabilization). Our research group is currently evaluating the semi-sitting exercise with the pelvis partially restrained, during an exercise leading to exhaustion, in order to verify whether back muscles fatigue faster than hip extensors and this in healthy and chronic LBP patients. This validation step is necessary before applying these principles on the targeted population.
Limitations of the study.

There are some limitations of this study that need to be addressed. These results cannot necessarily be generalized to patients with LBP that may have different back activation patterns, nor to obese subjects for whom the use of stabilization devices could be difficult. The fatigue of the back and hip extensor muscles was not assessed using a training task leading to fatigue. However, such a stabilization effect on the activation of lower back muscles has already been shown to be stable from the beginning (first 2 repetitions) to the end (last 2 repetitions) of an exercise performed to fatigue and having comparable conditions (dynamic contractions at the same pace, semi-sitting position, 50% MVC) (28). These results apply only to superficial extensor muscles of the trunk and to isotonic muscle contractions at a moderate load level (40% MVC) for the training of muscle endurance. In other words, to see whether or not these findings apply to the training of muscle strength, this study should be replicated at much higher load intensity (over 80% MVC). The findings are limited to the machine designs and body positions tested. Finally, regarding statistical power, the possibility of type I (false findings) and type II (missed findings) errors appears unlikely in the present study, except for MU-L4 where the Sexes factor (P = 0.104) could had reached statistical significance (type II errors) with more subjects in each group. The consistency of findings across the back muscles for the Stabilizations and Sexes main effects and across the hip extensors for the Positions main effect argues against type I errors.

CONCLUSION

The effect of pelvic stabilization and of two lower-limb configurations was tested relative to their capacity to preferentially recruit the back relative to hip extensor muscle groups. Our results demonstrated that a posterior pelvic stabilization (sacral pad) is sufficient to enhance the activation of different back muscles at the same level as a full pelvic stabilization (anteriorly and posteriorly). Furthermore, a semi-sitting position is effective to reduce the activation of two principal hip extensor muscles (gluteus and biceps femoris). Combining partial pelvic stabilization and a semi-sitting position would allow the exercise to train more specifically the targeted back muscles so that to induce more physiological adaptations, and this in both the sexes. This has implications for the training of back muscle endurance.

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REFERENCES


