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Core muscle activity in a series of balance exercises with different stability conditions

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ABSTRACT

Literature that provides progression models based on core muscle activity and postural manipulations is scarce. The purpose of this study was to investigate the core muscle activity in a series of balance exercises with different stability levels and additional elastic resistance. A descriptive study of electromyography (EMG) was performed with forty-four healthy subjects that completed 12 exercises in a random order. Exercises were performed unipedally or bipedally with or without elastic tubing as resistance on various unstable (uncontrolled multiaxial and uniaxial movement) and stable surfaces. Surface EMG on the lumbar multífidus spinae (LM), thoracic multífidus spinae (TM), lumbar erector spinae (LE), thoracic erector spinae (TE) and gluteus maximus (GM), on the dominant side of the body were collected to quantify the amount of muscle activity and were expressed as a % of the maximum voluntary isometric contraction (MVIC). Significant differences ($p < .001$) were found between exercises. The three unipedal standing exercises with additional elastic resistance generated the greatest EMG values, ranging from 19%MVIC to 30%MVIC. Postural manipulations with additional elastic resistance and/or unstable devices increase core muscle activity. An adequate exercise progression based on global core EMG could start with seated positions, progressing to bipedal standing stance (i.e., from either multiaxial or stable surface to uniaxial surface). Following this, unipedal standing positions may be performed (i.e., from either multiaxial or stable surface to uniaxial surface) and finally, elastic resistance must be added in order to increase EMG levels (i.e., from stable surface progressing to any of the used unstable surfaces).

1. Introduction

The lack of stability in the core muscles is a risk factor for developing low back pain [1] and this problem is associated with neuromuscular deficits [1,2] and decreased core muscle strength [1,3]. Besides prevention of low back pain, the strengthening of the stabilizing muscles of the trunk or core is considered of great importance to daily activities and sports [4].

Another reason to explain the growing interest of the scientific literature on this topic during the past decade is the training transference to those sport modalities that involve unstable environments [4]. In fact, stability is a fundamental skill for daily task and sport activities [5].

Higher instability conditions increase postural control and balance requirements, enhancing core muscle activity to stabilize the body [6]. Instability resistance training may be performed using the own body weight and/or with external loads, either on stable surface or unstable surface [7]. Postural manipulations as reducing the base of support [8,9] or performing standing exercises instead of seated exercises [10] has been recommended to challenge postural control and core muscle activity respectively. Exercises performed by reducing the base of support increased muscle activity in the stabilizer muscles of the ankle [11,12] and increased core muscle activity during bridging exercises [13]. However, the possibility to increase core muscle activity by narrowing the base of support during standing and seated positions remains uninvestigated and supposes a novel exercise variation. Furthermore, it is unknown if

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additional elastic resistance during these positions lead to higher core muscle activity.

While a progressive increase in the degree of instability during resistance training may be recommended during rehabilitation [14], literature that provides progression models based on muscle activity and postural manipulations is scarce. As far as we are concerned, there is only one study [15] that provided a core progression based on muscle activity and performed one exercise with an unipedal stance, although this modification not enhance muscle activity compared with the same exercise performed with an unstable device. Nevertheless, authors only used an unstable device that may be insufficient to enhance balance disruptions and muscle activity in experienced participants [16].

There are several studies investigating muscle activity when performing exercise on unstable surfaces [10], although authors did not report a progression model of different exercises that target the core musculature, especially involving changing the surface (i.e., uniaxial unstable surface, multiaxial unstable surface and a stable surface) and also involving postural manipulations (i.e., seated/standing and one leg stance/bipedal stance) with/without the addition of elastic resistance. All these variations may suppose different instability degrees and thus different muscle recruitment levels. Therefore, our purpose was to investigate the core muscle activity in a series of balance exercises with different stability levels and additional elastic resistance to establish a progression based on the amount of muscle activity. We hypothesized that progressive postural manipulations may involve higher amount of core muscle activity in order to maintain postural control and perform the exercise with the correct technique.

2. Methods

2.1. Subjects

Young university students (24 men and 20 women) participated voluntarily in this study. Subject characteristics (mean ± SD) are: 23.1 ± 2.8 years old; 66.1 ± 9.7 kg of body weight; 14.7 ± 7.9% of body fat; 170.7 ± 8.4 cm of height). Subjects included in the research had a minimum of 1 year of experience with resistance training. Exclusion criteria included musculoskeletal pain, neuromuscular disorders, joint or bone disease, previous ankle sprains and tendon, fascia or ligament inflammation. All subjects signed an informed consent form before starting the protocol, and the institution's review boards approved the study (H1340632215316). All procedures described in this section comply with the requirements listed in the 1975 Declaration of Helsinki and its amendment in 2008.

2.2. Procedures

Each subject took part in 2 sessions: familiarization and data collection. The familiarization session occurred 48–72 h before the data collection. Several restrictions were imposed on the volunteers: no food 3–4 h before and no stimulants or intense physical activity 12 h before the experimentation.

2.2.1. Familiarization

In the first session, the subjects were familiarized with the testing activities that would be performed on the day of data collection. Subjects practiced the exercises typically 1–3 times each until the subject felt confident and the researcher was satisfied that proper form was achieved. Height, body mass, and body fat percentage using bioelectric impedance (Tanita model BF-350, Arlington Heights, Illinois, USA) were obtained according to the protocols used in previous studies [17].

2.2.2. Data collection

The protocol started with the preparation of the subjects' skin and followed by electrode placement, maximal isometric voluntary contraction (MIVC) collection and exercise performance. Hair was removed from the skin overlying the muscles of interest, and the skin was then cleaned by rubbing with cotton wool dipped in alcohol for the subsequent electrode placement, positioned according to the recommendations of Cram, Kasman, and Holtz [18] on the lumbar multífidus spinae (LM), thoracic multífidus spinae (TM), lumbar erector spinae (LE), thoracic erector spinae (TE) and gluteus maximus (GM), on the dominant side of the body. Pre-gelled bipolar silver/silver chloride surface electrodes (Blue Sensor M-00-S, Medicotest, Olstykke, Denmark) were placed with an interelectrode distance of 25 mm. The reference electrode for each muscle was placed perpendicular to the axis of the other 2 active electrodes, at 10 cm from the midpoint of the 2 active electrodes, according to the manufacturer's specifications. The assessment of muscle activity was performed on the dominant side with the subjects barefoot in all exercises.

2.2.3. MIVC

A 5 s MIVC was performed to estimate the maximal electromyographic (EMG) amplitude. The subjects were instructed to slowly contract the muscle during the 1st second of data acquisition and then to perform the maximal contraction during the final 4 s. Subjects performed a back extension at maximum isometric effort according to Hibbs et al. [19].

2.2.4. Equipment

The different exercises were performed on stable (Thera-Band® Exercise Station, Hadamar, Germany) or unstable (Exercise Ball, Rocker Board and Soft Stability Trainer: Thera-Band®, Hadamar, Germany) surfaces with or without external resistance (Elastic tubing, Thera-Band®, Hadamar, Germany). The exercise station was a stable platform, the Rocker Board was unstable in the anteroposterior direction and the Exercise Ball and Soft Stability Trainer were unstable in a multi-axial direction. Furthermore, men used green exercise tubing and women used red exercise tubing, based on pilot studies to ensure the given position for each exercise could be maintained for 20 s. A Cross Line Auto Laser Level was fixated with a tripod (Black & Decker LZR6TP, New Britain, CT, USA) and used as visual feedback for subjects in connection to requested hip and knee joint positioning during exercises.

2.3. Exercise performance

Each subject completed the 12 exercises in a random order that was assigned to subjects employing Matlab software (Version 7.0, Mathworks Inc, Natick, MA, USA). Each exercise was performed for a duration of 20 s with a 2 min rest interval between exercises. Except for the Exercise Ball activities, all exercises were completed with 140° knee flexion (180° represents the straight knee position with the femur and tibia bones aligned) and 60° hip flexion (0° represents an erect posture with the femur extended). Exercise Ball activities were completed in a seated posture with 90° knee flexion and 20° hip flexion. A stainless steel goniometer (Baseline, White Plains, USA) was used to ensure the proper knee and hip degree before positioning the Laser.

Moreover, all exercises were completed with the arms parallel to the ground while maintaining a static position. All exercises are shown in Fig. 1. For the sake of brevity, each exercise was assigned a number designation as illustrated in Fig. 1. Exercises were performed in 3 separate positions (two leg stance, single leg stance and single leg stance with exercise tubing). Each exercise position was assumed on the 4 different platforms to alter the amount of stability for a total of 12 exercises.

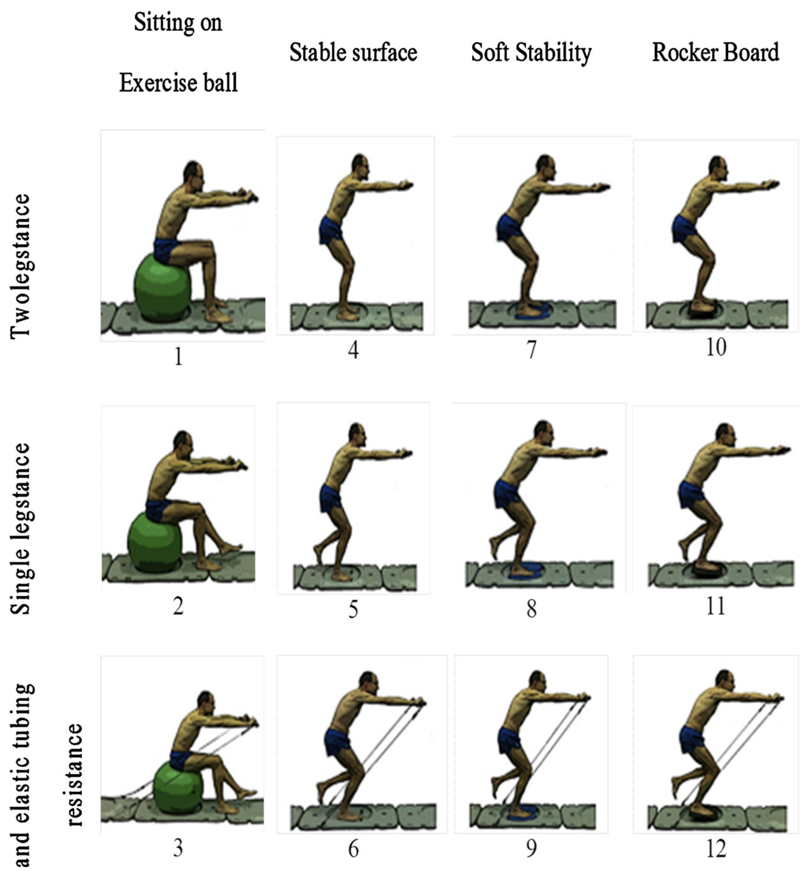

Fig. 1. The 12 exercises performed.

In all exercises, subjects held a bar (445 g) at a biacromial (shoulder) width and height. The shoulder width position was selected to reflect the shoulder position conventionally used in many other resistance exercises. The purpose of the bar was to ensure standardization of the exercises with and without elastic resistance as the elastic resistance exercise necessitated a bar to secure the elastic bands. To ensure consistent elastic tubing tension, the distance between standing and seated position was measured for each subject, hooking the elastic tubing to a steel chain with this distance.

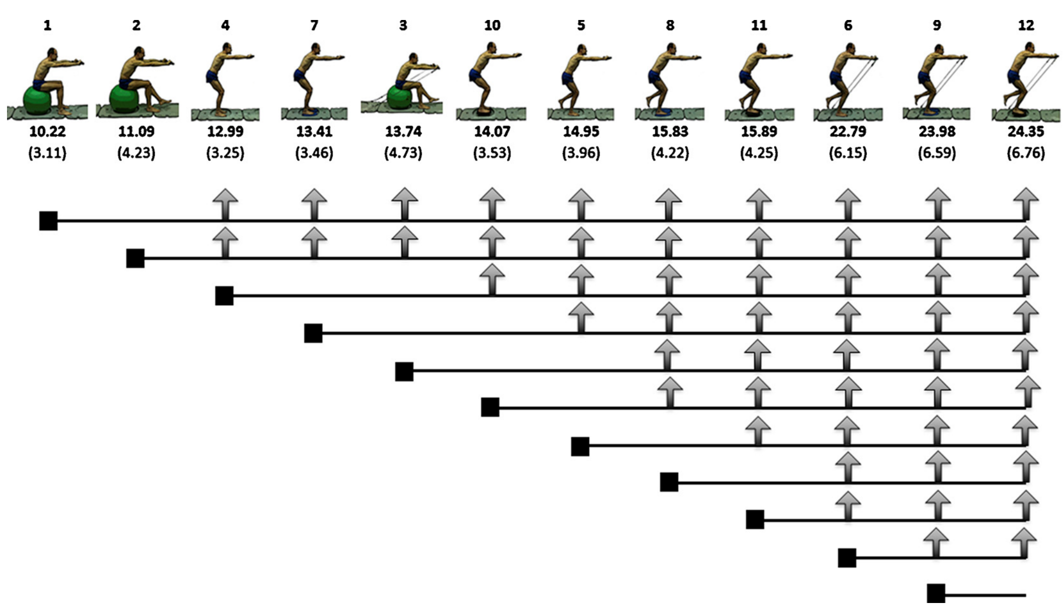

Fig. 2. Global mean EMG comparisons between conditions. Data expressed as mean percentage of the maximum isometric activation ($n = 44$). SEM values are in parentheses. Data correspond to the RMS of the Global mean. Arrows indicate significant differences ($p < .05$) between the exercise condition identified by a square and exercises corresponding to the arrows. Global mean = mean of all muscles (lumbar multífidus spinae, thoracic multífidus spinae, lumbar erector spinae, thoracic erector spinae and gluteus maximus.

2.4. Data analysis

Surface EMG amplitude in the time domain was quantified by using the root-mean-square (RMS) and processed as a moving average over 100 ms. The mean amplitudes of the RMS EMG signal were selected for every trial (exercises and MIVCs). Surface EMG signals of the exercises were analyzed by using the middle 16 s of the 20 s exercises. The EMG data obtained from each exercise were normalized to the RMS EMG value obtained from the MVIC recording for each one of the muscles investigated. MIVC EMG signals were analyzed by using the 3 middle seconds of the 5 s isometric contraction. All signals were bandpass filtered using a 20- to 400-Hz cutoff frequency and a fourth-order Butterworth filter employing a 14-bit analogue-digital (AD) converter. All signals were acquired at a sampling frequency of 1 kHz, amplified and converted from analog to digital. All records of myoelectrical activity (in microvolts) were stored on a hard drive for later analysis. To acquire the surface EMG signals produced during the exercises, an ME6000P8 (Mega Electronics, Ltd., Kuopio, Finland) biosignal conditioner was used. All surface EMG signal analyses were performed using Matlab (Version 7.0, Mathworks Inc, Natick, MA, USA). Global mean of all muscles (i.e., LM, TM, LE, TE and GM) was also calculated and analyzed.

2.5. Statistical analysis

The SPSS statistical software package (Version 17.0, SPSS Inc, Chicago, IL, USA) was used to analyze all data. Normality of the data distribution was tested using the Shapiro–Wilk's test. Statistical comparisons for each individual muscle between the 12 exercises were performed by using a one way repeated measures analysis of variance (ANOVA). Post hoc analysis with Bonferroni correction was used in the case of significant main effects. Significance was accepted when $p < .05$. Results are reported as means ± SE values.

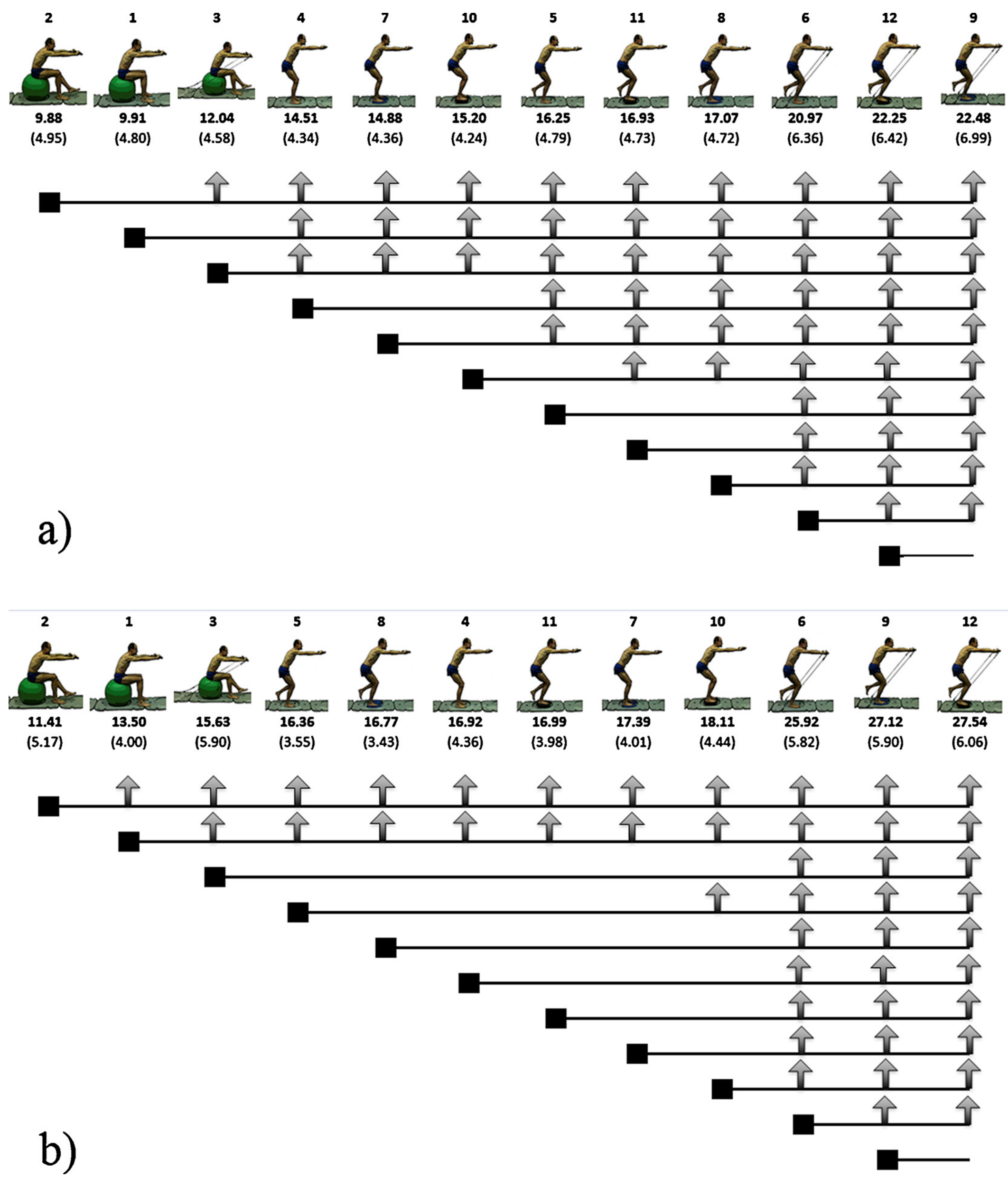

Fig. 3. LM and TM comparisons between conditions. Data expressed as mean percentage of the maximum isometric activation ($n = 44$). SEM values are in parentheses. Data correspond to the RMS of the LM. Arrows indicate significant differences ($p < .05$) between the exercise condition identified by a square and exercises corresponding to the arrows. LM = lumbar multífidus spinae. TM = thoracic multífidus spinae. (a) LM and (b) TM.

3. Results

All data were normally distributed. Significant differences were found between exercise conditions for LM ($p < .001$), TM ($p < .001$), LE ($p < .001$), TE ($p < .001$), GM ($p < .001$) and Global mean ($p < .001$), (Figs. 2–5).

There was a great similarity in the response of each muscle to the 12 exercise conditions. Figs. 2–5 illustrate that unipedal standing exercises with additional elastic resistance (exercises #6, #9 and #12) generated the greatest activation for all muscles.

In general, sitting exercises induced the lowest activation followed by bipedal and unipodal stance exercises with the highest activation with the unipedal stance exercises with elastic tubing.

4. Discussion

The global results of this study demonstrate that postural manipulations may increase core muscle activity, (i.e., a progressive reduction in the base of support from a seated position to a unipedal stance). Furthermore, the addition of unstable devices and elastic resistance in combinations or separately may increase muscle activity of core muscles. Findings based on global muscle activity results are discussed in more detail in the following texts.

Our findings support previous studies that reported a muscle activity increment in the ankle stabilizers while participants reduced the base of support during standing positions such as bipedal and unipedal stance [11,12] or higher core activity during bridging exercises with the left-leg lifted off the ground [13].

In accordance with Saeterbakken and Fimland [10] greater core muscle activity during standing exercises instead seated counterparts was found. These results and the higher balance requirements achieved by narrowing the base of support [9] suggests that progressive postural control disruptions may involve an increment amount of core muscle activity to maintain balance and perform the exercise with the correct technique. Notwithstanding, unipedal/bipedal stance during a seated position showed no significant

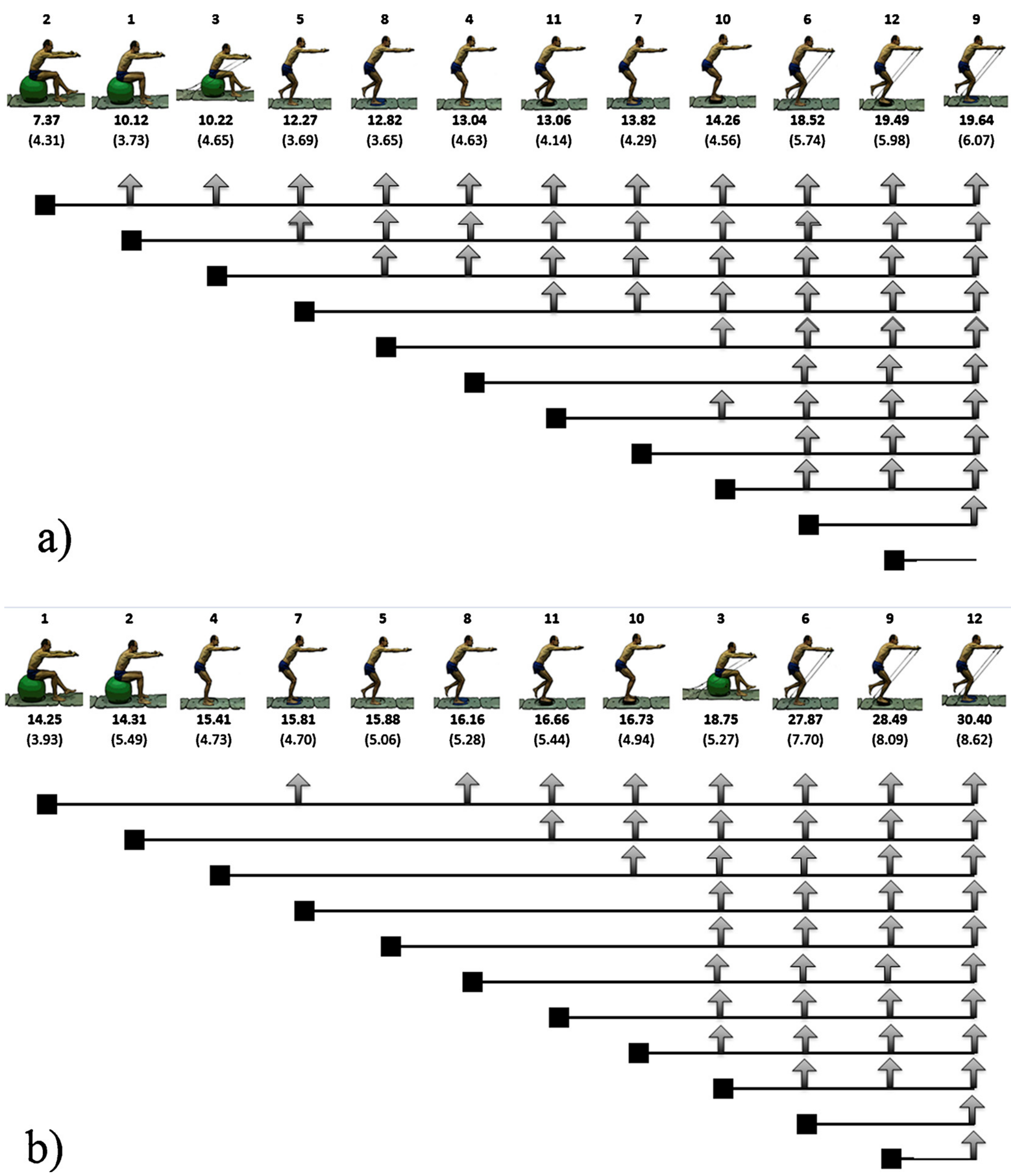

Fig. 4. LE and TE comparisons between conditions. Data expressed as mean percentage of the maximum isometric activation ($n = 44$). SEM values are in parentheses. Data correspond to the RMS of the LE. Arrows indicate significant differences ($p < .05$) between the exercise condition identified by a square and exercises corresponding to the arrows. LE = lumbar erector spinae. TE = thoracic erector spinae. (a) LE and (b) TE.

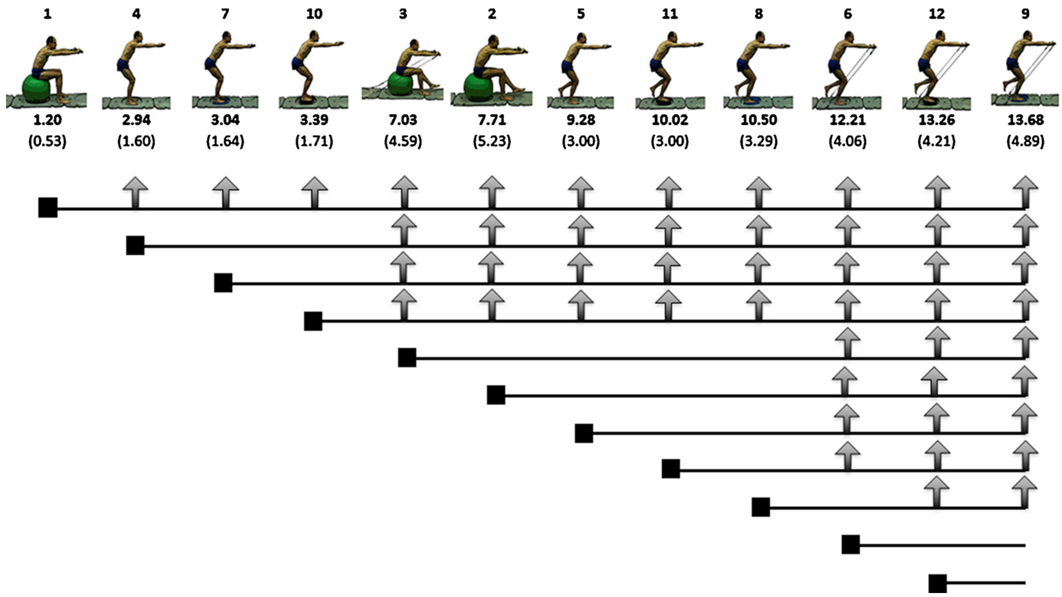

Fig. 5. GM comparisons between conditions. Data expressed as mean percentage of the maximum isometric activation ($n = 44$). SEM values are in parentheses. Data correspond to the RMS of the GM. Arrows indicate significant differences ($p < .05$) between the exercise condition identified by a square and exercises corresponding to the arrows. GM = gluteus maximus.

difference except during the addition of elastic resistance. This result may indicate that the extent of instability was insufficient to elicit significant differences during this position and condition where the body weight is also supported by the exercise ball.

Increased core muscle activity when performing the same exercises under moderately unstable versus stable conditions has been shown when performing different exercises [7]. However, as was previously stated by Wahl and Behm [16], not all instability training devices enhance muscle activity in resistance-experienced participants. Interestingly, exercises performed with uniaxial and multiaxial devices during standing positions not showed significative statistical difference whereas only those performed with uniaxial device were able to enhance core muscle activity compared with stable conditions, except with the addition of elastic resistance. This fact suggest that during a standing stance with the own body weight, core activation of the measured muscles may be more sensitive to antero-posterior movements or disruptions, at least with these devices, where the difference between them in the amount of stability may be too small to elicit significant muscle activity changes as has been demonstrated in a recent study [12]. In the same vein, Colado et al. [15] reported no significant core muscle activity difference between a static unipedal forward flexion and the same exercise performed with another multiaxial device (i.e., BOSU ball). Moreover, a study showed no differences in balance gains between two intervention groups that were assigned to either uniaxial or multiaxial training [20].

Different findings were achieved with the addition of elastic resistance during the standing unipedal positions, where the two exercises performed with the unstable device showed greater core muscle activity compared with the stable version. It seems that elastic tubing provide the needed additional resistance to enhance global muscle activity during the unipedal standing exercise with multiaxial device compared with the stable counterpart. In agreement with our results, greater core muscle activity was achieved during an isometric deadlift that allowed greatest %MVIC than their other variations [21]. Indeed, a linear relationship between isometric muscle force and surface EMG amplitude has been documented [22].

Muscle activity levels during all the performed exercises were in general low. However, the aforementioned exercises challenge the sensorimotor system while still provides sufficient intensity to activate the lower threshold, slow twitch, type I fibres, promoting motor control adaptations, especially important in the rehabilitation setting [7].

5. Conclusion

Postural manipulations with the addition of elastic resistance and/or unstable devices may increase core muscle activity. Exercises provided should be used to enhance postural and motor control adaptations. Data provided should serve to establish progressive levels of core muscle activity. For instance, an adequate exercise progression based on global core muscle activity could start with seated positions, progressing to bipedal standing stance (i.e., from either multiaxial or stable surface to uniaxial surface). Following this, unipedal standing positions may be performed (i.e., from either multiaxial or stable surface to uniaxial surface) and finally, elastic resistance must be added in order to increase electromyographic levels (i.e., from stable surface progressing to any of the used unstable surfaces).

Conflict of interest

None.

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