Journal of Electromyography and Kinesiology 21 (2011) 893–903

Contents lists available at SciVerse ScienceDirect

Journal of Electromyography and Kinesiology

journal homepage: www.elsevier.com/locate/jelekin

Abdominal muscle activation changes if the purpose is to control pelvis motion or thorax motion

Francisco J. Vera-Garcia [a], Janice M. Moreside [b], Stuart M. McGill [b,*]

[a] Sports Research Centre, Miguel Hernandez University of Elche, Avda. de la Universidad s/n, C.P. 03202, Elche, Alicante, Spain
[b] Spine Biomechanics Laboratory, Department of Kinesiology, University of Waterloo, Waterloo, ON, Canada N2L 3G1

ARTICLE INFO

Article history:
Received 15 February 2011
Received in revised form 8 August 2011
Accepted 8 August 2011

Keywords:
Spine
Trunk muscles
Electromyography
Kinematics
Motor control

ABSTRACT

The aim of this study was to compare trunk muscular recruitment and lumbar spine kinematics when motion was constrained to either the thorax or the pelvis. Nine healthy women performed four upright standing planar movements (rotations, anterior–posterior translations, medial–lateral translations, and horizontal circles) while constraining pelvis motion and moving the thorax or moving the pelvis while minimizing thorax motion, and four isometric trunk exercises (conventional curl-up, reverse curl-up, cross curl-up, and reverse cross curl-up). Surface EMG (upper and lower rectus abdominis, lateral and medial aspects of external oblique, internal oblique, and latissimus dorsi) and 3D lumbar displacements were recorded. Pelvis movements produced higher EMG amplitudes of the oblique abdominals than thorax motions in most trials, and larger lumbar displacements in the medial–lateral translations and horizontal circles. Conversely, thorax movements produced larger rotational lumbar displacement than pelvis motions during rotations and higher EMG amplitudes for latissimus dorsi during rotations and anterior–posterior translations and for lower rectus abdominis during the crossed curl-ups. Thus, different neuromuscular compartments appear when the objective changes from pelvis to thorax motion. This would suggest that both movement patterns should be considered when planning spine stabilization programs, to optimize exercises for the movement and muscle activations desired.

1. Introduction

The control of trunk motion in standing is a complex task for the motor system, as the harmonious activation of the trunk muscles must balance the moments about the three orthogonal axes together (flexion–extension, lateral bend, and axial twist) creating the desired motion. A single muscle contributes to the three moments plus motion which in turn must be counterbalanced by an appropriate tuning of other muscles. In standing, the trunk muscles must also ensure the stability of the spinal joints (McGill et al., 2003), to allow the spine to successfully bear load without the risk of buckling or experiencing pain through aberrant joint motion allowed by strained/damaged tissues (examples are in McGill, 2007) to facilitate the rib cage movements of breathing (Hodges et al., 2002), and to maintain the body's equilibrium in the upright posture (Preuss and Fung, 2008). Thus, the relatively large mass of the head, arms and trunk and their elevated position relative to the base of support emphasize the importance of an accurate control of trunk movements for the maintenance of the upright posture (Oddsson, 1990). Back pain patients appear to be able to control their pain by learning to create motion initiated by either the rib cage (thorax) or the pelvis (e.g. torsional control during the wall roll exercise after McGill, 2007). The mechanism remains obscure, thus motivating this study.

Despite many previous studies analyzing trunk muscular activation patterns in standing, most electromyographic (EMG) analyses have been limited to movements performed by the upper trunk and limbs (Butler et al., 2009; Juker et al., 1998; Larivière et al., 2000; Thorstensson et al., 1985). In this study, our main interest was to analyze trunk muscle recruitment patterns resulting from thorax motion compared to pelvis motion in the horizontal, sagittal and transverse planes. On the basis of previous electromyographic studies in the supine position, differences in muscular activation between thorax and pelvis motions could be expected.

Several previous studies of abdominal exercises have compared the abdominal muscle recruitment between upper and lower body movements in supine positions. The main purpose of many of these studies was to search for differences in muscular activation between several portions of rectus abdominis (RA) while comparing exercises in the upper body vs. the lower body (Clark et al., 2003; Lehman and McGill, 2001; Piering et al., 1993; Sarti et al., 1996; Willett et al., 2001). When upper trunk exercises (curl-ups or crunches) were compared to lower trunk exercises (reverse

* Corresponding author. Address: Spine Biomechanics Laboratory, Department of Kinesiology, University of Waterloo, 200 University Ave W., Waterloo, ON, Canada N2L 3G1.
E-mail address: mcgill@healthy.uwaterloo.ca (S.M. McGill).

1050-6411/$ - see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jelekin.2011.08.003

curl-ups and/or leg lowering/raising), both Clark et al. (2003) and Escamilla et al. (2006) found higher activation of upper and lower RA (URA and LRA) during upper trunk exercises. Sarti et al. (1996) and Willett et al. (2001) observed higher LRA activation during lower trunk exercises and no difference for URA, whilst Piering et al. (1993) documented no differences. On the other hand, results are more consistent for the external oblique (EO), as all three authors (Escamilla et al. (2006); Konrad et al. (2001) and Willett et al. (2001) found greater EO activation in lower trunk exercises when compared to those performed by the upper trunk. Most of the aforementioned findings on muscular recruitment were obtained during upper and lower trunk exercises performed in the sagittal plane. Vera-Garcia et al. (2010) recently compared lower trunk maximum voluntary isometric contraction (MVIC) techniques (in which participants were asked to attempt to move the pelvis against resistance), with the more conventional upper trunk MVIC techniques (in which thorax motion was resisted) in the horizontal, sagittal and transverse planes. Although a high intersubject variability was observed, numerous upper trunk MVIC techniques were more effective for maximum activation of EO, LRA, latissimus dorsi (LD) and upper erector spinae. Conversely, lower trunk MVIC techniques were more effective for internal oblique (IO), URA and lower erector spinae.

The results presented above suggest that performing trunk movements with the thorax or with the pelvis may generate different activation patterns. If so, this should be taken into consideration when designing fitness and rehabilitation exercise programs, especially when cuing patients to minimize or eliminate pain. Most of the studies cited above were conducted in a semi-supine position. This motivated the current study to compare trunk muscular activation between pelvis and thorax motions in the upright standing position, to enhance transference to daily activities.

The aim of this study was to compare muscle activation patterns of the abdominal wall and LD as well as lumbar spine kinematics in upright standing, when spine motion is "driven" from the pelvis or from the thorax. The movements compared were: pelvis vs. thorax rotations, anterior–posterior (A–P) translations, medial–lateral (M–L) translations, as well as pelvis vs. thorax circles. In addition, recruitment of the abdominal muscles was also analyzed during isometric upper and lower trunk flexion exercises in supine (conventional curl-ups, reverse curl-ups, cross curl-ups, and reverse cross curl-ups) to compare muscular activation patterns between thorax and pelvis motion. It was hypothesized that different EMG patterns would emerge based on the driver being the pelvis or the thorax.

2. Methods

2.1. Participants

A convenience sample of nine healthy women with good body awareness and competency at middle-eastern belly dance moves was used (Moreside et al., 2008; Vera-garcia et al., 2010) (mean age, height and body mass were 25.9 ± 5.5 yrs, 166.4 ± 6.8 cm and 71.9 ± 17.9 kg, respectively). Each woman signed a written informed consent form approved by the University Office for Research Ethics, as well as a similarly approved form permitting use of pictures or video clips for teaching, scientific presentations and/or publications. Individuals with known medical problems, histories of spinal or abdominal surgery, or episodes of back pain requiring treatment prior to this study were excluded.

2.2. Instrumentation and data collection

2.2.1. Trunk motions in standing and trunk exercises

Participants were asked to perform eight planar movements in upright standing (while attempting to minimize motion in the other planes) as well as four isometric curl-up exercises in supine. Planar movements consisted of: (a) pelvis and thorax rotations in the horizontal plane (Fig. 1);(b) pelvis and thorax A–P translations in the sagittal plane (Fig. 2);(c) pelvis and thorax M–L translations in the transverse plane (Fig. 3);(d) pelvis and thorax circles in the horizontal plane (Fig. 4). During pelvis movements, participants were requested to move the lower trunk and pelvis while keeping the upper body immobile. Conversely, during thorax movements, individuals were asked to move the upper trunk while keeping the pelvis still. Using a metronome, translating and twisting motions were constrained to approximately one repetition per 2 s, whereas circular motions of the pelvis and thorax were timed to a 4 s cadence as trunk motion velocity effects muscular recruitment (Thorstensson et al., 1985; Vera-Garcia et al., 2008). A 10 repetition set of each planar movement was executed. A 2 min rest was allowed between each set in order to avoid muscular fatigue.

Isometric curl-ups were carried out to analyze abdominal muscle recruitment during upper or lower trunk motion in a supine position. Upper trunk flexion on a secured pelvis was compared to lower trunk flexion on a secured thorax, in the sagittal plane with and without a twisting component to the right and left. This resulted in four curl-up activities of 10 s duration each: conventional curl-ups, reverse curl-ups, cross curl-ups, and reverse cross curl-ups.

Prior to data collection, each participant was instructed in planar movement techniques and cadences, as well as the trunk flexion exercises. Sufficient practice was allowed for the rhythm of the movement to be properly executed. Condition testing order was randomized across subjects.

2.2.2. Electromyography and ultrasonography

Surface electromyographic (EMG) signals were collected bilaterally on each subject (AMT-8, Bortec Biomedical Ltd., Calgary, Alberta, Canada, with a CMRR of 115 dB at 60 Hz, and input impedance of 10 G). The following trunk muscles and locations were used: *URA*, in the approximate centre of the second uppermost section of the muscle belly; *LRA*, in the approximate centre of the lowermost section of the muscle belly; *lateral aspect of EO* (*LEO*), approximately 3 cm anterior to and mid-way along a line drawn from the lateral pelvic crest to the lateral lower ribcage; *medial aspect of EO* (*MEO*), approximately 15 cm lateral to the umbilicus; *IO*, halfway between the anterior superior iliac spine of the pelvis and the midline, just superior to the inguinal ligament; and *LD*, lateral to T9 over the muscle belly. Although previous literature has shown these locations to represent the abdominal wall musculature adequately and minimize the effect of cross-talk (McGill et al., 1996), ultra-sonography (SonoSite Titan®, Bothell, USA) was also utilized to confirm appropriate placement of the electrodes for the abdominal muscles. Pregelled disposable bipolar Ag–AgCl surface electrodes (Blue Sensor, Ambu A/S, Denmark) were positioned parallel to the muscle fibers with an interelectrode distance of 3 cm. EMG signals were amplified to produce approximately ±2.5 V, and then A/D converted (12 bit resolution) at 1024 Hz.

MVIC techniques were carried out prior to the planar and the curl-up trials, to obtain reference values for normalizing EMG signals. The MVIC protocol included two sets of eight different maximal efforts performed as explained by Vera-Garcia et al. (2010). Briefly, participants performed: three MVIC trials in which thorax motion was resisted (upper trunk flexion, twisting and lateral bending), three MVIC trials in which pelvis motion was resisted (lower trunk flexion, twisting and lateral bending), a maximal effort abdominal hollowing, and a right and left shoulder rotation and adduction for LD. According to previous studies, a number of both upper and lower trunk MVIC techniques performed in the three cardinal planes seem to be necessary when seeking maximum electrical activity for abdominal EMG normalization (McGill, 1991; Ng et al., 2002; Vera-Garcia et al., 2010).

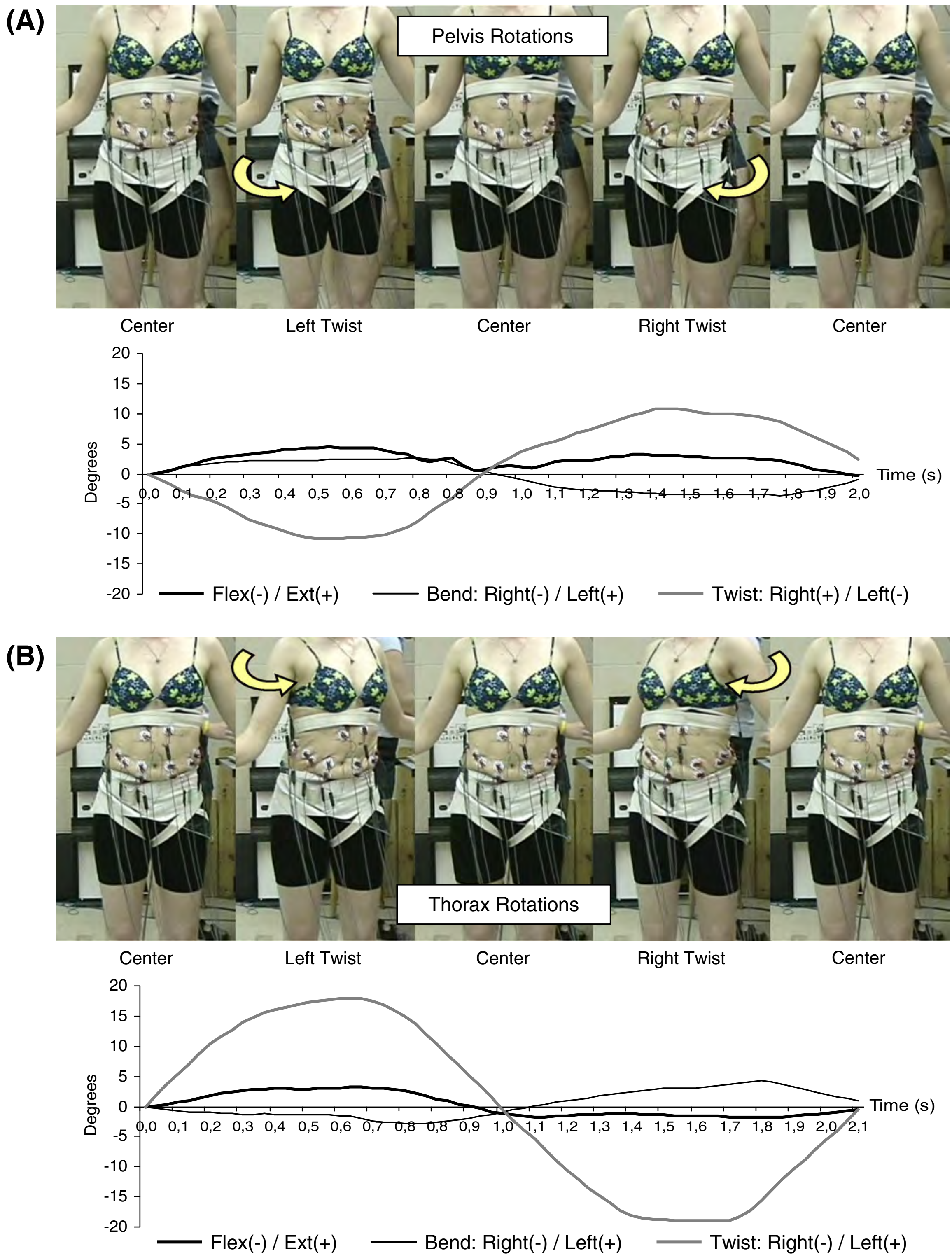


Fig. 1. Sequence of digital video images and lumbar spine 3D kinematics of a participant during a cycle of pelvis (A) and thorax (B) rotations in horizontal plane. Spine movements and video images have been temporary synchronized.

2.2.3. Three-dimensional kinematics

Lumbar spine kinematics were measured during planar movements in standing using an electromagnetic tracking instrument (3Space ISOTRAK, Polhemus Inc., Colchester, VT, USA), collecting at a sampling frequency of 32 Hz. The electromagnetic source was placed over the sacrum, with the receiver over the T12 spinous process. All angular measurements were made relative to the standing anatomical position.

2.2.4. Video analyses

Planar motions were video-taped, and temporally synchronized with the EMG and angular displacement data via a light

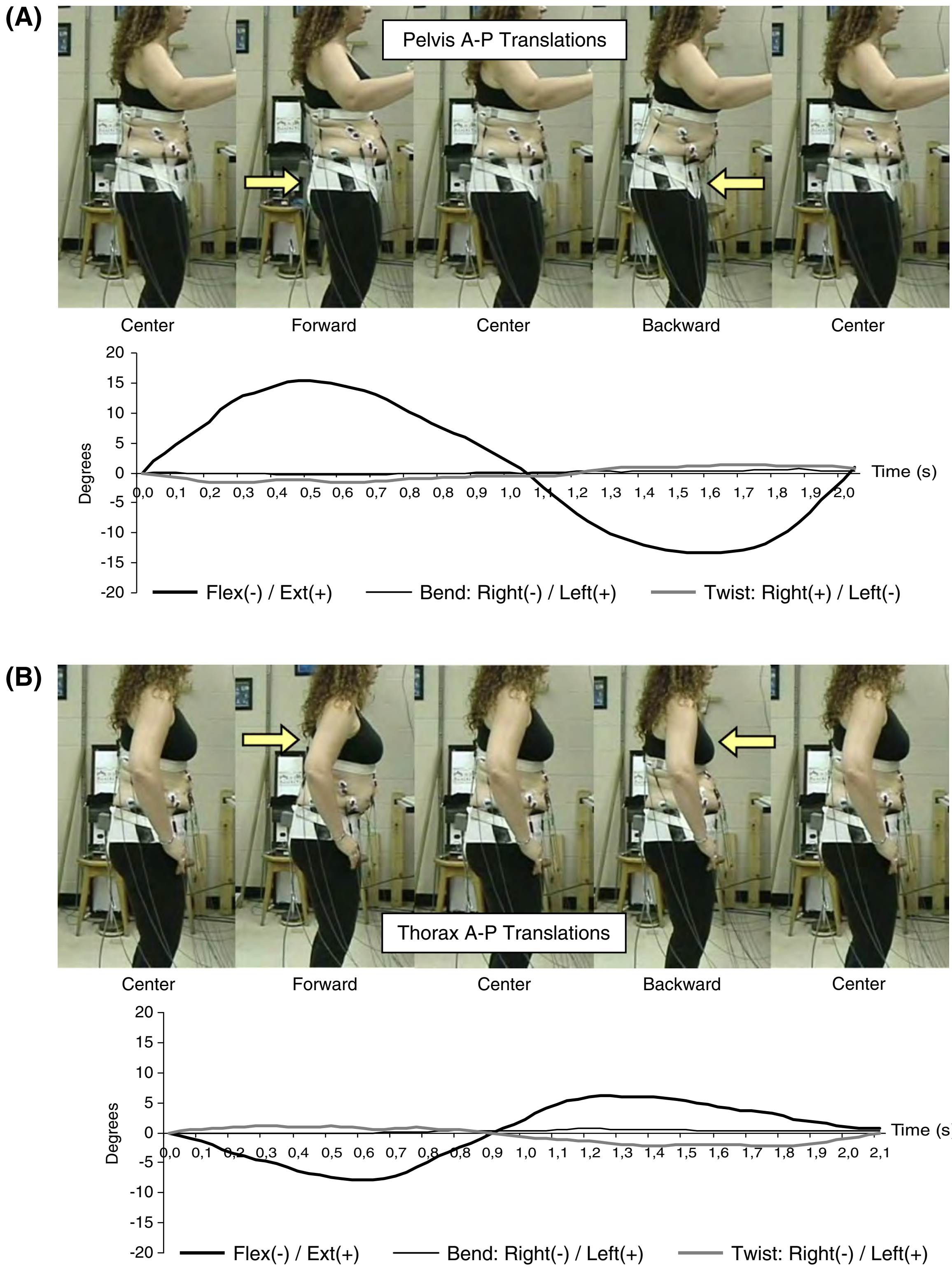


Fig. 2. Sequence of digital video images and lumbar spine 3D kinematics of a participant during a cycle of pelvis (A) and thorax (B) anterior–posterior translations in sagittal plane. Spine movements and video images have been temporary synchronized.

emitting diode at the onset of collection. After recording, each trial was visually examined by a researcher in order to verify the correct technique and cadence while thorax and pelvis motions were executed.

2.3. Data reduction

After visual inspection, EMG signals were high pass filtered (100 Hz) to remove heart rate artifact (Drake and Callaghan,

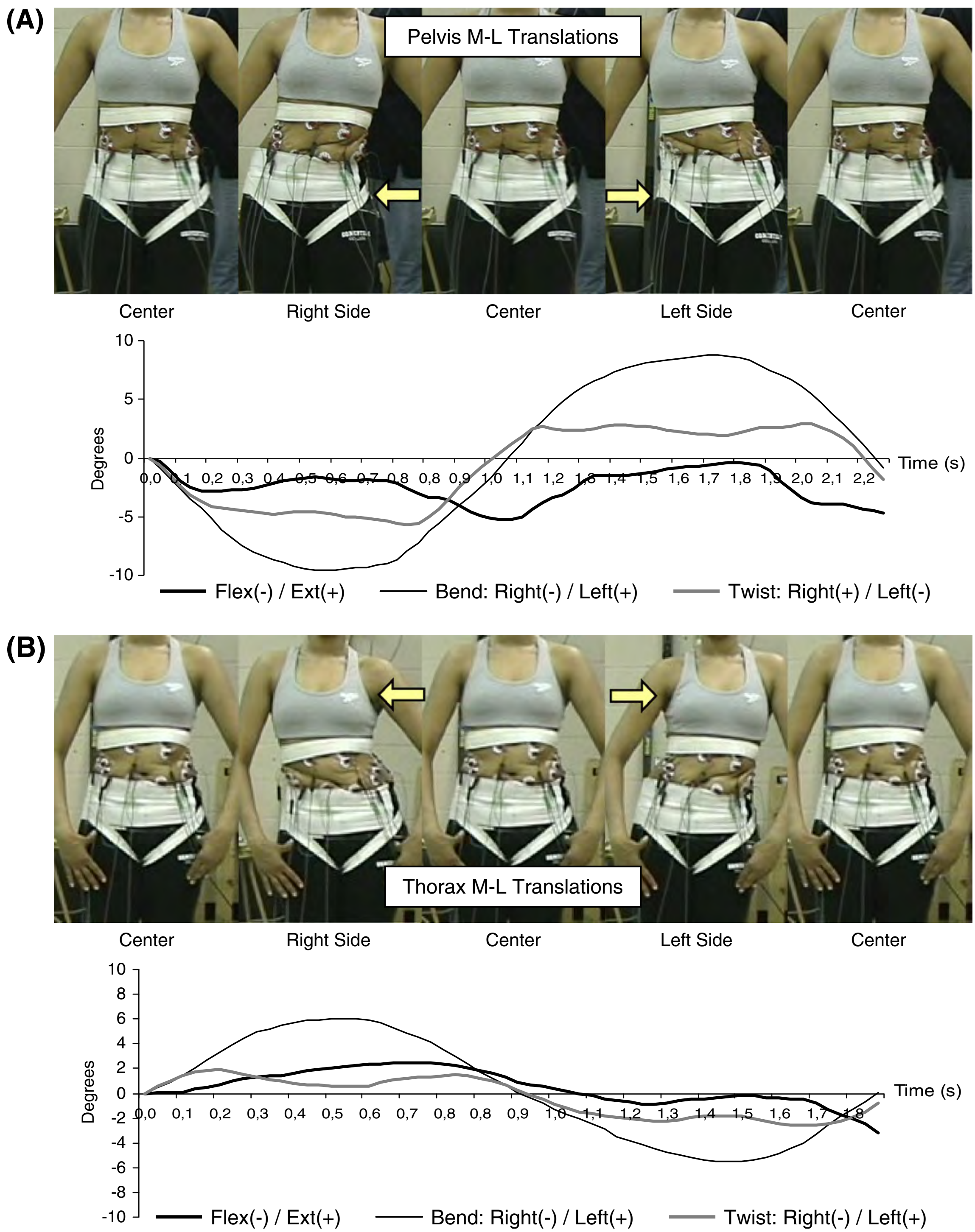


Fig. 3. Sequence of digital video images and lumbar spine 3D kinematics of a participant during a cycle of pelvis (A) and thorax (B) medial–lateral translations in transverse plane. Spine movements and video images have been temporary synchronized.

2006; Moreside et al., 2008; Potvin and Brown, 2004; Vera-Garcia et al., 2010), full wave rectified, low pass filtered (low pass Butterworth filter) with a cutoff frequency of 2.5 Hz, to mimic the frequency response of torso muscle (Brereton and McGill, 1998) and then normalized to the MVIC amplitudes. Examples of the filtered and normalized EMG data from right abdominal wall are shown in Fig. 5. Mean activation levels from the first 10 s of normalized EMG data were averaged across all the subjects for the various muscle groups and tasks. Peak muscle activation levels were also calculated across each 10 s trial. For each participant, right and left sides were compared using paired *t*-tests for assessing muscle symmetry. Since no significant differences were found between sides ($p > 0.05$), EMG amplitudes of right and left sides were averaged, resulting in a total of six muscle groups for each person (URA, LRA, LEO, MEO, IO and LD).

Lumbar kinematic data was obtained by visually examining the video-tapes of the execution, and selecting three repetitions of each planar trial in which a proper performance was verified. The

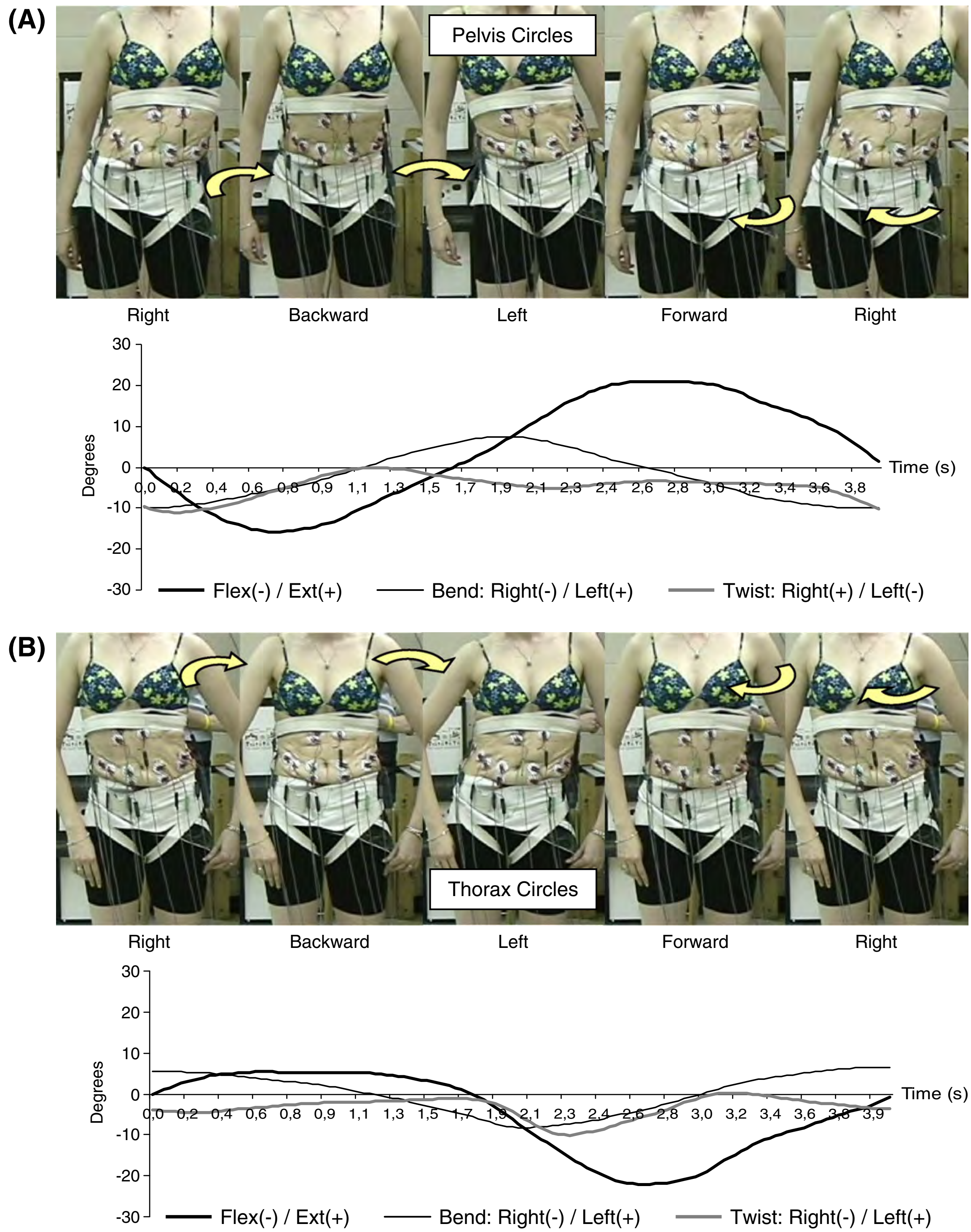


Fig. 4. Sequence of digital video images and lumbar spine 3D kinematics of a participant during a cycle of pelvis (A) and thorax (B) horizontal circles. Spine movements and video images have been temporary synchronized.

maximum amplitudes from the three repetitions were then averaged (range of lumbar motion) for each of the three orthogonal axes.

2.4. Statistical analyses

For each condition, a repeated measures analysis of variance was performed (SPSS version 18.0, SPSS Inc., Chicago, IL, USA) to compare the normalized EMG amplitudes of the trunk muscles and the range of 3D lumbar spine motion between thorax movements and pelvis motions. Where applicable, post hoc paired *t*-tests with a Bonferroni adjustment for alpha inflation were performed. An alpha level of 0.05 was considered significant for all analyses.

3. Results

3.1. Lumbar spine kinematics

Figs. 1–4 shows the lumbar angular 3D motions of a repetition for each standing condition of a subject. Reversal patterns of angular kinematics were observed for pelvis and thorax motions.

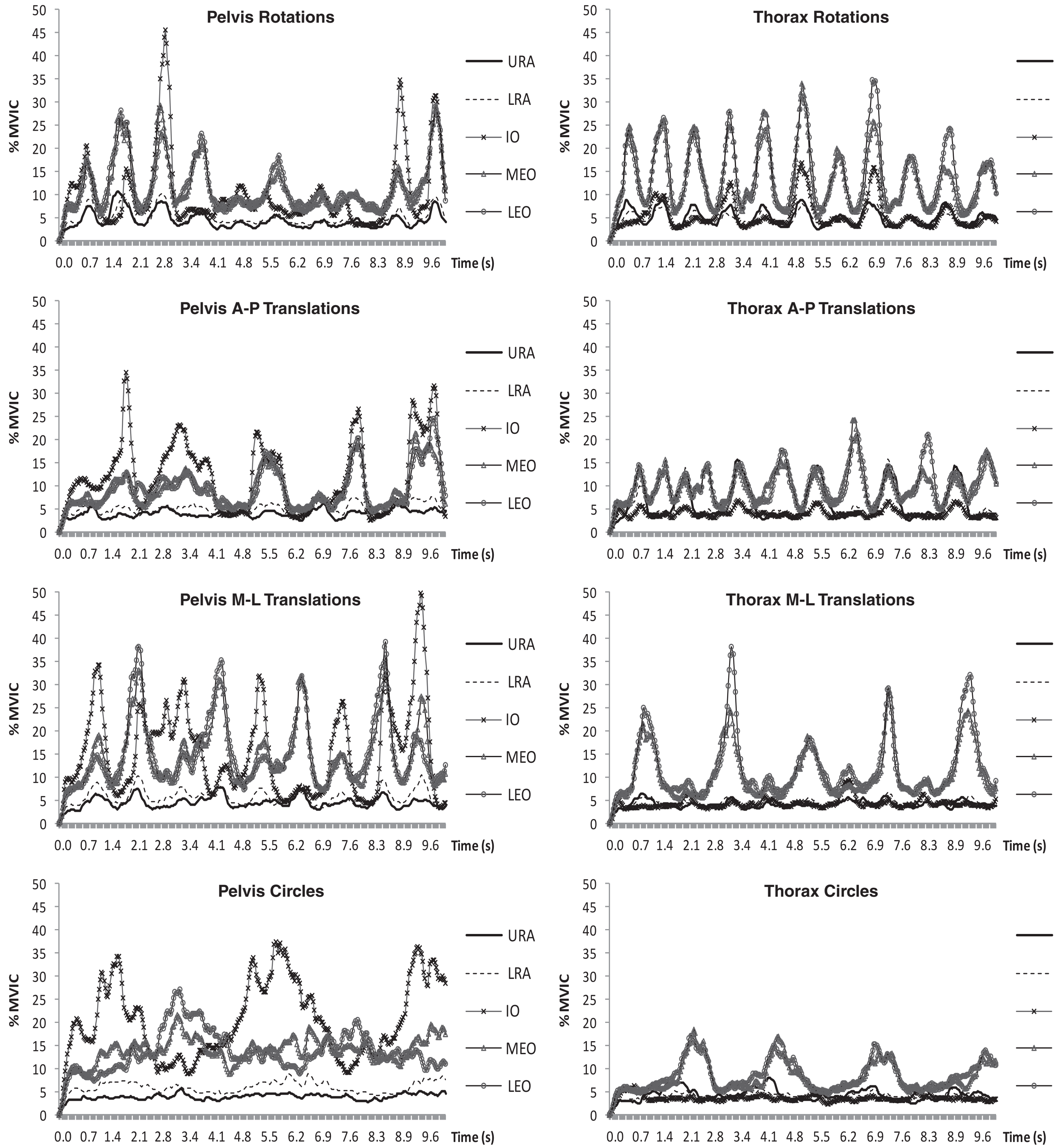


Fig. 5. Examples from one participant of the filtered and normalized EMG time histories representing right upper and lower rectus abdominis (URA and LRA), right medial and lateral aspects of external oblique (MEO and LEO) and right internal oblique (IO) over the first 10 s of the planar motions.

When executing the planar movements, most participants were able to constrain lumbar motion to the horizontal, sagittal, and frontal plane during trunk rotation, A–P translation and M–L translation, respectively (Table 1). Horizontal circles, although mainly sagittal, also included large amounts of lateral bend and twist. As reported in Table 1, in the horizontal circles and the M–L translation conditions, maximum amplitudes of the lumbar motion were higher for pelvis motions than for thorax motions (circles: $F = 8.654$, $p = 0.007$; M–L translations: $F = 20.907$, $p < 0.001$); but only reached statistical significance for lateral bending during M–L translations ($p < 0.001$). Conversely, rotation of the thorax elicited higher peak amounts of twisting than rotation of the pelvis ($p < 0.001$). For A–P translations, the peak angular amplitudes of pelvis and thorax conditions were similar ($F = 0.142$, $p = 0.710$).

3.2. Muscle activation patterns in standing

In all conditions, pelvis motion resulted in higher mean activation levels of IO than thorax motion, for a given motion (Fig. 6). Similarly, MEO showed significantly higher mean activation levels

Table 1
Averages (±SD) of the maximum amplitude (degrees) of the lumbar spine displacement in three orthogonal axes (flexion–extension, lateral bend, and twist) for the pelvis and thorax movements. *Indicates significant differences between pelvis and thorax motions ($p < 0.05$).

	Rotation			A–P translation			M–L translation			Circles		
	Flex	Bend	Twist*	Flex	Bend	Twist	Flex	Bend*	Twist	Flex	Bend	Twist
Pelvis	5.52 (1.9)	6.07 (2.2)	13.72 (5.3)	20.00 (10.4)	1.59 (0.7)	2.80 (1.2)	4.67 (1.7)	13.93 (2.6)	7.76 (3.5)	22.60 (11.1)	14.92 (5.6)	9.53 (4.4)
Thorax	3.23 (1.7)	5.76 (1.9)	20.29 (8.6)	18.41 (7.1)	1.75 (0.7)	2.92 (1.3)	3.46 (1.5)	8.30 (4.4)	5.43 (1.8)	13.65 (10.2)	8.40 (4.8)	5.14 (3.6)

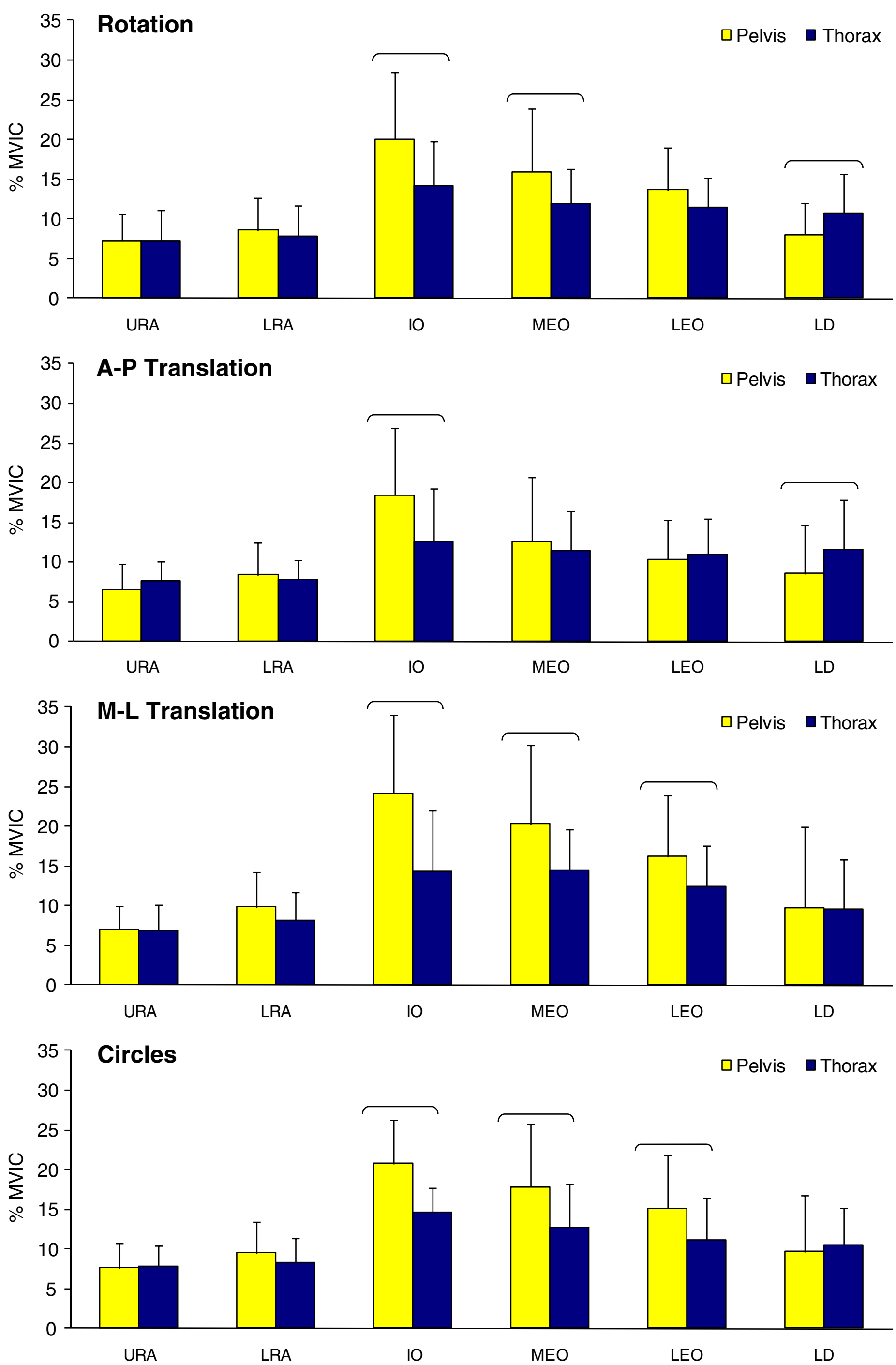


Fig. 6. Mean normalized EMG amplitudes for pelvis and thorax rotations, anterior–posterior (A–P) and medial–lateral (M–L) translations and horizontal circles in upright standing. Bracket above the bars indicates statistical differences between pelvis and thorax conditions ($p < 0.05$).

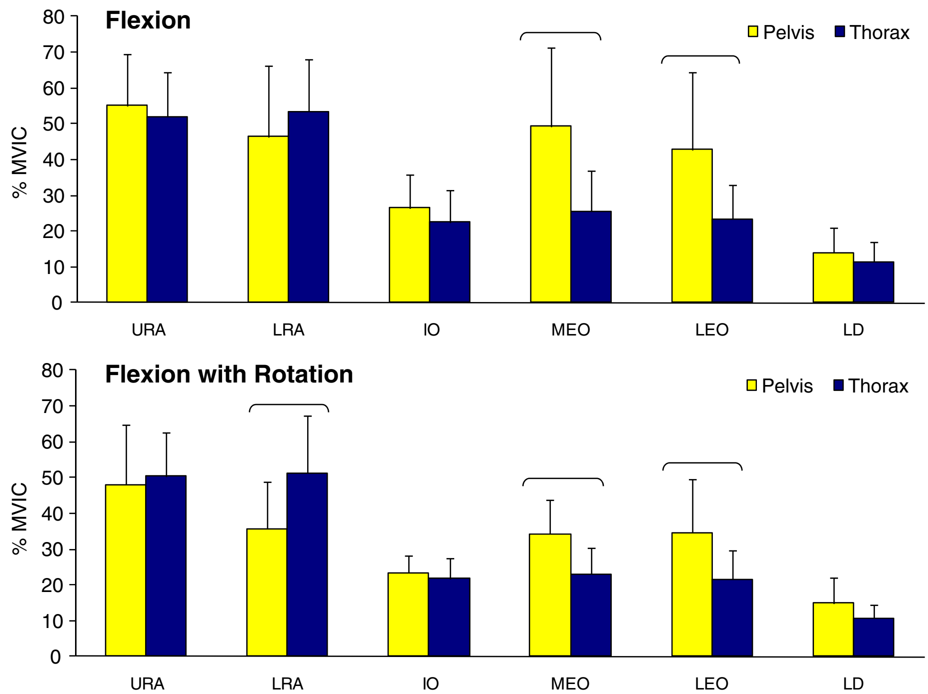


Fig. 7. Mean normalized EMG amplitudes for pelvis and thorax flexion and flexion with rotation in supine. Bracket above the bars indicates statistical differences between pelvis and thorax conditions ($p < 0.05$).

when the pelvis was driven in the rotation ($p = 0.032$), M–L translation ($p < 0.001$) and circle conditions ($p = 0.007$), and LEO in the M–L translation ($p = 0.006$) and circle ($p = 0.015$) conditions. Conversely, mean LD activation levels were significantly higher when driving thorax motion in the rotation ($p = 0.043$) and A–P translation ($p = 0.011$) conditions. Statistical differences between thorax and pelvis movements were not observed for URA and LRA.

Analysis of peak activation levels between thorax and pelvis motion demonstrated similar results. IO amplitude was higher in all planar movements when the pelvis was moved relative to the thorax ($p < 0.001$). EO showed a similar trend as the mean analysis, but only achieved significance during M–L translation ($p < 0.050$) and circles ($p < 0.008$). LD peak amplitude was again significantly higher when the thorax moved on a stationary pelvis for rotation ($p = 0.001$) and A–P translation ($p < 0.001$).

3.3. Muscle activation patterns in supine (curl-up exercises)

Mean and peak normalized EMG amplitudes of oblique muscles were higher for pelvis motions than for thorax motions, although the differences did not reach statistical significance for IO (Fig. 7). Conversely, EMG amplitudes of LRA were higher for thorax motions than for pelvis motions, with statistical significance during the crossed reverse curl-up ($p < 0.003$). URA and LD showed no statistical differences between thorax and pelvis.

Interestingly, while mean and peak levels of RA and EO activation were higher than those of IO during curl-ups in supine, the reverse was observed during trunk motions in upright standing (Figs. 6 and 7).

4. Discussion

Traditionally, electromyographic analyses of trunk motion in upright standing have analyzed movements constrained to the upper trunk (Juker et al., 1998; Larivière et al., 2000; Thorstensson et al., 1985). In this study, the differences in trunk muscular recruitment and kinematics between pelvis and thorax movements have been analyzed utilizing a specialized group of dancers with advanced ability to isolate thorax from pelvis motion. The major findings were that the muscular activation levels and the amplitude of the lumbar spine displacement varied, depending on whether the motion was being “driven” from the thorax or from the pelvis.

Clinicians have generally thought of the oblique muscles as moving the thorax on a relatively immobile pelvis in upright activities, inferring that the pelvis is already stabilized on the lower extremities via the pelvic girdle muscles. This would offer the obliques a relatively stationary origin on the pelvic rim, resulting in motion of the thorax when they contract. Indeed, this may be the case with thorax planar movements in our study. However, our results indicate that greater oblique activation occurs when the thorax is immobile in upright standing, and pelvis motion is allowed to occur. The differences shown in Fig. 6 were consistently higher for the IO (the muscle attaining the highest EMG amplitudes). Previous studies demonstrated the important activation of IO in standing which may be due to its role as an antigravity muscle holding the abdominal viscera (Floyd and Silver, 1950; Ono, 1958; Sánchez-Zuriaga et al., 2009). However, to the best of our knowledge, the differences in IO and EO activation between pelvis and thorax motions in standing have not been reported. On the basis of our findings, rehabilitation programs aimed at training the abdominal wall would do well to include movements driven by the pelvis in their protocol for activities in upright standing, given the higher activation levels of the oblique muscles during pelvis motion. Or, the corollary is that some patients need to control pelvic motion to control pain, suggesting training the same mechanism to limit motion.

Expanding this patient issue, when observing back pain patient behavior during training tasks to teach lumbar control, patients often initiate twisting motion with the pelvis resulting in pain (McGill, 2007). This pattern would be common when pulling open a heavy door, for example. Giving the patient the cue to stiffen the abdominal wall while controlling the twist with latissimus dorsi may assist in controlling both the twist and the pain. This clinical observation appears to have merit when noting the significant difference in LD activity while movement constraints change from the pelvis to the thorax. Previous literature has outlined the role of LD as a prime mover/stabilizer for shoulder adduction/internal rotation (Button et al., 2010; Irlenbusch et al., 2008), but its role in controlling the trunk movement/stability in rehabilitation and fitness has generally been ignored. Our results indicate a significant increase in LD activity during thorax A–P translation and twisting, compared to the same motions occurring at the pelvis, and LD mean and peak activation levels similar to MEO and LEO. Observing its importance in controlling upper trunk motions, activities targeting LD should be considered in a core training program.

Although some kinematic differences in lumbar range of motion were observed between pelvis and thorax movements (Table 1), these differences do not seem to explain the results obtained for the level of muscle activation (Fig. 6). While IO activation was consistently higher during pelvis movements in all standing conditions, the concurrent lumbar range of motion was higher during only two conditions: M–L translation and horizontal circles. Moreover, the lumbar range of twisting was higher in thorax movements compared to pelvis movements during trunk rotation. Thus, there seems to be no obvious relation between the differences in lumbar range of motion and associated changes in muscular activation when comparing pelvis and thorax motions. Future studies should explore the source of these differences in trunk muscular activation patterns between thorax or pelvis motion.

Lumbar kinematic differences between pelvis and thorax motions are difficult to explore in standing due to constraints of the multi-joint complexity of the movements: lateral shift of the pelvis, for example, will also be limited by the ability of the hip joints to accommodate this lateral motion, whereas trunk motion will be anatomically limited by available spine motion. In addition, postural stability challenges will differ when pelvis motion is compared to movement of the entire upper torso, possibly requiring alteration in muscular control.

Curl-up exercises also resulted in significant changes in EO and LRA activation levels when comparing lower trunk to upper trunk flexions. Both portions of the EO showed a consistently higher activation level when the pelvis was flexed, compared to thorax flexion (Fig. 7). In most conditions tested, whether supine or upright, there was an obvious increase in activation level (and thus force production) in the medial and lateral portions of EO when the pelvis was flexed, as compared to the reverse direction. IO followed the same trend with slightly higher activation during pelvic flexion, but showed no significant differences when the directionality of flexion changed. Interestingly, while greater activation levels of the abdominal wall muscles would be expected given the higher torque production during curl-up activities, IO activation levels changed very little between upright standing and supine curl-up conditions, indicating a tonic function of this muscle. Instead, the URA and LRA, in conjunction with the MEO and LEO, became the prime movers/stabilizers for trunk flexion against gravity, resulting in higher levels of muscular activation in supine. The flexion enhancing mechanism of the EO appears to take advantage of EO directing its force to the rectus via the linea semilunaris and redirecting the EO force more anteriorly down the rectus abdominis sheath (McGill, 1996).

The results of the trunk exercises confirm those of previous studies describing greater EO activation in lower trunk exercises compared to conventional curl-up exercises (Escamilla et al., 2006; Konrad et al., 2001; Willett et al., 2001). However, there is no consistency in the results of our or previous research on the activation of different portions of RA while performing upper trunk or lower trunk exercises. Thus, while our data support the results obtained by Clark et al. (2003) and Escamilla et al. (2006) on higher LRA activation in upper trunk exercises compared to lower trunk exercises, the opposite was observed by Sarti et al. (1996) and Willett et al. (2001), and no differences were found by Piering et al. (1993). As suggested by Monfort-Pañego et al. (2009), the reason for these differences may be the diversity of electromyographic methodologies used and differences in participants' skills and physical activity level.

Although this unique group of dancers provided advanced motor control strategies, there were some limitations to this data collection. Two of the most experienced dancers had BMI's above those which would be considered ideal for collecting an EMG signal that truly represents underlying muscle activity (30.5 and 35.8 kg/m^2). Especially during the curl-up activities, trunk flexion resulted in ‘‘buckling'' of the abdominal wall tissue, thus signal distortion may have occurred, due to signal attenuation by adipose tissue (Kuiken et al., 2003). In addition, the planar movements analyzed in this study do not represent normal physiological movement for most people, as most trunk motions are multi-planar in their direction. However, studying unique motor control strategies as demonstrated by these women allow us to identify motor patterns that are possible when extraneous movements are removed, and help develop an understanding of the different roles of the abdominal wall muscles. Finally, the possibility of electromyographic cross-talk affecting our EMG signals cannot be excluded, especially in the oblique muscles, which lie atop each other in the anterior abdomen. However, as was presented in the methodology section, every precaution was taken to ensure clear representation of each individual muscle based on recommended electrode sites (McGill et al., 1996) and ultra-sonography.

In conclusion, this study demonstrates that muscle activation patterns differ when trunk motion is ‘‘driven'' by the pelvis, compared to the thorax. Specifically, pelvis motions produced higher levels of activation of the oblique abdominal muscles for most trials and also produced larger lumbar displacements during horizontal circles and M–L translations. Conversely, activation levels of LD during rotations and A–P translations, and for LRA during the crossed curl-ups were higher during thorax movements, indicating that the switch from thorax to pelvis motion did not cause a universal increase or decrease in all muscle activity. Recognizing this in patients can direct the rehabilitation technique to possibly accomplish function with a pain-free strategy. Finally, rotational lumbar displacement was larger during thorax rotations when compared to pelvis motions. Overall, the results of this study provide insight into the neuromuscular control of voluntary trunk motions and may assist in prescribing trunk rehabilitation and training programs. ‘‘Driving'' lumbar spine motion by the pelvis results in different angular displacements of the spine compared to thorax movements, and requires alternative recruitment strategies of the trunk musculature.

Acknowledgments

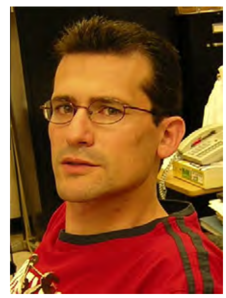
This study was made possible by financial support of the Natural Sciences and Engineering Research Council of Canada. The authors wish to thank the participants who offered their time to take part in this research.

References

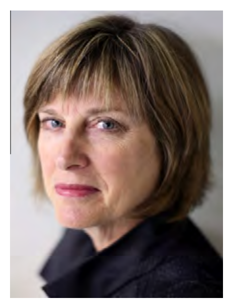
Brereton LC, McGill SM. Frequency response of spine extensors during rapid isometric contractions: effects of muscle length and tension. J Electromyogr Kinesiol 1998;8(4):227–32.

Butler HL, Hubley-Kozey CL, Kozey JW. Activation amplitude patterns do not change for back muscles but are altered for abdominal muscles between dominant and

non-dominant hands during one-handed lifts. Eur J Appl Physiol 2009;106(1):95–104.
Button J, Scott J, Taghizadeh R, Weiler-Mithoff E, Hart AM. Shoulder function following autologous latissimus dorsi breast reconstruction. A prospective three year observational study comparing quilting and non-quilting donor site techniques. J Plast Reconstr Aesthetic Surg 2010;63(9):1505–12.
Clark KM, Holt LE, Sinyard J. Electromyographic comparison of the upper and lower rectus abdominis during abdominal exercises. J Strength Cond Res 2003;17(3):475–83.
Drake JD, Callaghan JD. Elimination of electrocardiogram contamination from electromyogram signals: an evaluation of currently used removal techniques. J Electromyogr Kinesiol 2006;16(2):175–87.
Escamilla RF, Babb E, DeWitt R, Jew P, Kelleher P, Burnham T, et al. Electromyographic analysis of traditional and nontraditional abdominal exercises: implications for rehabilitation and training. Phys Ther 2006;86(5):656–71.
Floyd WF, Silver PHS. Electromyographic study of patterns of activity of the anterior abdominal wall muscles in man. J Anat 1950;84:132–45.
Hodges PW, Gurfinkel VS, Brumagne S, Smith TC, Cordo PC. Coexistence of stability and mobility in postural control: evidence from postural compensation for respiration. Exp Brain Res 2002;144(3):293–302.
Irlenbusch U, Bernsdorf M, Born S, Gansen HK, Lorenz U. Electromyographic analysis of muscle function after latissimus dorsi tendon transfer. J Shoulder Elbow Surg 2008;17(3):492–9.
Juker D, McGill S, Kropf P, Steffen T. Quantitative intramuscular myoelectric activity of lumbar portions of psoas and the abdominal wall during a wide variety of tasks. Med Sci Sports Exerc 1998;30(2):301–10.
Konrad P, Schmitz K, Denner A. Neuromuscular evaluation of trunk-training exercises. J Athl Training 2001;36(2):109–18.
Kuiken TA, Lowery MM, Stoykov NS. The effect of subcutaneous fat on myoelectric signal amplitude and cross-talk. Prosthet Orthot Int 2003;27:46–54.
Larivière C, Gagnon D, Loisel P. The comparison of trunk muscles EMG activation between subjects with and without chronic low back pain during flexion–extension and lateral bending tasks. J Electromyogr Kinesiol 2000;10(2):79–91.
Lehman GJ, McGill SM. Quantification of the differences in electromyographic activity magnitude between the upper and lower portions of the rectus abdominis muscle during selected trunk exercises. Phys Ther 2001;81(5):1096–101.
McGill SM. Electromyographic activity of the abdominal and low back musculature during the generation of isometric and dynamic axial trunk torque: implications for lumbar mechanics. J Orthop Res 1991;9:91–103.
McGill SM. A revised anatomical model of the abdominal musculature for torso flexion efforts. J Biomech 1996;29(7):973–7.
McGill SM. Low Back Disorders: Evidence Based Prevention and Rehabilitation. 2nd ed. Champaign, IL, USA: Human Kinetics Publishers; 2007.
McGill SM, Grenier S, Kavcic N, Cholewicki J. Coordination of muscle activity to assure stability of the lumbar spine. J Electromyogr Kinesiol 2003;13(4):353–9.
McGill S, Juker D, Kropf P. Appropriately placed surface EMG electrodes reflect deep muscle activity (psoas, quadratus lumborum, abdominal wall) in the lumbar spine. J Biomech 1996;29(11):1503–7.
Monfort-Pañego M, Vera-García FJ, Sánchez-Zuriaga D, Sarti-Martínez MA. Electromyographic studies in abdominal exercises: a literature synthesis. J Manipulative Physiol Ther 2009;32(3):232–44.
Moreside JM, Vera-Garcia FJ, McGill SM. Neuromuscular independence of abdominal wall muscles as demonstrated by middle-eastern style dancers. J Electromyogr Kinesiol 2008;18(4):527–37.
Ng JK, Kippers V, Parnianpour M, Richardson CA. EMG activity normalization for trunk muscles in subjects with and without back pain. Med Sci Sports Exerc 2002;34:1082–6.
Oddsson LI. Control of voluntary trunk movements in man. Mechanisms for postural equilibrium during standing. Acta Physiol Scand Suppl 1990;595:1–60.
Ono K. Electromyographic studies of the abdominal wall muscles in visceroptosis. Tohoku J Exp Med 1958;68(3–4):347–54.
Piering AW, Janowski AP, Moore MT, Snyder AC, Wehrenberg WB. Electromyographic analysis of four popular abdominal exercises. J Athl Training 1993;28(2):120–6.
Potvin JR, Brown SHM. Less is more: high pass filtering, to remove up to 99% of the surface EMG signal power, improved EMG-based biceps brachii muscle force estimates. J Electromyogr Kinesiol 2004;14:389–99.
Preuss R, Fung J. Musculature and biomechanics of the trunk in the maintenance of upright posture. J Electromyogr Kinesiol 2008;18(5):815–28.
Sánchez-Zuriaga D, Vera-Garcia FJ, Moreside JM, McGill SM. Trunk muscle activation patterns and spine kinematics when using an oscillating blade: influence of different postures and blade orientations. Arch Phys Med Rehabil 2009;90(6):1055–60.
Sarti MA, Monfort M, Fuster MA, Villaplana LA. Muscle activity in upper and lower rectus abdominus during abdominal exercises. Arch Phys Med Rehabil 1996;77(12):1293–7.
Thorstensson A, Oddsson L, Carlson H. Motor control of voluntary trunk movements in standing. Acta Physiol Scand 1985;125(2):309–21.
Vera-Garcia FJ, Flores-Parodi B, Elvira JL, Sarti MA. Influence of trunk curl-up speed on muscular recruitment. J Strength Cond Res 2008;22(3):684–90.
Vera-Garcia FJ, Moreside JM, McGill SM. MVC techniques to normalize trunk muscle EMG in healthy women. J Electromyogr Kinesiol 2010;20(1):10–6.
Willett GM, Hyde JE, Uhrlaub MB, Wendel CL, Karst GM. Relative activity of abdominal muscle during prescribed strengthening exercises. J Strength Cond Res 2001;15(4):480–5.



Francisco J. Vera-Garcia graduated (Hons) in Physical Education from University of Valencia (Spain) in 1996. He received his Ph.D. in Physical Activity and Sport Sciences from University of Valencia (Spain) in 2002. From 2004–2005 he was a post-doctoral fellow at the Spine Biomechanics Laboratory, Department of Kinesiology, University of Waterloo, Ontario, Canada. Currently, he is a Professor of Biomechanical Bases of Physical Activity at University Miguel Hernández of Elche, Alicante (Spain), and is a member of the Spanish Association of Sport Sciences. His research interests include spine function and stability, trunk muscular conditioning, and spine injury prevention.



Janice Moreside received her physiotherapy degree from the University of British Columbia (Vancouver), and has maintained a clinical practice for over 30 years. She has since obtained her Masters of Human Kinetics at the University of Windsor (2003), and a Ph.D. in Spine Biomechanics at the University of Waterloo (2010), studying with Dr. Stuart McGill. The main focus of her research has been the interaction of hip mobility with the lumbar spine.

Stuart McGill is a Professor of Spine Biomechanics at the University of Waterloo. He coordinates research on spine issues and sees challenging patients at the University.