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ORIGINAL

ELECTROMYOGRAPHIC STUDY OF TRUNK FLEXION EXERCISES ON INCLINED BOARD

ESTUDIO ELECTROMIOGRÁFICO DE EJERCICIOS DE FLEXIÓN DEL TRONCO SOBRE BANCO INCLINADO

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ABSTRACT

The purpose of this study was to analyze the electromyography of *rectus*, *external* and *internal oblique*, *erector spinae* and *biceps femoris* of 10 men and 10 women while performing isometric crunches on a board in different positions: horizontal (0º), inclined 10º with the head at the bottom (-10º) and at the top of the bench (+10º), and inclined 20º with the head at the bottom (-20º) and at the top of the bench (+20º). The results showed a muscular activation increase when the slope increased in the negative tilts (upside down). In the positive tilts, increasing the slope from +10º to +20º reduced the *rectus abdominis* activation, but increased the activation of the oblique muscles, especially of the *internal oblique*. Although men and women responded similarly to changes in the board tilt, women showed higher levels of *internal oblique* activation.

KEY WORDS: Inclined board, fitness, trunk muscles, electromyography.

RESUMEN

El objetivo del estudio fue analizar la electromiografía de *rectus*, *obliquus externus* y *obliquus internus abdominis*, *erector spinae* y *biceps femoris* de 10 hombres y 10 mujeres durante encorvamientos isométricos del tronco sobre un banco en diferentes posiciones: horizontal (0º), inclinado 10º con la cabeza en la parte inferior (-10º) y superior del banco (+10º) e inclinado 20º con la cabeza en la parte inferior (-20º) y superior del banco (+20º). Los resultados mostraron un incremento de la activación muscular al aumentar la pendiente en las inclinaciones negativas (cabeza abajo). En las inclinaciones positivas, el incremento de la pendiente desde +10º hasta +20º redujo la activación del *rectus abdominis*, pero incrementó la de los músculos oblicuos, especialmente la del *obliquus internus*. Aunque los hombres y las mujeres respondieron de forma similar ante los cambios en la inclinación, se encontraron mayores niveles de activación en el *obliquus internus* en las mujeres.

PALABRAS CLAVE: Banco inclinado, acondicionamiento físico, musculatura del tronco, electromiografía.

INTRODUCTION

Practicing regular trunk muscle conditioning exercises in structured training programs helps to improve abdominal muscle strength and endurance (Bell and Laskin, 1985; Vera-Garcia, 2003). The success of these programs depends on multiple factors, mainly, the number and type of exercises used (Axler and McGill, 1997; Juker, McGill, Kropf and Steffen, 1998), the type and speed of muscle contraction (Vera-Garcia, 2003; Vera-Garcia, Flores-Parodi, Elvira and Sarti, 2008) and the intensity, volume and training frequency (Cissik, 2002; Vera-Garcia, Monfort and Sarti, 2005b). In this way, electromyography is a useful tool to assess abdominal muscle recruitment and exercise intensity, helping physical activity and sports science professionals to develop adequate abdominal exercise programs.

In biomechanics, the election and prescription of exercises to strengthen abdominal muscles is based on two main criteria: efficiency and safety. An exercise is considered efficient when during its execution the abdominal musculature is activated with a high enough intensity to produce adaptations (Juker et al., 1998; Monfort-Pañego, Vera-Garcia, Sánchez-Zuriaga and Sarti-Martínez, 2009; Vera-Garcia et al., 2008; Vera-Garcia, Grenier, and McGill, 2000). On the other hand, safety is assessed through studies of the mechanical load on tissues, considering safe exercises those that do not impose high loads on the spine (Axler and McGill, 1997; Kavcic, Grenier and McGill, 2004*).* Among the exercises that have been considered efficient and safe, we can point out the following: *crunch* or *curl-up* (upper trunk flexion in lying supine) (Axler and McGill, 1997; Kavcic et al., 2004), *side bridge* (trunk stabilization exercise lying on the side, which consists in holding the pelvis lifted and the spine in a neutral position while resting on an arm and one or both legs) (Axler and McGill, 1997; Kavcic et al., 2004) and *bird dog* (trunk stabilization exercise in quadruped position, which consists in the contra-lateral raising of an arm and leg) (Kavcic et al., 2004).

In recent years there has been a great interest in the development of efficient and safe devices and equipment to perform trunk training programs. Most of these materials have been designed with two main objectives: a) to create abdominal co-activation patterns that increase spine stability, for example unstable surfaces (bosu, fitball, etc.) (Bressel, Willardson, Thompson and Fontana, 2009; Vera-Garcia et al., 2000) and oscillation poles (Bodyblade®, Flexibar®, etc.) (Moreside, Vera-Garcia and McGill, 2007; Sánchez-Zuriaga, Vera-Garcia, Moreside and McGill, 2009; Vera-Garcia, Moreside, Flores-Parodi and McGill, 2007); and/or b) to increase muscular activation levels using medicine balls (Vera-Garcia et al., 2007), free weights (Cerny, 1991), abdominal training machines (Sternlicht and Rugg, 2003; Vera-Garcia and Sarti, 1999), inclined boards (Escamilla, Babb, DeWitt, Jew, Kelleher, Burnham, Busch, D'Anna, Mowbray and Imamura, 2006; Guimaraes, 1991; Gutin and Lipetz, 1971; Monfort, 1998; Moraes, Bankoff and Pellegrinotti, 1995), etc.

Despite the great number of electromyography studies that have assessed the trunk muscle response in abdominal exercises, there are few studies that have analyzed contraction intensity or trunk muscle coordination while performing abdominal conditioning exercises on inclined boards (Escamilla et al., 2006; Guimaraes, 1991; Gutin and Lipetz, 1971; Monfort, 1998; Moraes et al., 1995). In these studies the electromyography of *rectus abdominis* and *external oblique* has been recorded while performing exercises such as *sit-ups* (trunk and hip flexions from supine to sitting position)

(Guimaraes, 1991; Gutin and Lipetz, 1971; Monfort, 1998; Moraes et al., 1995), *crunches* (Monfort, 1998) and *reverse crunches* (lower trunk flexion exercises in lying supine) (Escamilla et al., 2006; Monfort, 1998).

According to the results obtained in these studies, performing *crunches* (Monfort, 1998) and *reverse crunches* (Escamilla et al., 2006; Monfort, 1998) on inclined boards increases the intensity of *rectus* and *external oblique* activation, although this is not always the case with *sit-ups* (Guimaraes, 1991; Gutin and Lipetz, 1971; Monfort, 1998; Moraes et al., 1995). In these studies there was only a muscular activation comparison between exercises performed on an inclined board and a horizontal plane; therefore it is necessary to perform further research on trunk muscle response in different inclined boards. Another question to be answered is the participation of the deep abdominal muscles while using inclined boards, as we are only aware of one study which analyzed the activation of *internal oblique* (Escamilla et al., 2006). In this study a higher *internal oblique* activation was found while performing *reverse crunches* on an inclined board when compared to a horizontal plane.

During the use of inclined boards, participants normally place the part of the body that moves in the lower part of the bench, with the aim of increasing the exercise intensity. Therefore, for example, in a *crunch* execution participants are lying supine on the bench, with their feet held in the top part and with their thorax, arms and head in the lower part. We have no knowledge of studies which have analyzed other uses of inclined boards, as for example, placing the participants the other way round, this is to say, with the upper body in the top part of the bench.

The aim of this study was to use surface electromyography to analyze *rectus abdominis*, *external oblique*, *internal oblique*, *erector spinae* and *biceps femoris* recruitment during the execution of isometric *crunches* in the following positions: inclined position at 10º and 20º tilt from the horizontal plane with the head in the lower part of the bench (-10º and -20º tilt, respectively) (Figure 1A); horizontal or conventional position (0º) (Figure 1B); inclined position at 10º and 20º tilt from the horizontal plane with the head in the upper part of the bench (+10º and +20º tilt, respectively) (Figure 1C).

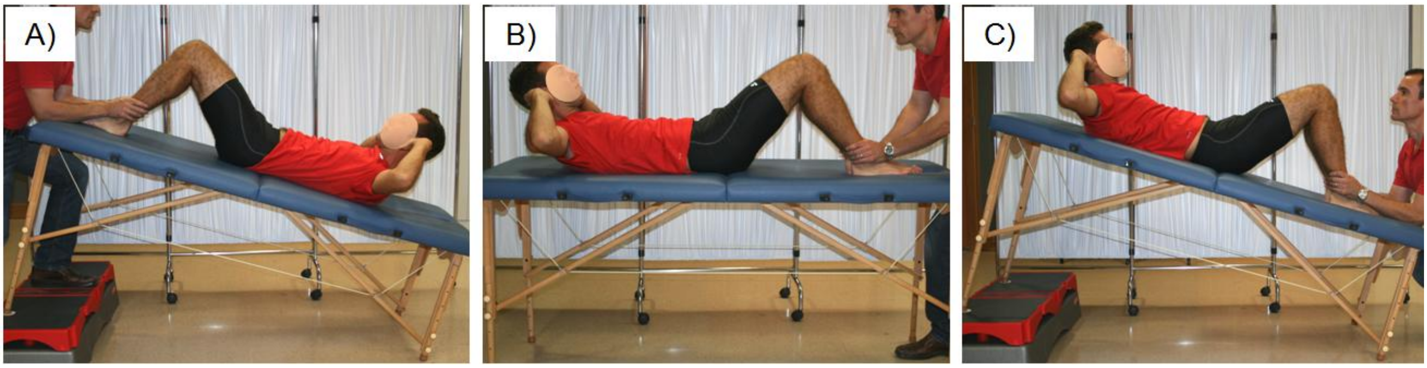

Figure 1. Images of the execution of the *crunch* exercise in different positions: A) Negative tilt (head down); B) Horizontal position (conventional exercise); C) Positive tilt (head up).

From a mechanical point of view, the negative tilt increase (head down) will increase the lever arm (distance between the centre of gravity of the body segments that we want to move and the fulcrum), and therefore, the difficulty of the exercise, due to which we hypothesize an increase of the muscle activation level. Likewise, the increase in the positive tilt (head up) will facilitate the raising of the thorax during the trunk flexion, which should reduce *rectus abdominis* activation (main flexor of the trunk). On the other hand, taking into account the role of *internal oblique* holding the abdominal viscera in standing position (Floyd and Silver, 1950; Keiichi, 1958; Vera-Garcia, Moreside and McGill, 2011), we hypothesize that the oblique muscle activation will not decrease with the increase of the positive tilt. In the same way, the referred muscles will not only activate to bend the trunk, but also to hold the abdominal viscera in their cavity when they are pushed downwards due to trunk flexion and the force of gravity.

MATERIALS AND METHODS

Participants

Twenty health individuals voluntarily took part in this study: 10 men (age = 23.44 ± 2.50 years; mass = 75.67 ± 4.96 kg; height = 1.76 ± 0.08 m) and 10 women (age = 22.66 ± 2.12 years; mass = 55.49 ± 8.14 kg; height = 1.62 ± 0.06 m). All individuals exercised regularly (1-3 days/week), but did not take part in any structured trunk muscle conditioning program. Following the Declaration of Helsinki, participants were informed of the study characteristics and signed a written consent before starting the research. Those individuals with medical problems, a history of abdominal or spine surgery, or episodes of back pain which had required treatment one year before the beginning of this study were excluded from the research.

Electromyography recording

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 they were monitored by Megawin® 2.5 program (Mega Electronics Ltd., Kuopio, Finland) and stored for their later analysis.

The EMG signals were recorded in the following muscles and locations of the right side of the body (Figure 2): *rectus abdominis* (RA), approximately 3 cm lateral to the right of the umbilicus (Garcia-Vaquero, Moreside, Brotons-Gil, Peco-Gonzalez and Vera-Garcia, 2012); *external oblique* (EO), approximately 15 cm lateral to the right of the umbilicus (Bouillon, Wilhelm, Eisel, Wiesner, Rachow and Hatteberg, 2012; Garcia-Vaquero et al., 2012); *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); *erector spinae* (ES), 3 cm lateral to the right of the spinous process of L3 (Garcia-Vaquero et al., 2012; Perroto, 2005); and *biceps femoris* (BF), the central point of the line between the ischial tuberosity and the lateral epicondyle of the right tibia (SENIAM guidelines; Hermens, Freriks, Disselhorst-Klug and Rau, 2000). The sites of the electrodes were 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 was carried out with a skin marker (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. 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. 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.

Figure 2. Location of the electrodes on the muscles analyzed in this study: RA, *rectus abdominis*; EO, *external oblique*; IO, *internal oblique*; ES, *erector spinae*; BF, *biceps femoris*.

In order to normalize the EMG signals, two series of maximal voluntary isometric contractions (MVCs) against manual resistance were carried out. For the abdominal muscles, the participant produced maximal contraction efforts in trunk flexion, and lateral bend and twist to the left and right. For ES and BF, maximal trunk and hip extensions in Biering-Sorensen position (Biering-Sorensen, 1984) and knee flexion in sitting position were performed. Each maximal contraction was maintained during 4-5 s. A 5 min rest was allowed between each series to avoid muscle fatigue. The MVC protocol has been described in previous studies (Vera-Garcia, Moreside and McGill, 2010).

Procedure

Prior to EMG recording, participants were verbally and visually instructed on correct exercise technique. Then participants carried out the isometric *crunches* in different angles (Figure 1): -20º, -10º, 0º, +10º and +20º. As Figure 1 shows, each *crunch* consisted in an upper trunk flexion until the inferior angle of the scapula lifted from the bench (Vera-Garcia, Arroyo Fenoll, López Elvira, Alonso Roque, Flores-Parodi and Sarti, 2005a; Vera-Garcia et al., 2008). Exercise execution was supervised by two researchers, who controlled the correct *crunch* position.

The order of the exercise performance in the different tilts was randomized between subjects to avoid that this fact influenced the results. During the EMG recording, participants performed a 10 s isometric contraction in each task. There was a 2 min rest between exercises.

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 MVCs. The center 6 s window of normalized EMG signal was averaged for each exercise and muscle.

Statistical analysis

A mixed-design repeated measures analysis of variance (ANOVA) was performed to compare the normalized EMG amplitudes between *board tilt* (within-subjects factor) and *sex* (between-subjects factor). 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

Figure 3 shows the mean normalized EMG obtained from RA, EO, IO, ES and BF in the different tasks. As can be seen in the graph, the abdominal muscle activation levels were low or moderate. The highest activation levels were obtained in RA (21.1-33.4% MVC), followed by IO (15.4-23.6% MVC) and EO (6.7-10.1% MVC). BF and ES hardly activated during the execution of the isometric *crunches*.

ANOVA showed no significant interaction *board tilt*sex* for none of the muscles analyzed ($p > 0.05$; $ή^2 \leq 0.122$). Nevertheless, there were significant differences in the *board tilt* factor for RA ($p \leq 0.01$; $ή^2 = 0.408$), EO ($p \leq 0.05$; $ή^2 = 0.157$), IO ($p \leq 0.01$; $ή^2 = 0.229$), ES ($p \leq 0.01$; $ή^2 = 0.369$) and BF ($p \leq 0.01$; $ή^2 = 0.403$). When changing from a negative tilt (head down) to a positive tilt (head up), there was a decrease in the muscle activation level, especially for RA. According to the results of the Bonferroni pairwise comparisons (Figure 3), there were significant differences in RA between the -20º tilt and the rest of the tilts ($p \leq 0.05$), except the comparison with the horizontal plane (0º), and between the -10º and +20º tilts ($p \leq 0.05$). In the same way, significant differences were also found between the -20º tilt and the rest of tilts in BF and ES ($p \leq 0.05$), and between the -20º tilt and the rest of positive tilts in IO ($p \leq 0.05$). There were no significant differences between the different conditions for EO. As seen in Figure 3, unlike RA results, there was a slight increase in the normalized EMG amplitude for the oblique muscles when changing from the +10º tilt to the +20º tilt, especially for IO. Nevertheless, although these differences showed a contrary tendency to that observed in RA, they were not statistically significant.

Regarding *sex* factor, ANOVA only found significant differences for IO ($p \leq 0.01$; $ή^2 = 0.415$). The activation levels for women (-20º tilt: 31.65% MVC; -10º tilt: 26.62% MVC; horizontal position: 24.83% MVC; +10º tilt: 20.29% MVC; +20º tilt: 21.85% MVC) were significantly higher than those for men (-20º tilt: 15.57% MVC; -10º tilt: 13.59% MVC; horizontal position: 11.59% MVC; +10º tilt: 10.54% MVC; +20º tilt: 10.88% MVC) in all positions.

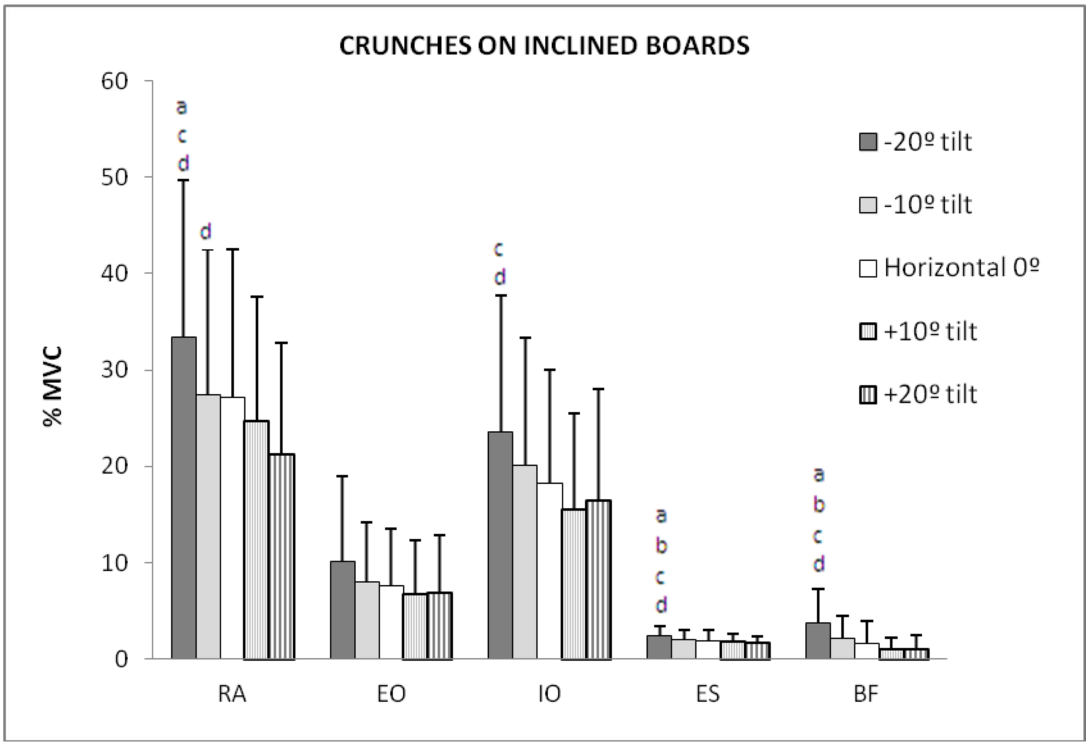

Figure 3. Mean and standard deviation of the normalized EMG of *rectus abdominis* (RA), *external oblique* (EO), *internal oblique* (IO), *erector spinae* (ES) and *biceps femoris* (BF) during isometric crunches performed in different tilts: a) -20º tilt from the horizontal position with head down; b) -10º tilt from the horizontal position with head down; c) horizontal position (0º); d) +10º tilt from the horizontal position with head up; e) +20º tilt from the horizontal position with head up.

Results of the multiple Bonferroni comparisons:

[a] indicates significant differences ($p \leq 0.05$) compared to -10º tilt.

[b] indicates significant differences ($p \leq 0.05$) compared to the horizontal position (0º).

[c] indicates significant differences ($p \leq 0.05$) compared to +10º tilt.

[d] indicates significant differences ($p \leq 0.05$) compared to +20º tilt.

DISCUSSION

Biomechanical studies have analyzed the efficiency and safety of different devices used for abdominal muscle conditioning. Among these we can highlight inclined boards, designed to increase trunk flexion exercise intensity. Nevertheless, only Monfort (1988) has analyzed the trunk muscle EMG when performing *crunches* in inclined boards. Other authors have also analyzed the efficiency of these devices in exercises such as the *reverse crunch* (Escamilla et al., 2006; Monfort, 1998) and the *sit-up* (Guimaraes, 1991; Gutin and Lipetz, 1971; Montfort, 1998; Moraes et al., 1995), but only Escamilla et al. (2006) have recorded the EMG of IO. In our study we analyzed the EMG of RA, EO, IO, ES and BF during the execution of isometric *crunches* in different inclined tilts (head up and head down) and in the horizontal plane. The results of this study confirm our hypotheses, as although there was an increase in the activation of all muscles when changing from horizontal plane to negative tilts (head down), the results were different between muscles when assessing the effect of the positive tilts (head up). Whilst RA activation decreased when changing from +10º tilt to +20º tilt, the obliques activation increased slightly.

Crunches are activities that are normally used in trunk muscle conditioning for their efficiency and safety (Axler and McGill, 1997; Kavcic et al., 2004). RA is the main flexor in these exercises, as it activates with the highest intensity (Figure 3), its fibers shorten in the sagittal direction and it generates flexor moments through a high lever arm (Kapandji, 1998). On the other hand, the bilateral activation of the oblique muscles also has a main role in trunk flexion (McGill, 1996). In this study, IO activation was higher than that of EO, which is consistent with the results of Andersson, Nilsson and Thortensson (1997) and Vera-Garcia et al. (2005, 2005a and 2008). Nevertheless, opposite results have been found in other studies (Juker et al., 1998), possibly due to methodological differences related with EMG signal normalization, exercise execution technique and electrode placement, among others.

When the *crunch* was performed head down in an inclined board, the role of the muscles did not change, but there was a significant increase in muscle activation. This data supports the previous findings by Monfort (1998). Mechanically, the increase of the activation of the trunk flexors when changing from a horizontal position to a -20º tilt may be explained by the increase of the lever arm of the upper body weight, this is to say, by the increase in the distance between the center of mass of the body segments to be moved and the fulcrum. This change in the lever arm increased the extensor moment, which meant a higher effort to maintain the *crunch* position, and therefore, a higher activation of the agonist muscles (RA, IO and EO).

On the other hand, the low BF and ES activation levels showed the poor implication of this musculature in trunk flexion exercises and, therefore, it confirmed that they are not agonist muscles of this action, as they are more activated during knee flexion or hip and trunk extension (Escamilla et al., 2006; Guimaraes, 1991; Konrad, Schmitz and Denner, 2001). The fact that the activation of both muscles increased in negative tilts could be due to the effort of BF to maintain the knee flexion during the exercise execution and to the compression of the ES electrodes against the bench (Vera-Garcia et al., 2008).

When *crunch* exercises were carried out in an inclined board with head up, the distance between the center of mass of the body segments to be moved and the fulcrum was reduced, reducing the extensor moment and therefore the flexor muscle activation. RA activity decreased when the tilt changed from horizontal position to +10º tilt and from +10º tilt to +20º tilt. On the other hand, although the oblique muscle activation decreased when the tilt changed from horizontal to +10º tilt, there was an increase when the tilt changed from +10º tilt to +20º tilt, especially for the IO (Figure 3), which is consistent with the initial hypothesis that postulated an increase of the oblique muscle activation with the increase of the slope in positive tilts. We have no knowledge of similar studies with which to compare our results; nevertheless these could be explained by the role of the abdominal muscles holding in the abdominal viscera (Floyd and

Silver, 1950; Keiichi, 1958; Vera-Garcia et al., 2011). Possibly, in these positive tilts, the upper trunk flexion and the force of gravity pushed the abdominal viscera downwards, stretching the abdominal wall fibers, especially those that are more transversal, as for example the IO fibers in the place where the electrodes were placed (Figure 2) (Ng et al., 1998; Urquhart et al., 2005). Therefore, the stretching of the muscle fibers could have triggered stretching reflexes that helped hold the abdominal viscera in their place and would justify the increase of the IO normalized EMG in the +20º tilt. Taking into account that different regions of the oblique muscles can be activated selectively depending on the task performed (Mirka, Kelaher, Baker, Harrison and Davis, 1997; Moreside, Vera-Garcia and McGill, 2008), we could have obtained different results, had we analyzed the IO in a region in which its fibers had a more longitudinal direction to the trunk.

In reference to the effect of *sex* on trunk muscle response, both men and women had similar responses to tilt change. Nevertheless, we found higher IO activation levels in women for all analyzed positions. Although there are studies that have found differences between sexes in RA, EO and IO activation during flexor moments in different positions (Anders, Brose, Hofmann and Scholle, 2007), most electromyographic studies on trunk exercises have found no differences in trunk muscle activation between men and women (García-Vaquero et al., 2012; Nelson, Bent-Forsythe and Roopchand-Marin, 2012; Sternlicht and Rugg, 2003). The higher IO activation in women could be due to anatomical differences between sexes, as for example, differences in skeletal muscle mass (Janssen, Heymsfield, Wang and Ross, 2000), pelvis shape and trunk muscle size (Marras, Jorgensen, Granata and Wiand, 2001). Nevertheless, the origin of these differences between sexes in the IO activation could also originate from the EMG signal normalization to maximum values (MVCs). In this sense, a previous study by Vera-Garcia et al. (2010) in female dancers found it difficult to perform MVCs that reached the real maximum values in the oblique musculature. In this way, it is possible that the reference values obtained for the women during the MVCs in our study were not real maximum values, but sub-maximum, which would have as a consequence that the EMG percentages obtained during the *crunches*, and calculated with respect to the MVCs values, were higher than they really are (Vera-Garcia et al., 2010). Future studies must explore the possible differences in the abdominal muscle activation between men and women, and also their possible relationship with anatomical, physiological and mechanical differences.

The interpretation of the results of this study is limited by the great EMG data variability between participants (Figure 3). This fact is normal in trunk electromyographic studies and it usually limits the finding of significant differences between the conditions analyzed (Vera-Garcia et al., 2010 and 2011). Future studies must corroborate our results by using a higher number of different tilts or positions and increasing the size and homogeneity of the sample.

CONCLUSIONS

The data of this study can be useful to establish different intensity exercise progressions. The increase of the tilt in the conventional inclined board exercises (head down) increased the normalized EMG of the analyzed muscles, and therefore it seems an adequate strategy to increase *crunch* intensity. On the other hand, taking into account that the positive inclination reduced the extensor moment, and as a consequence the flexor moment and the RA activation, the use of inclined boards with trunk, head and arms in the upper part, could be an adequate strategy to facilitate the execution of trunk flexion exercises in men and women with limited physical condition due to inactivity, illnesses or age.

The results of this study have also allowed a deeper insight into the study of trunk muscle functions and their differences depending on *sex*. When compared with the limb musculature, the activation of these muscles generates forces that not only help to produce different movements or postures, but also have an important effect on the abdominal, pelvic and thoracic organs (lungs, intestines, bladder, etc.). In this way, the increase in IO activation when changing from +10º tilt to +20º tilt, which reduces the extensor moment, seems to show the role of IO to hold in the abdominal viscera during this exercise.

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