Journal of Electromyography and Kinesiology 20 (2010) 10–16

Contents lists available at ScienceDirect

Journal of Electromyography and Kinesiology

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

MVC techniques to normalize trunk muscle EMG in healthy women

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

[a] Area of Physical Education and Sport, Department of Health Psychology, 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, 200 University Ave W., Waterloo, ON, N2L 3G1, Canada

ARTICLE INFO

Article history:
Received 12 December 2008
Received in revised form 2 March 2009
Accepted 23 March 2009

Keywords:
Electromyography
Normalization
Trunk muscles
Maximal isometric contractions

ABSTRACT

Normalization of the surface electromyogram (EMG) addresses some of the inherent inter-subject and inter-muscular variability of this signal to enable comparison between muscles and people. The aim of this study was to evaluate the effectiveness of several maximal voluntary isometric contraction (MVC) strategies, and identify maximum electromyographic reference values used for normalizing trunk muscle activity. Eight healthy women performed 11 MVC techniques, including trials in which thorax motion was resisted, trials in which pelvis motion was resisted, shoulder rotation and adduction, and un-resisted MVC maneuvers (maximal abdominal hollowing and maximal abdominal bracing). EMG signals were bilaterally collected from upper and lower rectus abdominis, lateral and medial aspects of external oblique, internal oblique, latissimus dorsi, and erector spinae at T9 and L5. A 0.5 s moving average window was used to calculate the maximum EMG amplitude of each muscle for each MVC technique. A great inter-subject variability between participants was observed as to which MVC strategy elicited the greatest muscular activity, especially for the oblique abdominals and latissimus dorsi. Since no single test was superior for obtaining maximum electrical activity, it appears that several upper and lower trunk MVC techniques should be performed for EMG normalization in healthy women.

1. Introduction

Surface electromyography (EMG) is a non-invasive technique that allows the evaluation of trunk muscular function in healthy and injured individuals. However, the EMG is a variable signal that depends on many recording factors, such as subcutaneous fat thickness, skin impedance and temperature, electrode size and placement, cross talk from adjacent muscles, and electromagnetic interference from nearby sources. This inherent variability affects the interpretation of the surface EMG (De Luca, 1997). Normalization of the signal accounts for some of the inter-subject and inter-muscular EMG variability, facilitating comparison between subjects, different muscles, or varying electrodes sites on the same muscle on different days (Lehman and McGill, 1999). Normalization is a procedure where the absolute EMG values (millivolts) are expressed as a percentage of a reference EMG value obtained during a calibration maximal or submaximal contraction test. The most widely used reference value is the maximal myoelectric activity, elicited by maximum voluntary isometric contractions (MVC's). EMG data expressed relative to the maximum (% MVC) have the advantage of having a physiological relevance; however, submaximal reference values are frequently used when MVC's are limited by aging, pain or other symptoms (e.g. Allison et al., 1998; Dankaerts et al., 2004; Marras and Davis, 2001). The issue addressed in this paper is the difficulty in finding the best exertion tasks to obtain the maximal amount of EMG amplitude. A group of women were recruited who had excellent control of torso muscles but seldom performed strength level exertions, namely dancers who practiced middle-eastern style belly dance.

Given the anatomical and functional differences between trunk muscles (McGill, 2002; Urquhart et al., 2005), MVC techniques in the three cardinal planes are performed to ensure that maximal activations are achieved (Allison et al., 1998; McGill, 1991; Ng et al., 2002). Generally, trunk flexion MVC tests are used for normalizing different portions of rectus abdominis, trunk bending and axial rotations for normalizing the oblique abdominals, and trunk extensions for lumbar and thoracic levels of erector spinae. Typically during these maximal isometric exertions, the thorax motion is resisted either through inextensible straps, padded bars and jigs, or by manual resistance applied by experimenters (for example: Dankaerts et al., 2004; Marras and Davis, 2001; McGill, 1991; Ng et al., 2002; Vezina and Hubley-Kozey, 2000). However, little effort has been devoted to asses and standardize MVC positions and strategies where pelvis motion is resisted (as opposed to resistance applied to the rib cage or upper torso). Previous work that our group has conducted (Moreside et al., 2008), in which motion was constrained to the upper or the lower trunk, provided the impression that the oblique abdominal muscles were activated at higher intensity levels when pelvis motion was performed as opposed to thorax motion.

This study was carried out to evaluate the effectiveness of a number of MVC techniques for normalization purposes, and

* Corresponding author.
E-mail address: mcgill@healthy.uwaterloo.ca (S.M. McGill).

1050-6411/$ - see front matter © 2009 Elsevier Ltd. All rights reserved.
doi:10.1016/j.jelekin.2009.03.010

included trials in which thorax motion was resisted (upper trunk MVC techniques) as well as trials in which pelvis motion was resisted (lower trunk MVC techniques). Specifically, muscular responses of several trunk muscles were recorded and analyzed in order to identify a maximum electromyographic reference point for each muscle, consistent across exertions and across subjects. It was hypothesized that the lower trunk MVC techniques may be more appropriate to obtain maximal levels of activation for some trunk muscles. Maximal abdominal co-activation maneuvers (maximal effort abdominal bracing and maximal effort abdominal hollowing), similar to what a body builder would do during posing, were also performed to evaluate the effect of un-resisted MVC techniques on muscular recruitment. A side benefit to this investigation of MVC techniques was that a better understanding of the different roles of the trunk muscles was obtained.

2. Methods

2.1. Participants

Eight healthy women volunteered to participate in this study. The mean age, body mass and height were 26.0 ± 5.8 years, 74.6 ± 17.0 kg and 167.0 ± 7.0 cm. All subjects were physically active, and in fact were practicing middle-eastern style belly dance (experience: 3.9 ± 3.3 year of practice). Dancers who demonstrated advanced trunk control and body awareness (Moreside et al., 2008) were recruited from the local dance troupes, with the assistance of local dance instructors. Each woman signed a written informed consent form approved by the Office for Research Ethics of the University of Waterloo. Subjects with known medical problems, histories of spinal or abdominal surgery, or episodes of back pain requiring treatment before this study were excluded.

2.2. Maximal voluntary isometric contractions

Eleven MVC techniques were carried out in different positions (Figs. 1 and 2), each lasting 3–4 s. An experimenter provided a matching resistance to the participants during the maximal exertions for restraining the subject's movement. In addition to the conventional trunk muscle MVC protocols in which thorax motion is resisted, a "reversed origin-insertion" attitude was also tested wherein the participants were asked to attempt to move the pelvis against resistance, as opposed to moving the thorax. The MVC techniques included: (1) *upper trunk flexion*: subject was in a sit-up posture positioned on a bench with the legs bent and feet strapped down with a belt. She then attempted to flex the upper trunk in the sagittal plane while her thorax was manually braced by the experimenter; (2) *upper trunk twisting right, and left*: in the same sitting supported position, the subject attempted to twist the upper trunk in the horizontal plane while her thorax was manually braced by the experimenter; (3) *lower trunk flexion*: subject attempted to flex the lower trunk in the sagittal plane while she was in a supine lying position, but with knees and hips both bent to approximately 90°. Her thorax was strapped down with a belt and her legs were manually braced by the experimenter; (4) *lower trunk twisting right, and left*: in the same lying and supported position, the subject attempted to twist the lower trunk in the horizontal plane while her legs were manually braced by the experimenter; (5) *upper trunk bending right, and left*: subject attempted to side bend the upper trunk in the frontal plane while she was in a side lying position, with the knees bent and strapped with a belt, and thorax and arms were manually braced by the experimenter; (6) *lower trunk bending*: subject maintained a right and left side bridge position (Axler and McGill, 1997; Juker et al., 1998; Kavcic et al., 2004) while maximally resisted downward pressure on the pelvis was applied by the experimenter; (7) *upper trunk extension*: subject was strapped in a prone position, with the torso horizontally cantilevered over the end of the bench (Biering-Sorensen position). She then attempted to extend the upper trunk in the sagittal plane and retract the shoulders (squeezing the scapulae together) while manual resistance was applied on the shoulders by the experimenter; (8) *lower trunk extension*: subject attempted to extend the lower trunk and the hips against manual resistance when in a prone position, with the torso on the bench and the legs horizontally cantilevered over the end of the bench; (9) *right and left shoulder rotation and adduction*: subject attempted to adduct and internally rotate the shoulder against manual resistance with the shoulder abducted and elbow flexed, both to 90°. In addition, two un-resisted maximal abdominal contraction were performed in standing; (10) *maximal effort abdominal hollowing*: subject attempted to maximally activate the deep abdominal muscles while drawing in the lower abdomen (Allison et al., 1998; O'Sullivan et al., 1998; Vera-Garcia et al., 2007); (11) *maximal effort abdominal bracing*: subject attempted to maximally activate all the abdominal wall without any change in the position of the muscles (Allison et al., 1998; Kavcic et al., 2004; Vera-Garcia et al., 2006, 2007). In order to assist these maximal maneuvers the subject tried to forcibly exhale against a closed glottis.

Before data collection, MVC techniques were taught to each subject by the experimenters, and sufficient practice was allowed to achieve a proper performance. The different MVC techniques were carried out in random order while two experimenters visually verified the correct performance of the maximal exertions. In order to ensure an isometric contraction, those trials which demonstrated active trunk motion were repeated. To avoid muscular fatigue, a 2 min rest was allowed between MVC trials. Participants were verbally encouraged during the maximal isometric efforts.

2.3. Electromyography recording

Surface EMG signals were bilaterally collected on each subject (AMT-8, Bortec Biomedical, Calgary, Canada, with a CMRR of 115 dB at 60 Hz, and input impedance of 10 GΩ). The following trunk muscles and locations were used: *upper rectus abdominis*, in the approximate centre of the second uppermost section of the muscle belly; *lower rectus abdominis*, in the approximate centre of the lowermost section of the muscle belly; *lateral aspect of external oblique*, 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 external oblique*, approximately 15 cm lateral to the umbilicus; *internal oblique*, halfway between the anterior superior iliac spine of the pelvis and the midline, just superior to the inguinal ligament; *latissimus dorsi*, lateral to T9 over the muscle belly; and *erector spinae at T9 and L5* (thoracic and lumbar erector spinae, respectively), located 5 and 1 cm lateral to each spinous process. Previous literature has shown these locations to adequately represent the abdominal wall musculature, while minimizing the effect of cross-talk (McGill et al., 1996). In addition, ultra-sonography was utilized to confirm the appropriate placement of the electrodes for the abdominal muscles (SonoSite Titan®, Bothell, USA). The precise electrode positions were drawn on the skin using a surface marker. Pregelled disposable bipolar Ag–AgCl disc surface electrodes (Blue Sensor, Ambu A/S, Denmark) were positioned parallel to the muscle fibers with an inter-electrode distance of 3 cm. The EMG signals were amplified to produce approximately ±2.5 V, and then A/D converted (12 bit resolution) at 1024 Hz.

2.4. Data reduction

Each trial was visually inspected and EMG signals marred with artifacts (such as the skin surface pressing against the testing ta-

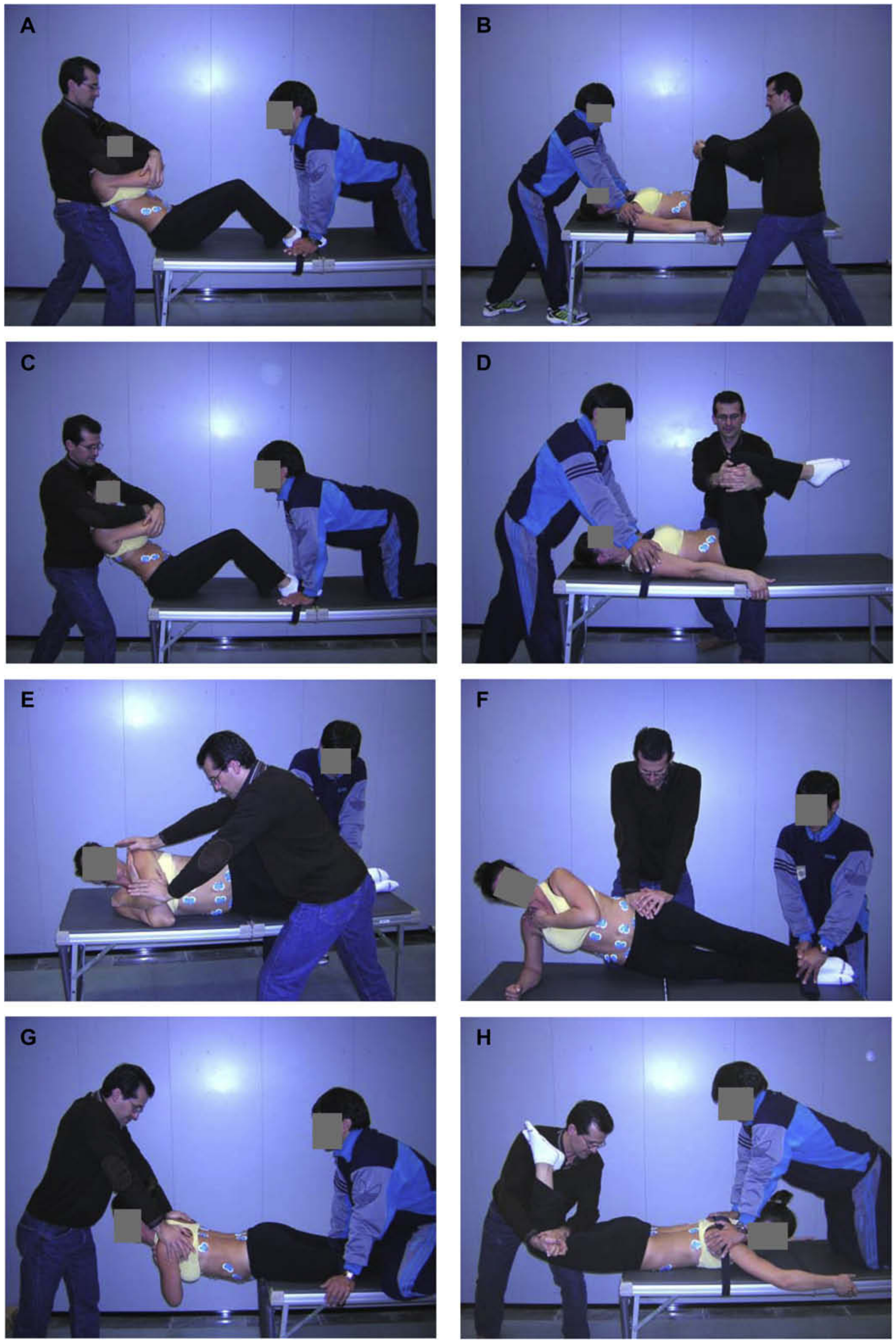

Fig. 1. Pictures of upper trunk (left column) and lower trunk (right column) MVC techniques: (A) upper trunk flexion; (B) lower trunk flexion; (C) upper trunk twisting; (D) lower trunk twisting; (E) upper trunk bending; (F) lower trunk bending; (G) upper trunk extension; and (H) lower trunk extension.

ble) and other technical problems were excluded from further analyses. As a result, 4.97% of the EMG channels were eliminated. Clean signals were then high pass filtered (100 Hz) to remove heart rate artifact (Drake and Callaghan, 2006; Potvin and Brown, 2004), full wave rectified, and low pass filtered (low pass Butterworth filter) with a cutoff frequency of 2.5 Hz. A 0.5 s moving average window was used to calculate the maximum EMG amplitude of each muscle across MVC techniques. Maximal EMG values were then used to normalize EMG signals obtained during each MVC maneuver.

2.5. Statistical analyses

Muscle symmetry was tested in the following way: since each MVC technique was an independent test, for each muscle and trial, the normalized EMG amplitude of the right and left sides were

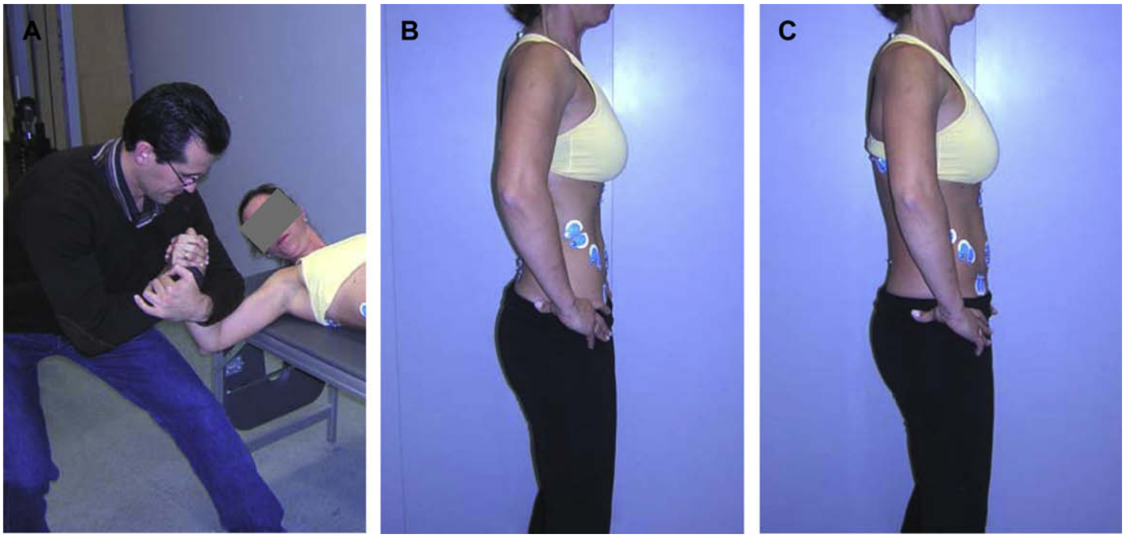

Fig. 2. Pictures of different resisted and un-resisted MVC techniques: (A) shoulder internal rotation and adduction; (B) maximal effort abdominal hollowing; and (C) maximal effort abdominal bracing.

compared using paired t-tests. A significance level of $p < 0.05$ with a Bonferroni correction factor was used, resulting in a level of significance of $p < 0.006$ (calculated by dividing 0.05 by the number of t-tests in each MVC technique). Since the only differences found between sides were for the lateral aspect of external oblique (lower trunk flexion: $p = 0.002$; upper trunk extension: $p = 0.006$), EMG amplitude of right and left sides were averaged in order to reduce the number of muscles. As a result, a total of 8 muscle groups were used for statistical analyses: upper rectus abdominis (URA), lower rectus abdominis (LRA), lateral aspect of external oblique (LEO), medial aspect of external oblique (MEO), internal oblique (IO), latissimus dorsi (LD), thoracic erector spinae (T9ES), and lumbar erector spinae (L5ES).

Differences in the methods to obtain an MVC were tested in the following way: One-way repeated measures analysis of variance was conducted to compare normalized EMG amplitudes from each of the 8 trunk muscles between MVC techniques. Where applicable, post-hoc analyses were performed using the Tukey HSD test to identify which method was preferred. An alpha level of 0.05 was considered significant for these analyses.

3. Results

No single MVC technique generated the highest activity level of any one muscle across all subjects. In fact, although lower trunk bending and maximal effort abdominal hollowing were the most effective technique for maximum activation of IO in a few participants (37.50% and 25% of participants, respectively), maximal electrical activities for IO were also found in 4 other MVC tests (Table 1). Table 1 presents the percentage of participants who reached their highest activity level in each MVC technique. Normalized EMG amplitudes, averaged across subjects, are presented in Table 2.

Moreover, when the normalized EMG amplitudes of IO were compared between MVC techniques, lower trunk bending and maximal effort abdominal hollowing were not significantly different from upper trunk bending, upper and lower trunk twisting, upper trunk flexion, and abdominal bracing ($p > 0.05$).

Maximal electrical activities for EO were primarily observed in trunk bending activities, followed by upper trunk twisting. Normalized EMG amplitudes found during the upper trunk bending were statistically higher than those observed during upper and lower trunk flexion and lower trunk twisting ($p < 0.05$).

For LD, maximal electrical activity was also found in several of the MVC techniques, but principally in upper trunk bending (Table 1). Normalized EMG amplitudes of upper trunk bending, upper and lower trunk twisting, upper trunk extension, and shoulder rotation and adduction were significantly higher than lower trunk bending, lower trunk extension, upper and lower trunk flexion, and maximal effort abdominal bracing and hollowing ($p < 0.05$).

As expected, rectus abdominis and erector spinae were maximally activated when sagittal torques were performed. Interestingly, although statistical differences in normalized EMG amplitudes were not found between upper and lower trunk flexion techniques ($p > 0.05$), the highest activity levels of URA were largely found during lower trunk flexions (45.54% of participants), and the maximal electrical activities of LRA were mostly reported during upper trunk flexions (68.75% of participants). For T9ES and L5ES the highest activity levels were found in upper and lower trunk extensions, respectively (Table 1). Nevertheless, significant differences in normalized amplitudes were neither observed between upper and lower trunk extensions ($p > 0.05$).

As shown in Table 2, large amounts of trunk muscle co-activation were observed in all resisted MVC tests; in fact, the normalized EMG amplitude rarely dropped below 20% MVC in any muscle. For example, during upper and lower trunk extensions, rectus abdominis, external oblique and internal oblique reached levels of 19.41–34.42% MVC, 26.72–61.06% MVC and 30.18–39.23% MVC, respectively.

4. Discussion

In this group of women, who presumably were skilled in recruitment and control of their torso muscles, but not necessarily used to strength exertions, the hypothesis that a resisted pelvis together with a variety of resistances are needed to find the maximum EMG amplitude is accepted. We observed that while these dancers had very good control of the torso muscles, they were generally not strong; several had difficulty in performing a competent sit-up. To our knowledge, a set of MVC techniques where pelvis motion is resisted has not been previously reported. The major finding was that there was great variability between participants as to which MVC technique elicited the greatest EMG activity. This was especially true for muscles with fibers oriented in oblique directions relative to the spine: IO, MEO, LEO and LD. As a result,

Table 1
Percentage of participants where each MVC technique (rows) resulted in the maximum electrical activity for each muscle portion (columns). For each muscle, the highest percentage of participants found in the MVC techniques is presented in bold. Muscular nomenclature: URA, upper rectus abdominis; LRA, lower rectus abdominis; LEO, lateral aspect of external oblique; MEO, medial aspect of external oblique; IO, internal oblique; LD, latissimus dorsi; T9ES, erector spinae at T9; and L5ES, erector spinae at L5.

MVC technique	Trunk muscle							
	URA	LRA	IO	MEO	LEO	LD	T9ES	L5ES
Upper trunk flexion	26.79	**68.75**	6.25	6.25	–	–	–	–
Lower trunk flexion	**45.54**	18.75	–	–	18.75	–	–	–
Upper trunk twisting	–	6.25	6.25	6.25	25	25	–	–
Lower trunk twisting	–	6.25	12.50	–	–	18.75	–	–
Upper trunk bending	–	–	12.50	**61.61**	**31.25**	**43.75**	–	–
Lower trunk bending	27.68	–	**37.50**	25.89	25	–	–	–
Upper trunk extension	–	–	–	–	–	–	**70.83**	23.81
Lower trunk extension	–	–	–	–	–	–	14.58	**76.19**
Shoulder rotation and adduction	–	–	–	–	–	12.50	14.58	–
Abdominal hollowing	–	–	25	–	–	–	–	–
Abdominal bracing	–	–	–	–	–	–	–	–

Table 2
Averages and standard deviations (±SD) of the normalized EMG amplitudes for the MVC techniques. Notice the large amount of trunk muscle co-activation recorded in most of the MVC maneuvers. Nomenclature: R, right; L, left; URA, upper rectus abdominis; LRA, lower rectus abdominis; LEO, lateral aspect of external oblique; MEO, medial aspect of external oblique; IO, internal oblique; LD, latissimus dorsi; T9ES, erector spinae at T9; and L5ES, erector spinae at L5.

		Flexion		Twist		Bend		Extension		Shoulder Rot.-Add.	Hollow	Brace
		Upper	Lower	Upper	Lower	Upper	Lower	Upper	Lower			
R-URA	Mean	78.20	89.56	67.05	70.58	55.19	86.03	24.45	21.75	44.10	17.23	24.91
	(SD)	(22.2)	(18.2)	(19.2)	(16.6)	(12.8)	(16.3)	(12.7)	(11.2)	(15.9)	(9.8)	(9.5)
R-LRA	Mean	95.96	78.76	76.35	59.87	65.98	67.28	29.28	34.42	41.60	22.65	23.81
	(SD)	(7.7)	(18.4)	(10.4)	(20.2)	(18.2)	(15.9)	(16.8)	(12.9)	(19.0)	(7.8)	(3.2)
R-IO	Mean	62.10	41.67	68.27	56.16	57.83	77.08	39.07	30.18	51.46	83.66	64.55
	(SD)	(21.5)	(19.0)	(19.3)	(21.9)	(26.9)	(25.6)	(21.3)	(12.7)	(19.8)	(19.3)	(21.6)
R-MEO	Mean	62.82	69.83	73.80	63.32	79.17	90.15	35.84	31.60	47.91	39.39	34.27
	(SD)	(20.3)	(20.9)	(16.8)	(21.0)	(23.4)	(17.2)	(13.5)	(11.5)	(13.2)	(15.8)	(11.0)
R-LEO	Mean	66.49	79.34	82.71	71.74	90.22	89.20	61.06	40.96	58.71	38.62	33.25
	(SD)	(15.5)	(17.9)	(13.1)	(16.1)	(11.3)	(12.3)	(16.9)	(9.6)	(13.8)	(15.1)	(8.6)
R-LD	Mean	42.63	34.21	76.36	83.70	83.77	37.97	78.59	42.94	72.66	27.87	31.76
	(SD)	(12.1)	(20.2)	(20.8)	(18.1)	(25.4)	(13.4)	(26.2)	(15.0)	(23.0)	(21.6)	(19.6)
R-T9ES	Mean	27.49	34.61	54.65	61.68	54.72	34.70	93.44	79.42	65.23	22.07	27.49
	(SD)	(8.4)	(12.2)	(14.7)	(18.4)	(13.3)	(14.9)	(12.5)	(16.4)	(18.6)	(12.7)	(18.9)
R-L5ES	Mean	18.36	18.03	24.78	19.21	23.00	43.82	89.79	94.75	31.91	13.77	12.92
	(SD)	(10.1)	(5.1)	(8.8)	(7.5)	(14.2)	(21.9)	(14.9)	(9.5)	(19.9)	(8.7)	(5.2)
L-URA	Mean	84.86	91.93	71.00	72.51	58.75	79.85	21.87	21.84	44.59	15.39	22.51
	(SD)	(14.6)	(15.3)	(9.8)	(8.1)	(13.0)	(16.4)	(8.7)	(12.3)	(17.4)	(5.4)	(6.5)
L-LRA	Mean	95.00	83.81	73.82	56.72	54.90	63.29	19.41	25.78	32.10	24.32	24.13
	(SD)	(9.8)	(16.0)	(11.6)	(17.7)	(10.6)	(12.2)	(7.2)	(13.1)	(15.8)	(10.2)	(7.2)
L-IO	Mean	52.32	40.62	61.17	63.91	62.37	88.38	39.23	37.76	48.20	75.95	51.66
	(SD)	(15.3)	(10.6)	(12.7)	(26.2)	(22.6)	(14.7)	(17.8)	(20.2)	(21.7)	(25.2)	(15.1)
L-MEO	Mean	57.30	53.70	68.92	48.27	94.31	73.53	34.36	26.72	47.72	34.13	28.30
	(SD)	(16.7)	(12.5)	(15.8)	(14.8)	(15.1)	(17.9)	(20.8)	(6.3)	(13.9)	(16.5)	(9.1)
L-LEO	Mean	54.92	59.32	73.66	60.18	90.38	85.29	40.00	28.19	53.39	33.95	30.57
	(SD)	(17.8)	(19.8)	(16.8)	(17.3)	(12.9)	(14.2)	(8.3)	(9.4)	(12.8)	(16.6)	(11.0)
L-LD	Mean	37.62	37.47	78.49	73.85	85.36	53.19	78.18	44.14	78.59	29.56	30.13
	(SD)	(14.5)	(22.6)	(22.6)	(17.0)	(23.7)	(18.1)	(11.5)	(9.9)	(16.9)	(18.3)	(14.8)
L-T9ES	Mean	26.89	37.22	60.71	56.91	63.76	38.39	95.77	86.76	65.26	25.52	24.96
	(SD)	(12.3)	(16.5)	(18.0)	(27.4)	(21.5)	(11.0)	(8.0)	(10.1)	(19.3)	(12.2)	(10.9)
L-L5ES	Mean	13.89	13.13	21.35	18.08	22.93	41.58	90.60	98.71	26.78	12.11	11.68
	(SD)	(2.3)	(3.0)	(8.1)	(7.6)	(10.6)	(18.0)	(9.6)	(3.4)	(10.9)	(6.8)	(2.5)

a number of both upper and lower trunk MVC techniques seem to be necessary when seeking maximum electrical activity for EMG normalization in healthy women, or at least the pool of dancers such as were tested here.

As is conventional practice (Konrad et al., 2001; Ng et al., 2002), maximal activation of RA and ES were generally demonstrated during sagittal torque maneuvers (Table 1). However, no previous investigations have compared the effectiveness of upper and lower trunk techniques for obtaining maximum electrical activity. In our study, while most individuals reached the maximum activations of T9ES during the upper trunk extension (71% of participants), lower trunk extension most frequently resulted in the greatest muscle activity for L5ES (76% of participants). Therefore, it seems that performing only the conventional upper trunk extension technique may not be the most appropriate for recruiting all erector spinae sites in all people. This justifies a technique we have used for a number of years (Axler and McGill, 1997; Kavcic et al., 2004; McGill, 1991; Vera-Garcia et al., 2006, 2007) where the torso is cantilevered out over a strength testing table in a prone posture and an extension exertion of the entire spine is coupled with slight extension movement of the lumbar spine. This slight change in lordosis appears to create higher EMG activity along the entire erector spinae while remaining essentially an isometric task.

Regarding the controversy that continues to exist about using upper or lower trunk flexion torques to differentially activate URA and LRA (Lehman and McGill, 2001; Moreside et al., 2008; Sarti et al., 1996; Vera-Garcia et al., 2000), statistical differences for the normalized EMG amplitude of URA and LRA between upper and lower trunk flexion MVC techniques were not found in this study ($p > 0.05$). Nevertheless, Table 1 shows a interesting trend in our data, i.e. the highest activity levels of LRA and URA were principally found during the upper trunk flexion (69% of participants) and lower trunk flexion (46% of participants), respectively. These findings conflict with the view that upper trunk flexion torques are more effective for URA activation and lower trunk flexion torques for LRA activation. Although we do not have an actual explanation for the trend observed in our data, it might be related to the type of task analyzed (maximum contractions) or the special group of dancers who have participated in our study. Given the controversy on this topic, we believe both type of torques (upper and lower trunk MVC techniques) may be needed in order to ensure maximum activation of upper and lower portions of rectus abdominis.

As demonstrated by several studies (e.g. McGill, 1991; Ng et al., 2002), LD needs testing in several cardinal planes to obtain maximal activation. In fact, in our study, upper trunk bending, upper and lower trunk twisting, upper trunk extension, and shoulder rotation and adduction all generated similar mean levels of LD activation (between 73% and 85% MVC) (Table 2). For the oblique abdominals, resisted isometric contractions are usually performed in twisting and lateral bending to obtain maximum EMG activity. However, we found that twisting techniques tended to be less effective than bending techniques for maximum activation. In fact, the normalized EMG amplitudes of the twisting MVC techniques, averaged across subjects, varied between 60% and 70% MVC in most cases, and only reached the 80% MVC for right LEO (Table 2). Given these findings and those from previous studies (Konrad et al., 2001; McGill, 1991; Ng et al., 2002), trunk bending MVC techniques seem to be necessary for normalizing the EMG of external obliques, rather than trunk twisting MVC maneuvers. Nevertheless, rotation maximal exertions may be more appropriated for normalizing the EMG of IO (McGill, 1991; Ng et al., 2002).

Interestingly, although the un-resisted MVC techniques (i.e., maximal effort abdominal bracing and maximal effort abdominal hollowing) produced the smallest levels of trunk muscular activation (e.g., the mean normalized activities of rectus abdominis and external oblique were below 25% and 40% MVC, respectively), maximal abdominal hollowing resulted in the highest IO activation for 25% of the participants. Vera-Garcia et al. (2006) and Vera-Garcia et al. (2007) have shown that IO plays a large role in creating abdominal bracing and hollowing maneuvers; however, to the best of our knowledge, no previous studies have reported the abdominal recruitment while maximally co-activating the abdominal wall during hollowing MVC techniques. It should be taken into account that our findings could be affected by the ability of our subjects to draw in the abdominal wall, since some of them were highly trained in the art of middle-eastern dance, and therefore, may be more familiar and skilled with movements that involve abdominal hollowing actions. Healthy untrained individuals and patients with lumbar segmental instability appear to have difficulty performing abdominal hollowing exercises (O'Sullivan et al., 1997, 1998; Vezina and Hubley-Kozey, 2000); consequently, if our subjects had not had experience in such tasks the results may have been different.

Interpretations of the results of this study are limited to our subjects being healthy, physically active women. The maximal exertions performed here may not be suitable for patients with low back disorders and pain. It should be noted that large amounts of trunk muscular agonist–antagonist co-contraction were observed during the maximal exertions. MVC techniques impose high forces on the spine that may produce some damage to the tissues, especially in patients with low back disorders and/or pain. As has been shown, trunk muscle agonist–antagonist co-contraction is a strategy used by the motor system to stabilize the spine (Gardner-Morse and Stokes, 1998; Granata and Marras, 2000; McGill, 1991; Vera-Garcia et al., 2006, 2007). In cases where MVC tests produce pain, sub-maximal tests or other normalization procedures should be considered (Allison et al., 1998; Dankaerts et al., 2004; Marras and Davis, 2001). In addition, gender differences in MVC techniques have not received much attention, and thus future investigations should compare trunk muscular recruitment of women and men while performing MVC techniques.

Although we have analyzed several resisted and un-resisted MVC techniques, it must be recognized that additional techniques, different from the ones used in this investigation, might have produced higher EMG amplitudes. For example, over the years we have tested several body builders and noticed that they had good control and body awareness and were able to produce MVC's for nearly every muscle simply by co-contracting during their poses. An inherent limitation of this study was the subjective nature of these maximal exertions, especially considering that our participants had no previous experience in performing trunk MVC maneuvers. However, it is not uncommon to have subjects participate in the lab who are not used to performing maximum contractions. It is our clinical observation over 25 years that it is more difficult to obtain these maximum contractions in women (even in female athletes). Nevertheless, in order to try to obtain a "true" MVC, subjects were verbally encouraged during the maximal contractions, and considerable guided practice was carried out to achieve a proper performance.

In summary, no single test was superior for obtaining MVC's. Subjects demonstrated a high variability in the MVC technique that elicited maximum muscle activity. This implies that a variety of tasks may be needed if a true maximum is desired. Nonetheless a compromise can be struck between reducing the number of MVC tasks to minimize fatigue while still increasing the chance of obtaining an MVC. To provide a basis for normalization, the following MVC techniques appear to be the tasks of choice: upper and lower trunk flexion for rectus abdominis; upper trunk bending for MEO, LEO and LD; lower trunk bending for IO; upper trunk extension for T9ES; and lower trunk extension for L5ES. This assumes that the spine and trunk is sufficiently robust to support the resultant loads.

Acknowledgments

This study was made possible by financial support of the Natural Sciences and Engineering Research Council of Canada. Dr. Francisco J. Vera-Garcia was supported by a post-doctoral grant (Generalitat de Valencia, Spain). The authors wish to thank the dancers who offered their time and expertise to take part in this study.

References

Allison GT, Godfrey P, Robinson G. EMG signal amplitude assessment during abdominal bracing and hollowing. J Electromyogr Kinesiol 1998;8(1):51–7.

Axler CT, McGill SM. Low back loads over a variety of abdominal exercises: searching for the safest abdominal challenge. Med Sci Sport Exer 1997;29:804–11.

Dankaerts W, O'Sullivan PB, Burnett AF, Straker LM, Danneels LA. Reliability of EMG measurements for trunk muscles during maximal and sub-maximal voluntary isometric contractions in healthy controls and CLBP patients. J Electromyogr Kinesiol 2004;14:333–42.

De Luca CJ. The use of surface electromyography in biomechanics. J Appl Biomech 1997;13:135–63.

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.

Gardner-Morse MG, Stokes IA. The effects of abdominal muscle coactivation on lumbar spine stability. Spine 1998;23:86–91.

Granata KP, Marras WS. Cost-benefit of muscle cocontraction in protecting against spinal instability. Spine 2000;25:1398–404.

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 Sport Exer 1998;30:301–10.

Kavcic N, Grenier S, McGill SM. Quantifying tissue loads and spine stability while performing commonly prescribed low back stabilization exercises. Spine 2004;29:2319–29.

Konrad P, Schmitz K, Denner A. Neuromuscular evaluation of trunk-training exercises. J Athl Training 2001;36:109–18.

Lehman GJ, McGill SM. The importance of normalization in the interpretation of surface electromyography: a proof of principle. J Manip Physiol Ther 1999;22:444–6.

Lehman GJ, McGill SM. Quantification of the differences in electromyographic activity magnitude between upper and lower portions of the rectus abdominis muscle during selected trunk exercises. Phys Ther 2001;81(5):1096–101.

Marras WS, Davis KG. A non-MVC EMG normalization technique for the trunk musculature: part 1. Method development. J Electromyogr Kinesiol 2001;11:1–9.

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 Orthopaed Res 1991;9:91–103.

McGill SM. Low back disorders: evidence based prevention and rehabilitation. Champaign, Illinois: Human Kinetics Publishers; 2002. p. 45–86.

McGill S, Juker D, Kropf P. Appropriately placed EMG electrodes reflect deep muscle activity (psoas, quadratus lumborum, abdominal wall) in the lumbar spine. J Biomech 1996;29(11):1503–7.

Moreside JM, Vera-Garcia FJ, McGill SM. Neuromuscular independence of abdominal wall muscles as demonstrated by middle-eastern style dancers. J Electromyogr Kinesiol 2008;18:527–37.

Ng JK, Kippers V, Parnianpour M, Richardson CA. EMG activity normalization for trunk muscles in subjects with and without back pain. Med Sci Sport Exer 2002;34:1082–6.

O'Sullivan PB, Phyty GD, Twomey LT, Allison GT. Evaluation of specific exercise in the treatment of chronic low back pain with radiological diagnosis of spondylolysis and spondylolisthesis. Spine 1997;22(24):2959–67.

O'Sullivan PB, Twomey L, Allison GT. Altered abdominal muscle recruitment in patients with chronic back pain following a specific exercise intervention. J Orthopaed Sport Phys Ther 1998;27(2):114–24.

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.

Sarti MA, Monfort M, Fuster MA, Villaplana LA. Muscle activity in upper and lower rectus abdominis during abdominal exercises. Arch Phys Med Rehab 1996;77:1293–7.

Urquhart DM, Barker PJ, Hodges PW, Story IH, Briggs CA. Regional morphology of the transversus abdominis and obliques internus and external abdominis muscles. Clin Biomech 2005;20:233–41.

Vera-Garcia FJ, Brown SHM, Gray JR, McGill SM. Effects of different levels of torso coactivation on trunk muscular and kinematic responses to posteriorly applied sudden loads. Clin Biomech 2006;21:443–55.

Vera-Garcia FJ, Elvira JLL, Brown SHM, McGill SM. Effects of abdominal stabilization maneuvers on the control of spine motion and stability against sudden trunk perturbations. J Electromyogr Kinesiol 2007;17:556–67.

Vera-Garcia FJ, Grenier SG, McGill SM. Abdominal response during curl-ups on both stable and labile surfaces. Phys Ther 2000;80(6):564–9.

Vezina MJ, Hubley-Kozey CL. Muscle activation in therapeutic exercises to improve trunk stability. Arch Phys Med Rehab 2000;81:1370–9.

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 graduated in 1977 from the University of British Columbia (Vancouver), with a degree in physical therapy. She has practiced physiotherapy since then in various cities in Canada and England. Janice received her Masters of Human Kinetics at the University of Windsor (Canada) in 2003, and is currently a PhD candidate at the University of Waterloo, studying in the Spine Biomechanics laboratory with Dr. S. McGill. The main focus of her research is the neuromuscular control of the spine and trunk, and the effect of hip mobility on the lumbar spine.

Stuart McGill is a Professor of Spinal Biomechanics and an author of many scientific publications that address the issues of lumbar function, low back injury mechanisms, development of evidence-based rehabilitation and performance exercise, and the formulation of injury avoidance strategies.