# EXERCISES FOR THE TORSO PERFORMED IN A STANDING POSTURE: SPINE AND HIP MOTION AND MOTOR PATTERNS AND SPINE LOAD

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## ABSTRACT

McGill, SM, Karpowicz, A, Fenwick, CMJ, and Brown, SHM. Exercises for the torso performed in a standing posture: spine and hip motion and motor patterns and spine load. *J Strength Cond Res* 23(2): 455–464, 2009–The purpose of this study was to document the muscle activity, spine motion, spine load, and stiffness during several movement-based or "functional" exercises and to assess the effect of technique change. Eight subjects, all healthy men from a university population, were instrumented to obtain surface electromyography of selected trunk and hip muscles, together with video analysis and electromagnetic lumbar spine position sensor to track spine posture. Exercises included a walkout in the sagittal plane that compared an upright form against a wall with those performed on the floor, overhead cable pushes, lateral cable walkouts, the good morning exercise, and the bowler's squat. Generally, muscle activation levels were quite modest even though the tasks were quite strenuous in many cases. Even though similar joint moments were required in different exercises, the pattern of activity between muscles was different. Abdominal bracing increased spine stiffness at the expense of more spine load. Thus, muscle activity seems to be constrained in "functional" exercises. There are several possible reasons for this. Single muscles cannot be activated to 100% of the maximum voluntary contraction in functional exercises because this would upset the balance of moments about the 3 orthopedic axes of the spine, or it would upset the balance of stiffening muscles around the spine required to ensure stability of the spinal column. The one exception was the floor walkout, which resulted in full activation of the rectus abdominis; however, this was a sagittal plane task without the joint moment constraints of multiplanar exercise. Therefore, maximal muscle activity is observed during single-plane tasks, but muscle activation levels were constrained during functional tasks. Thus, strength training muscles may not help in "functional multiplanar" tasks. These data can be used to assist decisions regarding the selection of exercises, specifically choices regarding the starting challenge, progression, exercise form, and possibly corrective technique for those who have spine concerns, or those simply looking for performance enhancement.

**KEY WORDS** stability, lumbar, corrective exercise, clinical technique

## INTRODUCTION

Exercises designed to challenge the torso musculature (abdominal, back, and hip muscles) are performed for a variety of reasons. The purpose of this study was to document the muscle activity and spine motion during several exercises and to assess the effect of technique change. Whereas some exercises are designed to isolate specific muscles, the exercises chosen for this study were considered movement-based exercises, which some refer to as "functional" exercises. Exercises included a walkout in the sagittal plane that compared performing the exercise in an upright posture against a wall with those performed on the floor, overhead cable pushes, lateral cable walkouts with 2 arm positions, a modified good morning exercise, and the bowler's squat. Subissues included the effect of standing on 1 or 2 legs (good morning exercise) and the effect of intentional abdominal bracing (cable walkouts and overhead cable push) shown to enhance spine stability (7,14). Bracing means simply stiffening the abdominal wall, neither hollowing the muscles inward nor pushing them outward. These data may be helpful to those who design exercise programs, for a variety of reasons.

There were 2 hypotheses tested in this study: 1) when performing an abdominal brace during the exercise, an increase in lumbar spine stiffness would be observed, and 2) expert correction would lead to less deviated spine motion/position and would help increase the muscle activation of the torso musculature.

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## METHODS

### Experimental Approach to the Problem

Electromyography (EMG) and spine motion were recorded during the performance of sagittal walkouts, cable walkouts, overhead cable pushes, good mornings, and the bowler's squat. The external load was recorded, and photographs were digitized to calculate moments about the low back. Normalized EMG spine motion for each trial was processed by an EMG-to-force model, which calculated the muscular stiffness of the spine as well as muscle compression and shear loading of the spine. Thus, analysis revealed whether abdominal bracing increased the lumbar spine stiffness during the performance of the exercise and whether there were any differences in spine motion and the muscular force produced (% maximum voluntary contraction [MVC]) during each exercise.

### Subjects

Electromyographic signals and spine posture were collected from 8 healthy men aged 21.6 years (*SD* 4.1), 1.82 m tall (*SD* 0.06), with a mass of 74.6 kg (*SD* 10.7).

All participants were healthy and active; however, the tasks were novel to some. Participants were given instructions on how to properly complete the exercises, but none were skilled in any of the exercises before the experiment. All subject recruitment and data collection procedures were performed in accordance with the university office of research and ethics guidelines.

### Procedures

Before instrumentation, the area of the skin to which the electrodes were to be adhered was shaved and cleansed with a 50/50 $H_2O$ and ethanol solution. Pairs of Ag-AgCl surface electrodes were positioned with an interelectrode distance of about 2.5 cm.

Sixteen channels of EMG were collected from electrode pairs placed bilaterally over the following muscles: rectus abdominis lateral to the navel (RRA, LRA), external oblique about 3 cm lateral to the linea semilunaris but on the same level of rectus abdominis electrodes (REO, LEO), internal oblique caudal to the external oblique electrodes and the anterior superior iliac spine and still cranial to the inguinal ligament (RIO, LIO), latissimus dorsi over the muscle belly when the arm was positioned in the shoulder midrange (RLD, LLD), thoracic erector spinae approximately 5 cm lateral to the spinous process (actually longissimus thoracis and iliocostalis at T9) (RUES, LUES), lumbar erector spinae approximately 3 cm lateral to the spinous process (actually longissimus and iliocostalis at L3) (RLES, LLES), right gluteus medius in the muscle belly found by placing the thumb on the anterior superior iliac spine and reaching with the fingertips around to the gluteus medius (RGMED), gluteus maximus in the middle of the muscle belly approximately 4 cm lateral to the gluteal fold (RGMAX), rectus femoris approximately 5 cm caudal to the inguinal ligament (RRF), and biceps femoris over the muscle belly midway between the knee and hip.

The EMG signals were amplified and then A/D converted with a 12-bit, 16-channel A/D converter at 2048 Hz. Each subject was required to perform a maximal contraction of each measured muscle for normalization of each channel (8). For the abdominal muscles, each subject adopted a sit-up position and was manually braced by a research assistant. The subject then produced a maximal isometric flexor moment followed sequentially by a right and left lateral bend moment and then a right and left twist moment. Little motion took place. Each participant also performed an isometric reverse curl-up by adopting a supine position where he attempted to lift his pelvis off the table while a research assistant restrained his knees. Subjects were further instructed to attempt to twist right and left. For the spine extensors and gluteal muscles, a resisted maximum extension in the Biering Sorensen position was performed (12). A specific gluteus medius–normalizing contraction was also attempted with resisted side-lying abduction (i.e., the clam). Each participant lay on his left side with the hips and knees flexed. Keeping his feet together, each participant abducted the right thigh to parallel, and a research assistant restricted further movement. Normalizing contractions for rectus femoris were attempted with isometric knee extension performed from a seated position with simultaneous hip flexion on the instrumented side. The maximal amplitude observed in any normalizing contraction for a specific muscle was taken as the maximum for that particular muscle. The EMG signals were normalized to these maximal contractions after full-wave rectification and low-pass filtering with a second-order Butterworth filter. A cutoff frequency of 2.5 Hz was used to mimic the EMG to force frequency response of the torso muscles (2).

Lumbar spine position was measured about 3 orthogonal axes using a 3 Space IsoTRAK electromagnetic tracking instrument (Polhemus Inc, Colchester, Vt). This instrument consists of a single transmitter that was strapped to the pelvis over the sacrum, with a receiver strapped across the ribcage, over the T12 spinous process. In this way, the position of the ribcage relative to the pelvis was measured (lumbar motion). Spine posture was normalized to that obtained during standing (thus corresponding to 0° of flexion-extension, lateral bend, and twist). A second transmitter was strapped to the lateral femoral condyle of the right leg to track hip motion.

### Description of Exercises

Exercises are shown in Figure 1.

Sagittal walkouts: Facing the wall with their hands on the wall at shoulder height, subjects "walked" their hands up the wall and held this outstretched position. This was repeated on the floor for comparison. Starting in a pushup posture, subjects "walked" their hands forward, creating a body bridge, to a distance at which they felt they could maintain the posture.

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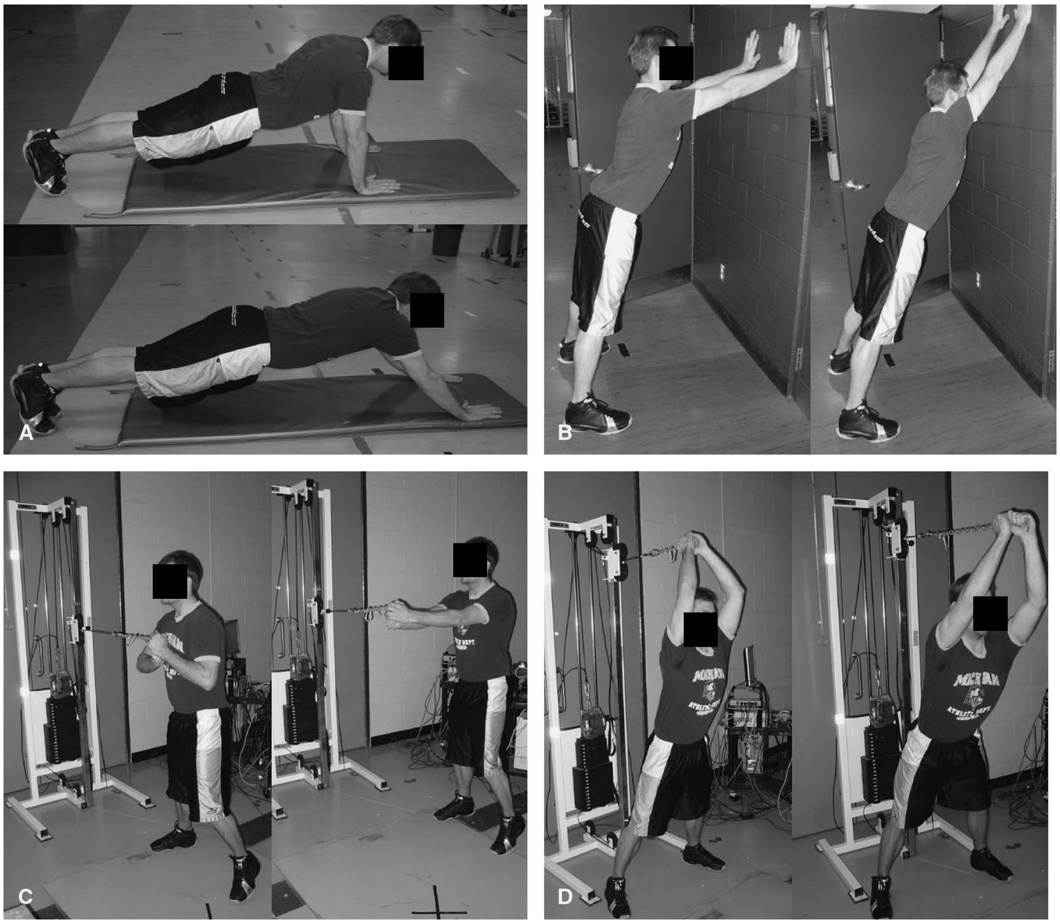

**Figure 1.** A) Sagittal walkouts completed on the floor; B) sagittal walkouts done on the wall; C) cable walkouts; D) overhead cable push.

Cable walkouts: Grabbing the cable in both hands, subjects side-stepped away. First, the cable was held close to the body, and then the cable was held with outstretched arms. The cable load varied (mean 5.4 kg, *SD* 1.6 kg). These were conducted first giving the subjects no specific instructions, and then the task was repeated after instructing the subjects to brace the abdominal wall.

Overhead cable push: The cable handle was held in both hands with the arms outstretched overhead. The instruction issued was to constrain the flexion motion only at the hips. First, subjects stood on both feet and then repeated the exercise on only 1 foot. Both exercises were then repeated following instructions to consciously brace the abdominal wall. The cable load was selected to be challenging but still performed without a break in form (mean 5.2 kg, *SD* 1.6 kg).

Good mornings: Subjects stood with their arms overhead and then flexed at the hips as far as possible. They were instructed not to flex the spine. Both 1- and 2-legged stance variations were collected.

Bowler's squat: The variation of a 1-legged squat that is similar to the bowling motion.

When practicing the exercises, each participant qualitatively determined the highest load he could move for each cable exercise (overhead cable push, cable walkouts) without losing form, jerking the cable, or causing injury to himself. Therefore, the exercises would be challenging to the musculature, but the participants would maintain good form.

### Spine Load and Stiffness Estimation

Briefly, normalized EMG signals and lumbar spine position data were entered into an anatomically detailed model of the lumbar spine. This model represents approximately 90 muscle fascicles and 6 lumbar joints (L5-sacrum to T12-L1). The force and stiffness generated by each muscle fascicle were estimated from a distribution-moment (9) approach incorporating the normalized muscle activation, muscle cross-sectional area, stress-generating capability, length, and velocity. Muscle compressive force was computed as the summation of the force of all muscle fascicles acting along

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the anatomic compressive axis of the L4-L5 joint. Lumbar spine stiffness was computed as the average of the rotational joint stiffness (13) estimated across each lumbar joint about the flexion/extension axis. A more detailed description of the various components of the modeling techniques can be found elsewhere (5).

### Data Analysis

Sagittal walkouts: Peak EMG of the entire trial was compared between wall and floor walkouts.

Cable walkouts: Four variations of the exercise (arms outstretched, arms held close to the body, arms outstretched with brace, and arms held close to the body with brace) were performed. Each exercise was sectioned into 2 main phases, listed as follows: 1) side-stepping away from the cable machine and 2) side-stepping toward the cable machine (the right leg was closest to the cable machine). The 2 phases were subdivided into 2 groups as follows: 1) when the right him was fully abducted (max hip abduction) and 2) when the right him was fully adducted (max hip adduction; hip position was measured by a 3-space sensor on the right leg). Therefore, peak EMG was taken from each variation of the exercise, when the hip was fully abducted and adducted during both phases of either walking away or walking toward the cable machine.

Overhead cable push: Four variations of the overhead cable push were completed (single-leg stance, double-leg stance, single-leg stance with an abdominal brace, and double-leg stance with an abdominal brace). Peak EMG was taken from 2 phases of each exercise as follows: 1) initiation of the exercise and 2) performing the exercise.

Good mornings: Both the single- and double-leg stances were individually analyzed.

### Statistical Analyses

For sagittal walkouts, a 1-way repeated-measures analysis of variance (ANOVA) was performed: (between factor, exercise = 2 levels, $\alpha = 0.05$). For cable walkouts, a 2-way repeated-measures ANOVA was performed (within factors, direction and phase: 4 levels; exercise: 4 levels, $\alpha = 0.05$). For the overhead cable push, a 2-way repeated-measures ANOVA was performed (within factors, direction: 2 levels; exercise: 4 levels, $\alpha = 0.05$). For good mornings, a 1-way ANOVA (between factor, exercise = 2 levels, $\alpha = 0.05$). Each ANOVA was followed by a least squared means post hoc analysis where main effects were found.

## RESULTS

The results are organized by exercise in all their variations.

### Sagittal Walkouts

These walkout exercises were new to most of the subjects. Wall walkouts are clearly lower-level challenges compared with the floor walkout, which caused maximal activation of the rectus abdominis with less activity in the internal oblique, and less still in the external oblique (see Figure 2). All abdominal muscles increased peak activity, as did the right upper erector spinae, right latissimus dorsi, and right gluteus medius (all $p$ values $<0.03$). Despite the instruction to maintain a neutral spine, subjects extended their spines almost 4° on average when holding the maximal wall walkout posture, and they flexed their spines almost 4° when holding the maximal floor walkout posture.

### Cable Walkouts

The activation level of the RRA and RIO muscles when the arms were held close to the body (RRA = 5.9% MVC; RIO = 7.5% MVC) or with the arms outstretched (RRA = 8.3% MVC; RIO = 9.6% MVC) significantly increased by performing an abdominal brace (arms close: RRA = 11.4% MVC, RIO = 22.5% MVC; arms outstretched: RRA = 9.3% MVC, RIO = 20.4% MVC) ($F = 4.01$, $p = 0.0211$; $F = 6.33$, $p = 0.0031$) (see Figure 3). Similarly, bracing the abdominals significantly increased the level of activation in the LRA and REO muscles both with the arms outstretched (LRA = 4.9% MVC; REO = 12.1% MVC) and with the arms close (LRA = 4.3% MVC; REO = 15.4% MVC) than when performing the exercise with the arms held close without bracing (LRA = 2.5% MVC; REO = 9.6% MVC) ($F = 4.05$, $p = 0.0203$; $F = 3.30$, $p = 0.0402$). Higher activation of the LEO muscle was

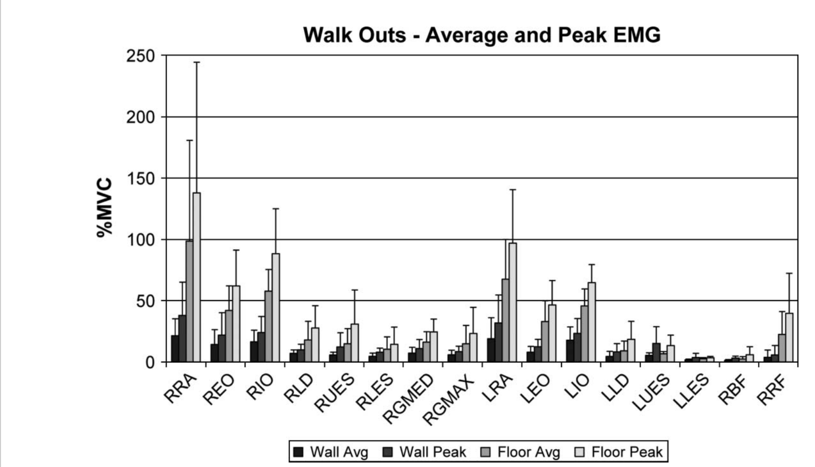

**Figure 2.** Peak and average muscle activation between walkouts completed on the wall and walkouts on the floor.

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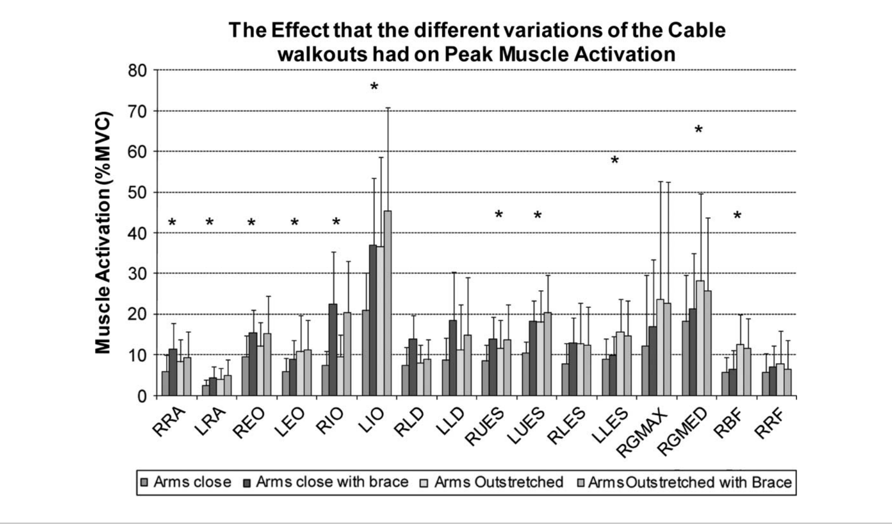

**Figure 3.** Increase in muscle activation from holding the arms close to the body and keeping the arms outstretched, with and without an abdominal brace, during the cable walkouts.

observed when bracing the abdominals and having the arms outstretched (11.2% MVC) or keeping the arms held close to the body (8.9% MVC) compared with performing the exercise with the arms held close to the body and no bracing of the abdominals (5.9% MVC; $F = 4.14$, $p = 0.0195$). Activation of the LIO and LUES muscles when bracing and having either the arms outstretched (LIO = 45.3% MVC; LUES = 20.3% MVC) or holding the arms close to the body (LIO = 37% MVC; LUES = 13.9% MVC), or by having the arms outstretched and no brace (LIO = 36.6% MVC; LUES = 11.7% MVC), were all significantly higher than performing the exercise with the arms held close without a brace (LIO = 20.9% MVC; LUES = 8.5% MVC) ($F = 6.55$, $p = 0.0027$; $F = 7.72$, $p = 0.0012$). Higher activation of the LLES and RBF muscles was observed when completing the exercise with and without an abdominal brace and holding the arms outstretched (LLES = 15.7 and 14.7% MVC; RBF = 12.5 and 11.7% MVC) compared with keeping the arms held close to the body with and without bracing (LLES = 9.9 and 9% MVC; RBF = 6.4 and 5.8% MVC) ($F = 5.84$, $p = 0.0046$; $F = 11.20$, $p = 0.0001$). The activation of the RGMED muscle when holding the arms outstretched, with and without abdominal bracing (25.7 and 28.1% MVC), had significantly higher activation levels than during the exercise with the arms held close to the body without abdominal bracing (18.2% MVC; $F = 3.16$, $p = 0.0459$).

Also, side-stepping away from the cable machine required larger REO activation (13.7% MVC) compared with walking towards the cable machine (12.5% MVC; $F = 6.10$, $p = 0.0429$). Peak activation taken when the hip was fully abducted (13.7% MVC) was significantly larger than when the hip was fully adducted (13.7% MVC; $F = 6.38$, $p = 0.395$).

An interaction between the exercise performed and the phase at which peak EMG was taken was observed from the RGMAX muscle ($F = 3.19$, $p = 0.0446$). When the arms were outstretched, the peak activation of the RGMAX muscle when the hip was fully adducted (31.1% MVC) was

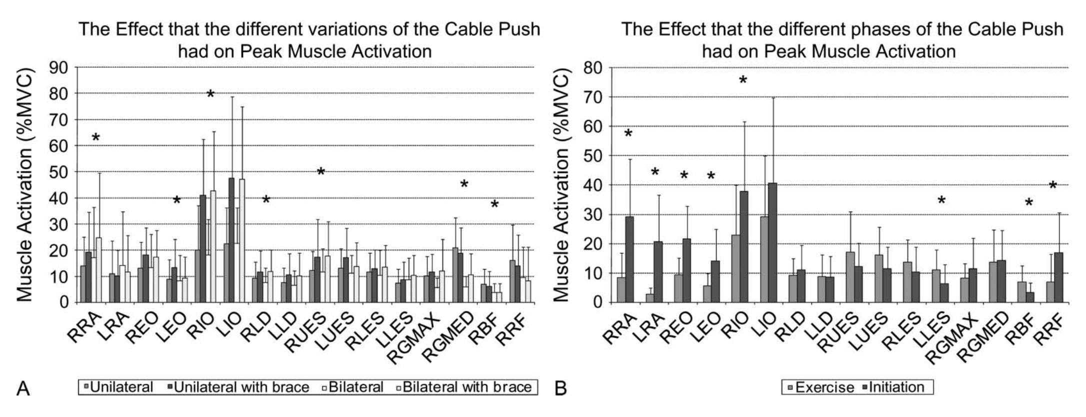

**Figure 4.** A) The effect that each variation of the overhead cable presses had on peak activation of all muscles. B) The effect that the different phases of the overhead cable push (initiation and exercise phase) had on peak electromyographic data of all muscles.

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significantly larger than when the hip was fully abducted (16% MVC), as well as when the hip was fully adducted and the arms were close to the body with and without a brace (10.2 and 14.2% MVC; $F = 3.19$, $p = 0.0446$). Also, bracing with the arms outstretched resulted in significantly higher peak activation during maximum hip adduction (24.5% MVC) than by bracing and keeping the arms close to the body ($F = 3.19$, $p = 0.0446$).

For the RUES and RLD muscles, there was a 3-way interaction between the exercise performed, direction of walking, and the time at which peak EMG was taken ($F = 3.35$, $p = 0.0383$).

No significant differences were found in the muscle activation levels of the RLES and RRF LLD muscles.

Performing cable walkouts with the arms outstretched during the exercise increased the twisting moment from about 30 to 54 N·m, compared with having the arms close to the body (Table 1). This increased moment resulted in anterior/posterior shear, spine compression, and spine stiffness. Bracing the abdominals resulted in more spine stiffness and more spine load–for example, the cable walkouts with arms outstretched (no brace) resulted in 3345 N of compression and in 4185 N with a brace.

### Overhead Cable Push

The cable load for each subject ranged between 10 and 20 lb (45–90 N). The LEO muscle's activation level was significantly higher when performing the exercise on 1 leg with an abdominal brace (13.3% MVC) vs. without a brace (8.8% MVC) and using a 2-leg stance with and without a brace (9.4 and 8.2% MVC; $F = 3.28$, $p = 0.0410$) (see Figure 4). When performing the exercise on 1 leg with and without an abdominal brace, the RBF (6.2 and 6.9% MVC) and RGMED (18.8 and 20.9% MVC) muscle activation levels are significantly higher than by standing on both legs with and without a brace (RBF = 3.9 and 3.8% MVC, RGMED = 10.6 and 5.9% MVC) ($F = 4.80$, $p = 0.0107$; $F = 12.09$, $p < 0.0001$). Also, abdominal bracing (single leg = 41% MVC; double leg = 42.6% MVC) elicited significantly larger activation of the RIO muscle than performing the exercises without the brace (single leg = 20.1% MVC; double leg = 18.2% MVC; $F = 10.57$, $p = 0.0002$). The activation of the RRA muscle was higher when performing the exercise with a double-leg stance and bracing the abdominals (24.7% MVC) than without the brace (17.2% MVC), or the single-leg stance without a brace (14% MVC; $F = 3.27$, $p = 0.0416$). Higher activation of the RLD muscle was observed when an abdominal brace was performed during both variations of the exercise (single leg = 11.7% MVC; double leg = 11.8% MVC) when compared with the double-leg stance without a brace (7.7% MVC; $F = 4.53$, $p = 0.0134$). Also, when performing the exercise with a double-leg stance and bracing the abdominals, the RUES muscle activation level (17.8% MVC) was significantly higher than performing the double-leg (11.7% MVC) and single-leg variations without a brace (12.2% MVC); combining an abdominal brace with the single-leg stance (17.3% MVC) was significantly higher than the double-leg stance without any bracing ($F = 3.26$, $p = 0.0417$).

During the initiation of the exercise, the LEO (14.2% MVC), LRA (20.7% MVC), REO (21.6% MVC), and RRF (16.9% MVC), RIO (37.9% MVC), and RRA (29.1% MVC) levels of activation were significantly higher than during the exercise phase (LEO = 5.7% MVC; LRA = 2.8% MVC; REO = 9.4% MVC; RRF = 7% MVC; RIO = 23% MVC; RRA = 8.5% MVC ) ($F = 10.62$, $p = 0.0139$; $F = 14.27$, $p = 0.0069$; $F = 20.40$, $p = 0.0027$; $F = 5.90$, $p = 0.0454$; $F = 8.05$, $p = 0.0251$; $F = 12.91$, $p = 0.0088$). However, the activation levels of the LLES (11.1% MVC) and RBF (7% MVC) muscles were higher when completing the exercise, compared with the initiation (LLES = 6.4% MVC; RBF = 3.4% MVC) ($F = 9.30$, $p = 0.0186$; $F = 8.78$, $p = 0.0210$).

The LIO muscle was affected by an interaction between the variation of the exercise performed and the phase at which peak muscle activation was taken. The peak activation during the initiation of the double-leg (58.6% MVC) and single-leg (53.6% MVC) stance variations was significantly larger than when performing the exercise (35.6 and 41.5% MVC) and the initiation of both the double-leg and single-leg stance performed without a brace (26.7 and 23.5% MVC, respectively; $F = 3.19$, $p = 0.0447$). The peak recorded during the exercising phase of the double-leg and single-leg stance performed with a brace were both significantly larger than without a brace (26.7 and 21.4% MVC; $F = 3.19$, $p = 0.0447$).

**Table 1.** Summary of the average moment calculated during the overhead cable press (at L4/L5 and the hip) and the cable walkouts (arms in and arms outstretched).

| Exercise | Twist moment (N·m) | *SD* |
|---|---|---|
| Cable walkouts–arms in (L4/L5) | 29 | 12 |
| Cable walkouts with brace–arms in (L4/L5) | 27 | 10 |
| Cable walkouts–arms out (L4/L5) | 54 | 10 |
| Cable walkouts with brace–arms out (L4/L5) | 57 | 11 |

| Exercise | Flexion moment (N·m) | *SD* |
|---|---|---|
| Overhead cable press (hip) | 83 | 24 |
| Overhead cable press with brace (hip) | 81 | 24 |
| Overhead cable press (L4/L5) | 72 | 20 |
| Overhead cable press with brace (L4/L5) | 70 | 21 |

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Similarly, the RGMAX muscle was affected by an interaction between the variation of the exercise performed and the phase at which peak muscle activation was taken. The peak muscle activation recorded when performing a brace in a double stance (17% MVC) was significantly larger than the exercise phase (7.1% MVC) and the initiation phase of the double-leg stance without a brace (6.4% MVC) and the initiation of the single-leg stance with and without a brace (12.1 and 10.1% MVC, respectively). The initiation and exercise phase (11.3% MVC) of the single-leg stance performed with a brace was significantly larger than the peak recorded at the initiation and exercise phase (4.9% MVC) of the double-leg stance without a brace; during the exercise phase, the single-leg stance without a brace (10.1% MVC) was significantly larger than the exercise phase of the double-leg stance without a brace ($F = 5.19$, $p = 0.0077$).

No significant differences were observed in the LLD, LUES, and RLES activation levels.

Despite the instruction to only flex at the hips, subjects flexed the lumbar spines on average to approximately 20°.

The flexion moment produced at both the hip and low back was 83 and 72 N·m (Table 1). The resulting compression was 2327 N on average, but this was increased to 3006 N when an abdominal brace was used (Table 2). Bracing had a 34% increase in spine compression (Table 3).

### Bowler's Squat

The bowler's squat was a difficult exercise to quantify because it is a dynamic task with complex, 3-dimensional motion, with large excursions. A typical pattern is shown in Figure 5 in which EMG time histories and spine and hip motion are shown. Muscle activation profiles are relatively modest, with the largest amplitudes observed in the gluteus medius. This seems to belong to those exercises that challenge whole-body balance together with balancing muscles about the many joints involved in the task.

### Good morning

Most of the flexion motion occurred about the hip for the 1- and 2-legged stances (50 and 55°, respectively) during the good morning exercise compared with 21 and 20°, respectively, about the lumbar spine. The highest amplitudes of activation were observed in the upper spine extensors (about 17% MVC; see Figure 6). Standing on 1 leg enhanced the activity in the hip extensors (gluteus medius in particular) and the rectus femoris ($p < 0.01$).

**Table 2.** Summary of the anterior/posterior shear, muscle compression, lateral bend stiffness, axial twist stiffness, and flexion extension stiffness during the cable walkouts and overhead cable press.

| | | Kinetic variables about L4/L5 | | | | |
|---|---|---|---|---|---|---|
| Cable walkouts–arms in | | Anterior/posterior shear (N) | Compression (N) | Lateral bend stiffness | Axial twist stiffness | Flexion extension stiffness |
| No brace | Average | −464 | 2743 | 4128 | 2201 | 2167 |
| | *SD* | 192 | 1000 | 1776 | 858 | 851 |
| With brace | Average | −714 | 3902 | 5962 | 3351 | 2982 |
| | *SD* | 235 | 1332 | 2375 | 1118 | 1172 |
| Cable walkouts–arms out | | Anterior/posterior shear | Compression | Lateral bend stiffness | Axial twist stiffness | Flexion extension stiffness |
| No brace | Average | −553 | 3345 | 5073 | 2882 | 2581 |
| | *SD* | 260 | 1472 | 2463 | 1258 | 1128 |
| With brace | Average | −694 | 4185 | 6484 | 3541 | 3327 |
| | *SD* | 226 | 1611 | 2927 | 1317 | 1462 |
| Overhead cable press | | Anterior/posterior shear | Compression | Lateral bend stiffness | Axial twist stiffness | Flexion extension stiffness |
| No brace | Average | −584 | 2327 | 3825 | 2002 | 1900 |
| | *SD* | 207 | 853 | 1802 | 777 | 728 |
| With brace | Average | −760 | 3006 | 4782 | 2658 | 2388 |
| | *SD* | 123 | 621 | 1223 | 560 | 541 |

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**Table 3.** Summary of the percent increase in anterior/posterior shear, muscle compression, lateral bend stiffness, axial twist stiffness, and flexion extension stiffness during the cable walkouts and overhead cable press by adding torso bracing.

| | Average percent increase in back load and spine stiffness | | | | |
|---|---|---|---|---|---|
| Cable walkouts–arms in | Anterior/posterior shear | Compression | Lateral bend stiffness | Axial twist stiffness | Flexion extension stiffness |
| Average | 55 | 46 | 52 | 55 | 42 |
| *SD* | 24 | 27 | 39 | 21 | 37 |
| Cable walkouts–arms out | Anterior/posterior shear | Compression | Lateral bend stiffness | Axial twist stiffness | Flexion extension stiffness |
| Average | 32 | 29 | 32 | 27 | 30 |
| *SD* | 19 | 17 | 18 | 20 | 12 |
| Overhead cable press | Anterior/posterior shear | Compression | Lateral bend stiffness | Axial twist stiffness | Flexion extension stiffness |
| Average | 46 | 34 | 32 | 39 | 26 |
| *SD* | 38 | 26 | 36 | 28 | 30 |

## DISCUSSION

As far as we are aware, several of these exercises have not been quantified before. They are used clinically in an attempt to balance chains of muscles and joints (11) and also in performance training. With some exceptions, the muscle activation levels were quite modest even though the tasks were quite strenuous in many cases. For example, the overhead cable push resulted in quite low spine loads (about 2330 N without conscious bracing and 3000 with) compared with a standard sit-up, which results in more than 3300 N (1). There are several possible reasons for this observation. First, single muscles cannot be activated to 100% MVC in these whole-body standing exercises that do not isolate joints. This is because most torso muscles create moments about the 3 orthopedic axes of the spine (10). If a muscle were activated to a higher level, unwanted moments would occur that would have to be balanced by other muscles. This places a constraint on the activation level of any muscle in a "functional exercise." Perhaps this is why the highest muscle activity (more than 100% MVC in rectus abdominis in the floor walkouts) was seen in a sagittal plane task. The 3-dimensional joint moment constraints hold the peak muscle activity levels in check during the whole-body multiplanar exercises. Second, the spine must first achieve sufficient stability to handle any imposed loads without a risk of buckling (5,6). Stability is achieved only with a balancing of stiff muscles around the spine (3,4). Changing the activity of a single muscle would require adjustments in all other muscles to ensure the balance of stiffness. For example, the cable walkouts were close to maximum effort, yet activity in the internal oblique muscles (the highest observed) was below 50% MVC. One would assume that they were activated primarily to generate twisting moment, together with playing a role in ensuring spine stability. Had they been activated to higher levels, they would have created torques about the lateral bend and, most likely, the flexion axis. These would have had to have been balanced by elevated activity in other muscles. Perhaps these constraints are 1 aspect of what separates "functional" exercises from muscle isolationist exercises, in which machines create constraints to allow single muscles to activate to very high levels. However, similarly high, single-muscle activation levels outside of the machine constraints would place the system in jeopardy of poor performance from mismatched moments or even joint instability. For general interest, the spine compressive loads associated with supporting the twisting moment will be problematic for some people with bad backs. The cable walkout minimizes spine twist while the twisting torques are generated, making this a preferred approach for sparing the spine.

Different exercises cause different interplay between muscles. For example, even though the overhead cable push and the walkout exercises are sagittal plane abdominal challenges, the walkouts preferentially recruit the rectus abdominis while the overhead cable pushes preferentially challenge the internal oblique. These differences indicate that the neuromuscular system simply does not have 1 scheme to create a flexor

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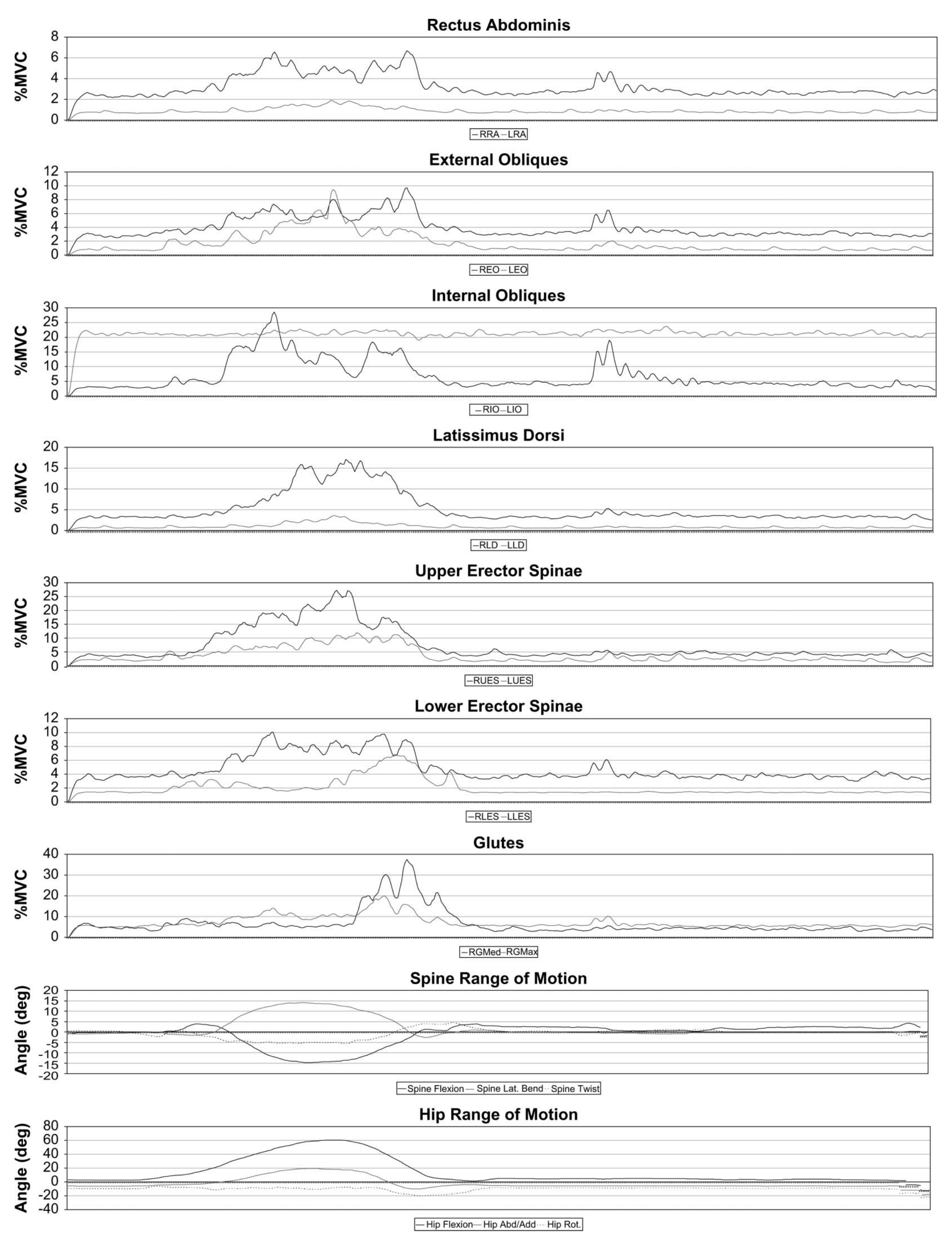

**Figure 5.** Electromyographic amplitudes for spine and hip motion during the bowler's squat.

moment. Several schemes seem necessary to ensure stability, buttress shear loads, and satisfy moment demands. Different variations of exercise are needed to train these various aspects.

Good clinical technique and vigilant exercise coaching can make an exercise tolerable, particularly if it is used for rehabilitation of patients. For example, many people with back pain have lumbar flexion intolerance. Despite the instruction to not move the spine, subjects flexed 20° during the overhead cable push and during the good morning exercise. Perhaps this was because the load was close to

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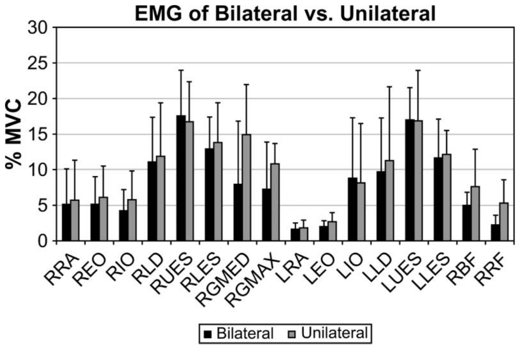

**Figure 6.** Muscle activation during the good morning exercise, both bilaterally and unilaterally.

maximum. This may have been too heavy a load to maintain good form. In addition, bracing can stiffen the spine, which will make an exercise tolerable for those with spine instability and, in many activities, will enhance performance. However, this increased stability comes with the price of higher spine loads.

Several limitations influence the interpretation of the results reported here. The subjects all were healthy; the elderly, children, and patients with pain may respond differently. However, this was primarily a descriptive study, and the data may serve to inform practitioners of the muscle challenges and spine loads associated with some of these exercises, at least those values developed when young men performed the tasks.

## Practical Applications

The exercises quantified in this study demonstrated migration between different muscles when performing variations that required similar moment generation. Somehow, the motor control system is able to organize the activity in all muscles to achieve joint stability and balance 3 moments about each joint. There seem to be constraints on maximal muscle activity when performing multiplanar exercises, even though they require substantial exertion. Maximal activity was only observed when these constraints were removed, such as in a purely sagittal plane task. The data presented here document different forms of exercise and how these techniques influence spine stiffness and load.

These data can be used to assist decisions regarding the selection of exercise–specifically, choices regarding the starting challenge, progression, exercise form, and, possibly, corrective technique for those who have spine concerns or who simply are looking for performance enhancement.

Maximal muscle activity was observed when single-plane tasks were attempted, but muscle activation levels are constrained in multiplanar functional tasks. Thus, strength training muscles may not help in “functional multiplanar” tasks. Functional exercises train strength throughout the linkage, but they remain highly constrained such that individual muscle strengths are not maximally challenged.

## Acknowledgments

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