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ORIGINAL

TRUNK MUSCLE ACTIVATION IN SPINE STABILIZATION EXERCISES

ACTIVACIÓN DE LOS MÚSCULOS DEL TRONCO EN EJERCICIOS DE ESTABILIZACIÓN RAQUÍDEA

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ABSTRACT

The aim of this study was to analyze the trunk muscle coactivation during spine stabilization exercises. The electromyography of rectus abdominis, external and internal oblique and erector spinae was recorded while performing the *back bridge*, the *front bridge* and the *right and left side bridge* exercises. The muscular activation levels needed to stabilize the trunk in the *bridge* exercises were low or moderate. Abdominal muscles were mainly activated in the *frontal* and *lateral bridge*, and erector spinae in the *back bridge*. All trunk muscles from

the side of the arm of support were activated during the *lateral bridges*. On the contrary, *frontal* and *back bridges* isolated the abdominal and lumbar muscle activation, respectively. These results may facilitate the stabilization exercise selection to design trunk muscle conditioning programs.

KEYWORDS: Spine stability, trunk muscles, electromyography, fitness, health.

RESUMEN

El objetivo del estudio fue analizar la coactivación de los músculos del tronco durante ejercicios de estabilización del raquis. Para ello, se registró la electromiografía de los músculos rectus, obliquus externus y obliquus internus abdominis y erector spinae durante la realización del *punte dorsal*, el *punte ventral* y el *punte lateral derecho e izquierdo*. Los niveles de activación muscular necesarios para estabilizar el tronco durante la ejecución de los *puentes* fueron bajos o moderados. Los músculos abdominales se activaron principalmente en el *punte ventral* y *lateral*, y el erector spinae en el *punte dorsal*. En los *puentes laterales* se activaron todos los músculos del lado del brazo de apoyo. Por el contrario, los *puentes ventral* y *dorsal* aislaron la activación de los músculos abdominales y lumbares, respectivamente. Estos resultados podrían facilitar la selección de ejercicios de estabilización para el diseño de programas de acondicionamiento de los músculos del tronco.

PALABRAS CLAVE: Estabilidad del raquis, musculatura del tronco, electromiografía, acondicionamiento físico, salud.

INTRODUCTION

Lumbar spine pathologies have a high prevalence in society today (National Health Survey 2006: 24.01% of Spanish population over 16 years old) and elevated social health costs (Gómez-Conesa and Valbuena Moya, 2005). Among the methods used for prevention and treatment of these types of injuries we can currently point out spine stabilization exercise programs. The aim of these exercises is to promote muscular coactivation patterns to improve motor control and spine stability (McGill, 2002; McGill, Grenier, Kavcic and Cholewicki, 2003).

During the last fifteen years many spine stabilization exercises have been prescribed. In general, these exercises consist of holding the spine in “neutral” position (i.e., keeping the physiological curves of the spine) when it is exposed to internal or external forces which compromise its stability. For example, in the *bridge* exercises (Bjerkefors, Ekblom, Josefsson and Thorstensson, 2010; Ekstrom, Donatelli and Carp, 2007; Kavcic, Grenier and McGill, 2004; Konrad, Schmitz and Denner, 2001; McGill and Karpowicz, 2009; Stevens, Bouche, Mahieu, Coorevits, Vanderstraeten and Danneels, 2006) participants must maintain different postures without resting the pelvis on the floor, against

gravity. In the *bird dog* or the *dead bug* participants must keep the spine in neutral position against forces caused by the movement of the limbs (Bjerkefors et al., 2010; Ekstrom et al., 2007; Kavcic et al., 2004; McGill and Karpowicz, 2009; Stevens, Vleeming, Bouche, Mahieu, Vanderstraeten and Danneels, 2007). Another way to challenge the motor system's capacity to stabilize the spine is through dynamic or static exercises on unstable surfaces (Imai, Kaneoka, Okubo, Shiina, Tatsumura, Izumi y Shiraki, 2010; Lehman, Hoda and Oliver, 2005; Stevens et al., 2006; Vera-García, Grenier, and McGill, 2000), such as the *bosu* or the *fitball*, or through the use of oscillating poles (Moreside, Vera-García and McGill, 2007; Sánchez-Zuriaga, Vera-García, Moreside and McGill, 2009; Vera-García, Moreside, Flores-Parodi and McGill, 2007b). These poles (Bodyblade®, Flexibar®, etc.) are flexible and elastic materials which when shaken oscillate at different frequencies and amplitudes. The oscillation of these poles and the movements carried out when making them oscillate involve an important challenge to the individual's capacity to stabilize the spine and pelvis.

In Biomechanics, the best choice of exercises for each training program is based mainly on efficiency and safety criteria. Surface electromyography allows us to evaluate the efficiency of stabilization exercises through the analysis of the muscle activation intensity and coactivation patterns (see for example: Ekstrom et al., 2007; Konrad et al., 2001; McGill and Karpowicz, 2009; Stevens et al., 2006 and 2007). Different studies have shown that the coordinated coactivation of the trunk muscles favors spine stiffness and confers stability to its structures (Vera-García, Brown, Gray and McGill, 2006; Vera-García, Elvira, Brown and McGill, 2007a; Vera-García et al., 2007b). On the other hand, stability is reduced if the trunk muscles are not activated with an adequate trunk coactivation pattern (Brown, Vera-García and McGill, 2006). In addition, computerized mathematical models allow us to evaluate the safety of the exercises through the calculation of the mechanical load caused on the spine during the exercises (Axler and McGill, 1997; Kavcic et al., 2004; Moreside et al., 2007). According to NIOSH (National Institute for Occupational Safety and Health, 1981), spine compression forces over 3400 N could imply an important risk for the individual.

Based on safety and efficiency criteria, *bridges* are some of the most widely used stabilization exercises. For example, the *back bridge*, lying supine (Bjerkefors et al., 2010; Ekstrom et al., 2007; Imai et al., 2010; Kavcic et al., 2004; Konrad et al., 2001; Lehman et al., 2005; Stevens et al., 2006), the *side bridge*, lying sideways (Ekstrom et al., 2007; Imai et al., 2010; Kavcic et al., 2004; Lehman et al., 2005; McGill y Karpowicz, 2009) and the *front bridge*, lying prone (Ekstrom et al., 2007; Imai et al., 2010; Lehman et al., 2005; McGill y Karpowicz, 2009). Biomechanical studies have shown that the *back bridge* and the *side bridge* activate the trunk muscles without causing high compression forces that compromise the lumbar spine structures (Kavic et al., 2004). Nevertheless, although electromyographic studies have analyzed the participation of trunk muscles in *front, back and/or side bridges*, we need a

deeper insight into the knowledge of the muscle coactivation patterns generated during the execution of these exercises.

The purpose of this study was to analyze the electrical activity of the abdominal and lumbar muscles when performing the *back bridge*, the *front bridge* and the *right and left side bridge* (Figure 1). We try to explore the connection between different muscle coactivation patterns and the lumbo-pelvic region stability, providing useful information for the prescription of trunk stabilization exercises.

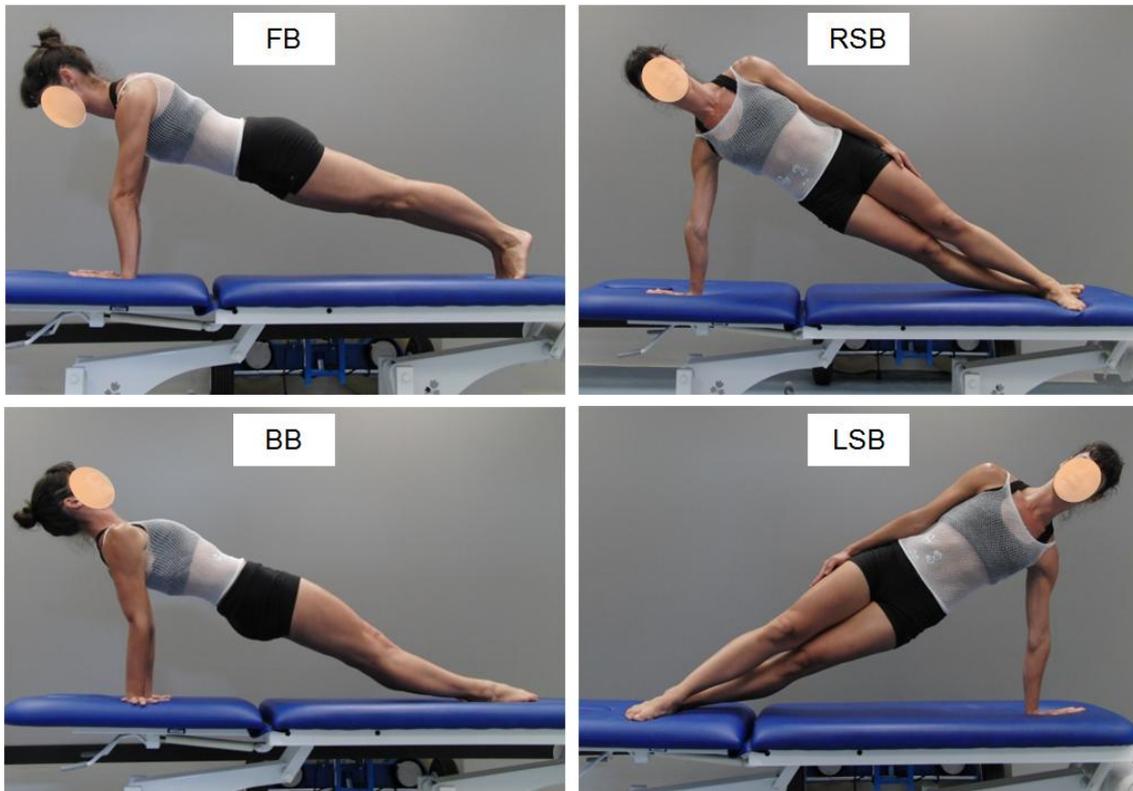


Figure 1. FB) Front bridge; BB) Back bridge; RSB) Right side bridge; LSB) Left side bridge.

MATERIALS AND METHODS

Participants

Sixteen asymptomatic women voluntarily took part in the study (age: 24.38 ± 4.54 years; mass: 57.74 ± 4.95 kg; height: 1.64 ± 0.04 m). Prior to the study participants were informed of the characteristics of the research and they signed a written informed consent which was approved by the Ethics Committee of the Institution. All of them were young women, familiar with the practice of trunk muscle conditioning exercises. Those women with a history of abdominal surgery, previous history of lower back pain or muscle-skeletal, heart or metabolic injuries which did not advise the performance of the exercises were excluded from the study.

Data collection

Surface electromyographic (EMG) signals were collected on each subject using the *Muscle Tester ME6000*[®] (Mega Electronics Ltd., Kuopio, Finland). This is an eight-channel portable microcomputer with an 8-channel A/D conversion (14 bit resolution), a common-mode rejection ratio of 110 dB and a band-pass filter of 8-500 Hz. Sampling frequency was programmed at 1000 Hz. The EMG signals were transferred via an optical cable to a compatible computer where it was monitored by Megawin[®] 2.5 program (Mega Electronics Ltd., Kuopio, Finland) and stored for its later analysis.

The EMG signals were recorded in the following muscles and locations: rectus abdominis (RA), approximately 3 cm lateral to the right of the umbilicus; external oblique (EO), approximately 15 cm lateral to the right of the umbilicus; internal oblique (IO), the geometric center of the triangle formed by the right side inguinal ligament, the outer edge of the rectus sheath and the imaginary line joining the anterior superior iliac spine and the umbilicus (Ng, Kippers and Richardson, 1998; Urquhart, Barker, Hodges, Story and Briggs, 2005); and erector spinae (ES), 3 cm lateral to the right of the spinous process of L3. The placing of the electrodes was adapted to each participant depending on their individual anatomical characteristics.

In order to make the placing of the electrodes easier, a topographic marking through palpation of the different anatomical points with a skin marker was carried out (Delagi, Perotto, Lazzeti and Morrison, 1981). Skin zones for electrode placements were shaved and cleaned with an alcohol swab in order to reduce impedance. Pre-gelled disposable bipolar Ag-AgCl surface electrodes (Arbo Infant Electrodes, Tyco Healthcare, Germany) were placed parallel to the muscle fibers with a centre-to-centre spacing of 3 cm. After placing the electrodes the subject was asked to perform different movements to ensure the precise placement of the electrodes and to test the EMG signal quality. With the aim of isolating and protecting the electrodes on those subjects with a high transpiration, it was necessary to place an adhesive tape on the non metallic part of the electrode. In the same way, an elastic mesh (Elastofix[®] S N^o7) was placed on the trunk to reduce the electromyography cable movement.

In order to normalize the trunk muscle EMG, two series of maximal voluntary isometric contractions (MVICs) against manual resistance were carried out. For the abdominal muscles, the participant produced maximal isometric efforts in trunk flexion, lateral bend and twist. For the extensor muscles, maximal trunk extensions were performed. Each maximal contraction was maintained during 4-5 s and a 5 min rest was allowed between each series. The MVICs were carried out prior to the stabilization exercises. The MVICs protocol has been described in previous studies (Vera-García, Moreside and McGill, 2010).

Procedure

Participants carried out the following stabilization exercises:

Front bridge (FB in Figure 1): The subject was lying prone, resting her hands and her feet on the bench, with the trunk fully aligned with the lower limbs and the spine in neutral position. The hands and the feet were placed at the width of the shoulders and hips, respectively.

Back bridge (BB in Figure 1): The subject was lying supine, resting her hands and feet on the bench, with the trunk fully aligned with the lower limbs and the spine in neutral position. The hands were placed at the width of the shoulders and the feet were placed together.

Right side bridge (RSB in Figure 1): The subject was lying on her right side, supporting her weight on her right hand. The right foot was resting on the floor on its outer side and the left foot was placed just in front of it, resting on its internal side. The subject maintained the pelvis lifted, with the trunk fully aligned with the lower limbs, and the spine in neutral position.

Left side bridge (LSB in Figure 1): Similar to the previous exercise, but performed on the left side.

Prior to EMG recording, participants were verbally and visually instructed on correct bridge exercise technique. The performance order was randomized between subjects. Each isometric exercise was held during 5 s. There was a 2 min rest between exercises. The execution was supervised by two researchers, who controlled the correct positioning of the participants.

Data reduction

Initially the EMG data was revised to eliminate possible artifacts. Then the EMG signals were full wave rectified, averaged every 0.01 s (Software MegaWin 2.5[®]) and normalized to maximum EMG values obtained during the MVICs. In order to rank the exercises by level of muscular activation, the center 3 s window of normalized EMG signal was averaged for each exercise and muscle.

Statistical analysis

With the aim of comparing the mean normalized EMG, a two-factor repeated-measures analysis of variance (ANOVA) was carried out (muscle and task). When ANOVA showed the existence of significant differences, a Bonferroni post-hoc analysis was used to establish the origin of these differences. The null hypothesis was discarded at a significance level of 95% ($p \leq 0.05$). Statistical data analysis was performed with the program SPSS 18.0.

RESULTS

Table 1 shows the average normalized trunk EMG for each exercise. They showed that the muscle activation levels needed to stabilize the trunk during the execution of the *bridges* were low-moderate. In this way, the EO was the only muscle that exceeded 30% of the MVIC during the execution of the tasks (*right side bridge*: 66.4% of MVIC).

Table 1. Mean and standard deviation (in brackets) of the normalized EMG for right rectus abdominis (RA), right external oblique (EO), right internal oblique (IO) and right erector spinae (ES) during the execution of the stabilization exercises.

EXERCISES	RA	EO	IO	ES
Front bridge	26.5 (14.4) ^d	36.1 (14.7) ^d	26.4 (14.8) ^d	8.0 (7.3)
Right side bridge	18.9 (9.5)	66.4 (29.9) ^{a,c,d}	28.3 (16.7)	20.8 (7.4)
Left side bridge	5.7 (3.3) ^b	2.6 (1.4)	10.3 (7.2) ^b	7.3 (4.4) ^b
Back bridge	2.8 (1.7)	2.1 (1.4)	6.4 (4.2) ^b	37.4 (10.8) ^{a,b,c}

Result of comparisons between muscles (post hoc Bonferroni):

^a indicates significant differences ($p \leq 0.05$) compared to RA.

^b indicates significant differences ($p \leq 0.05$) compared to EO.

^c indicates significant differences ($p \leq 0.05$) compared to IO.

^d indicates significant differences ($p \leq 0.05$) compared to ES.

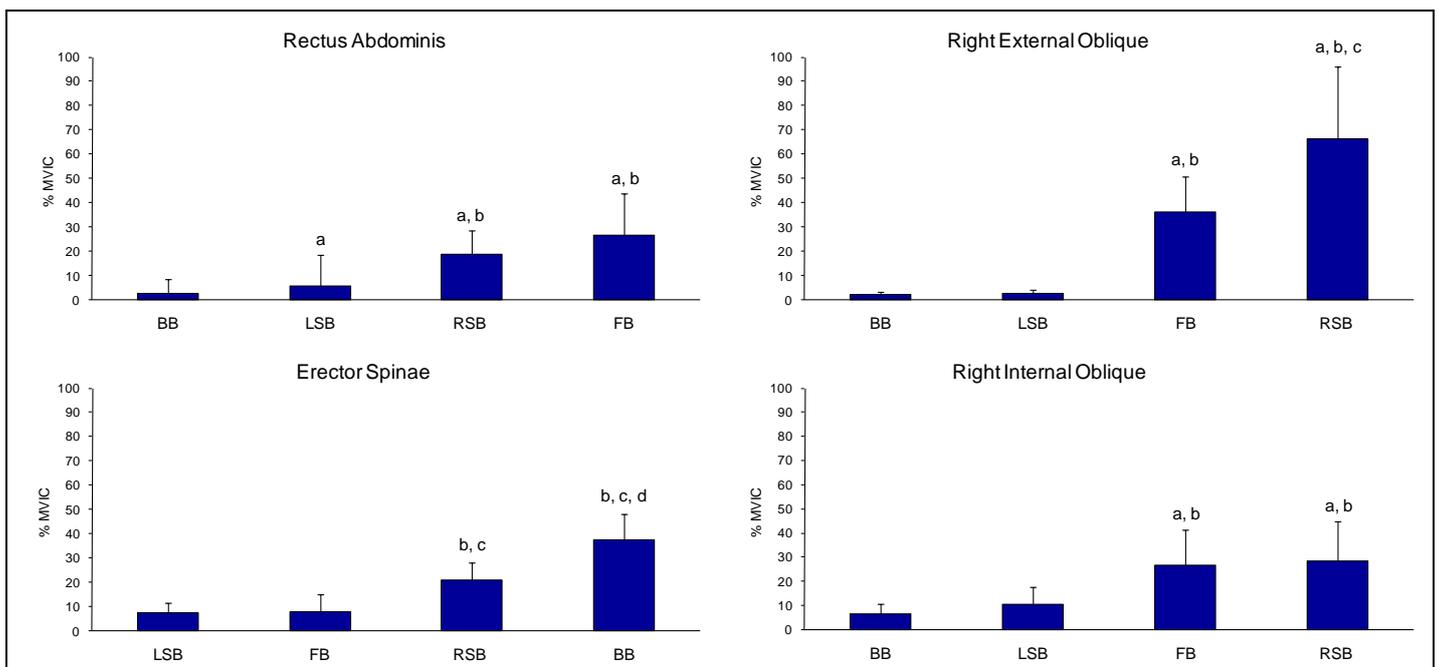


Figure 2. Comparison of the mean normalized EMG of each muscle between tasks: front bridge (FB), right side bridge (RSB), left side bridge (LSB) and back bridge (BB). Exercises have been ordered from lower to higher activation level. In the same way, Bonferroni pair comparison results are also shown: ^a indicates significant differences ($p \leq 0.05$) compared to BB; ^b indicates significant differences ($p \leq 0.05$) compared to LSB; ^c indicates significant differences ($p \leq 0.05$) compared to FB; ^d indicates significant differences ($p \leq 0.05$) compared to RSB.

The ANOVA showed a significant muscle*task interaction ($F = 43.304$; $p \leq 0.001$). When the comparison was carried out between muscles, there were differences in all the exercises analyzed (Table 1). In the *front bridge*, the abdominal muscle activation was significantly higher than that of the ES ($p \leq 0.006$), especially that obtained by the EO (36.1% MVIC). In the *right side bridge*, although all the right side muscles were co-activated, the EO activation level was also higher ($p \leq 0.001$). On the other hand, in the *left side bridge*, the activation of the right side muscles of the trunk was very low. The IO was the only muscle with an average activation higher than 10% of MVIC. To finish, in the *back bridge*, the highest activation level was found in the ES (37.4% MVIC), reaching significant differences when compared to the activation levels recorded in the abdominal muscles ($p \leq 0.001$).

As Figure 2 shows, the highest abdominal activation levels were found in the *front bridge* and in the *right side bridge*, although for the oblique muscles (especially the EO), the *side bridge* showed higher activation levels than the *front bridge*. On the other hand, the ES obtained higher activation in the *back bridge*, followed by the *right side bridge*.

DISCUSSION

Bridges are exercises designed to develop muscle coactivation patterns that facilitate trunk postural control and spine stabilization (McGill, 2002). These tasks are not always selected using scientific criteria which would be advisable, as sometimes it is done based on the trainers, coaches or physiotherapists' experience. The aim of our study was to describe the participation of abdominal and back muscles in the execution of the most currently used *bridges* (*front*, *back* and *side bridges*) and, in this way, provide useful information in the design of stabilization exercise programs.

As both, our results (Table 1) and those of previous studies show (Kavcic et al., 2004; Lehman et al., 2005; Stevens et al., 2006), low or moderate activation levels are needed to maintain the trunk raised from the bench and the spine in neutral position while performing the *bridges*. In this way, results of studies that have measured trunk mechanical stability show that it is not necessary to generate high levels of activation to stabilize the spine when faced with the forces to which it is confronted in most daily tasks (Cholewicki and McGill, 1996; Vera-García et al., 2006, 2007a and 2007b). On the other hand, it is important to generate muscle coactivation patterns that guarantee spine stability (Brown et al., 2006; McGill et al., 2003).

In this study, the muscle coactivation patterns recorded during the isometric *bridges* performance were characterized by the preferential activation of those muscles that counterbalanced the weight of the lower part of the body, maintaining the trunk in neutral position against gravity. Depending on how the body was positioned during each *bridge* (supine, prone or lateral), the muscle recruitment pattern changed, modifying the relative contribution of each muscle.

In the *back bridge*, ES reached the highest activation levels (37.4% MVIC), as it is the only analyzed muscle that generates trunk extension moments. Similar results have been obtained in previous studies (Ekstrom et al., 2007; Kavcic et al., 2004; Konrad et al., 2001; Lehman et al., 2005; Stevens et al., 2006). In these studies ES activation levels oscillated between 13% MVIC (Kavcic et al., 2004) and 36.96% MVIC (Konrad et al., 2001), depending on the differences in exercise execution techniques and EMG procedures. Unlike most researches, the *bridges* analyzed in our study were performed with extended elbows (*high bridges*), whilst in other studies the *front bridge* was carried out resting the shoulder girdle and the feet soles (with knees flexed) on the floor (Ekstrom et al., 2007; Kavcic et al., 2004; Konrad et al., 2001; Lehman et al., 2005; Stevens et al., 2006). Regarding surface EMG, the different normalization techniques used, and differences in the recording and treatment of the signal, make the direct comparison between the muscle activation levels obtained in the different studies difficult (Monfort-Pañego, Vera-García, Sánchez-Zuriaga and Sarti-Martínez, 2009).

In the *front bridge*, the abdominal muscles were activated (26.4-36.1% MVIC) to generate a flexor moment that allowed the participant to maintain the pelvis lifted against gravity. RA is considered the main trunk flexor, as it generates moments of force with a perpendicular direction to the sagittal plane (flexor moment) and its lever arm is higher than the rest of the abdominal muscles (Kapandji, 1988). Nevertheless, in our study, as in the studies by Lehman et al. (2005) and Imai et al. (2010), EO was the muscle which reached the highest activation levels. Despite this, in the studies by Ekstrom et al. (2007) and McGill and Karpowicz (2009) no important differences between the abdominal muscles were found. Once again, the origin of these discrepancies between studies can originate in the differences in exercise performance and EMG recording and treatment.

In the *right side bridge*, the posture was maintained due to the coactivation of the right trunk muscles. Because of their more lateral position, the oblique muscles, especially EO, have a higher capacity to stabilize the trunk in this type of *bridges*, reaching higher levels of muscular activation (Ekstrom et al., 2007; Imai et al., 2010; Kavcic et al., 2004; Lehman et al., 2005; McGill and Karpowicz, 2009). RA and ES also reached not high but significant levels of activation (around 20% of MVIC). In the *left side bridge* the right side trunk muscles were hardly activated, as if they had done so they would have generated forces that might have lowered the pelvis. In the exercises carried out in the frontal plane (lateral flexion or inclination), the muscles of the left and right side of the trunk worked as antagonists to each other, this is to say, the right side muscles are agonist of the flexion moments to the right and the left side muscles are agonist of the flexion moments to the left (McGill and Karpowicz, 2009).

From a practical point of view, Figure 2 allows the physical activity, sport and health professionals to choose the exercises that activate with higher intensity

levels each of the analyzed muscles. In this way, the *front bridge* and the *right side bridge* activated the abdominal muscles with a level of activation suitable for the development of muscular endurance. Regarding the lumbar muscles, the ES was activated with a higher intensity in the *back bridge*, although it also reached relatively high levels in the *right side bridge*. Although the extension function of the ES is more widely known, its most lateral fascicles also generate lateral flexion moments (Hubley-Kozey, Butler and Kozey, 2012). Traditionally, lateral flexion exercises have been used to train the oblique muscles, but their effect on the rest of the trunk muscles has been overlooked.

The analyzed exercises in this study were carried out in the sagittal (*back and front bridge*) or front plane (*side bridge*). To perform efforts in the horizontal plane (rotation) during the execution of the *bridges*, we need to raise or move one lower or upper limb. For example, when removing one of the 4 support points during the *front bridge* execution (raising an arm or a leg), the body tends to twist, being necessary to activate the rotator muscles to maintain the position. Future studies should analyze the trunk muscle recruitment when performing *bridges* with limb motion, as we are only aware of studies that have analyzed the effect of the movement of the lower limbs during the *back bridge* execution (Bjerkefors et al., 2010; Ekstrom et al., 2007; Kavcic et al., 2004; Stevens et al., 2006).

The participants in this study were healthy women with experience in spine stabilization exercise performance. If the sample had been comprised of people with a low physical condition or without prior knowledge in the execution of these exercises, possibly the muscle activation levels would have been different. Future studies should compare trunk muscle electromyography during the execution of *bridges* in different populations (sedentary people, patients with back pain, novice males and females, etc.).

CONCLUSIONS

Bridges generated low or moderate muscular coactivation patterns that can be used to improve spine stabilization and muscle endurance. These patterns were characterized by the preferential activation of those muscles that counteracted gravity, this is to say, the abdominal muscles in the *front bridge*, the muscles from the side of the arm of support in the *side bridge* and the erector muscles in the *back bridge*. This information will allow physical activity, sport and health professionals to choose the best exercises when prescribing trunk stabilization exercises.

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