Motricidade © Edições Desafio Singular
2014, vol. **10**, n. **4**, pp. **84-93** http://dx.doi.org/10.6063/motricidade.10(4).3395

Muscle activation differences between stable push-ups and push-ups with a unilateral v-shaped suspension system at different heights

Diferenças na ativação muscular entre a realização de flexões com apoio fixo e com um sistema de suspensão unilateral em forma de V em diferentes alturas

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ARTIGO ORIGINAL | *ORIGINAL ARTICLE*

ABSTRACT

This study was designed to analyze upper extremity and core muscle activation performing push-ups under different stability conditions and body positions. Trained university male students (n= 29) performed 3 push-ups each under stable conditions and using suspension device (AirFit Trainer ProTM) with their hands at 2 different heights (i.e., 10 and 65 cm). Push-up speed was controlled using a metronome and the testing order was randomized. The average amplitudes of the electromyographic root mean square of the Triceps Brachii, Upper Trapezius, Anterior Deltoid, Clavicular Pectoralis, Rectus Abdominis, Rectus Femoris, Lumbar Erector Spinae and Gluteus Maximus were recorded and normalized to the maximum voluntary isometric contraction. A repeated-measures analysis of variance with a Bonferroni post hoc test was used to analyze data. Suspended push-ups provided greater activity than the stable condition, except for the Anterior Deltoid and Clavicular Pectoralis. Therefore, suspended push-ups are especially advantageous if the goal of the exercise is targeting the TRICEP, TRAPS and/or core training. Overall, performing push-ups at 65 cm from the floor decreases exercise intensity and muscle activity in comparison with the 10 cm position.
Keywords: EMG, suspension training, core, body position

RESUMO

Este estudo foi realizado com vista a analisar a ativação muscular do tronco e "core" na realização de flexões sob diferentes condições de estabilidade e posições corporais. Estudantes universitários do sexo masculino treinados (n= 29) realizaram três flexões de braços em condições estáveis e em suspensão (AirFit instrutor ProTM) com as mãos em duas alturas diferentes (10 e 65 cm). A velocidade de execução foi controlada usando um metrónomo sendo a ordem dos testes aleatória. A amplitude média da atividade eletromiográfica do *Triceps Brachii, Upper Trapezius, Anterior Deltoid, Clavicular Pectoralis, Rectus Abdominis, Rectus Femoris, Lumbar Erector Spinae* e *Gluteus Maximus* foram registados e normalizados tendo por base a contração isométrica máxima. Foi utilizada a análise de variância para medidas repetidas, com o teste de Bonferroni para análise dos dados. Flexões de braços suspensas proporcionam maior atividade muscular do que realizadas em condição de estabilidade, com exceção do *Anterior Deltoid* e *Clavicular Pectoralis*. Portanto, flexões de braços suspensas são especialmente vantajosas se o objetivo for o treino dos *Triceps Brachii*, *Upper Trapezius* e/ou dos músculos do "core". A realização de flexões a 65 cm do chão diminui a intensidade do exercício e a atividade muscular comparativamente com a posição a 10 cm.
Palavras-chave: eletromiografia, treino em suspensão, core, posição corporal

Manuscript received January 20, 2014; Revised February 18, 2014; Accepted March 13, 2014

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INTRODUCTION

The push-up is a popular exercise for strengthening the upper body (Gouvali & Boudolos, 2005; Youdas et al., 2010). The push-up is simple to learn and can be customized (Gouvali & Boudolos, 2005). Variations in the exercise may change muscular activation patterns (Youdas et al., 2010). One possible modification is varying the height of the hands and performing the exercise in unstable conditions. Several authors reported muscle activity changes when they compared unstable push-ups with standard floor push-ups (Freeman, Karpowicz, Gray, & McGill, 2006; Lehman, Macmillan, MacIntyre, Chivers, & Fluter, 2006). Lehman et al. (2006) discovered that push-ups performed using unstable devices activate the triceps brachii in a greater extent. Freeman et al. (2006) found that unstable push-ups lead to a higher percentage of maximum voluntary isometric contraction (MVIC) especially for the abdominal wall. Similarly, Marshall and Murphy (2005) found higher rectus abdominis muscle activation during the unstable condition than in the stable condition.

A relatively new potential variation of the push-up consists of performing the exercise with a suspension training device. However, only one study regarding suspended push-ups has been published and these authors did not study upper extremity muscles (Beach, Howarth & Callaghan, 2008). Beach et al. (2008) reported a significant increase in abdominal wall activity during push-ups performed with suspended chains compared with the stable conditions.

One of several types of suspension training systems are those that provide greater unilateral motion because of the movement allowed by a pulley and thus also provide a different instability degree. However, there is a lack of evidence with regard to the effects that provide this kind of suspension devices on muscle activation during push-up exercises at different heights in comparison to traditional floor push-ups. Therefore, this study aimed to compare muscle activation of the upper extremity and core muscles during push-ups performed in stable and unstable conditions (i.e., stable and unilateral v-shaped suspended system) at different heights (i.e., 10 and 65 cm). Our first hypothesis was that the greater unstable degree and the unilateral motion allowed by the use of the suspension device would significantly increase global muscle activation of upper extremity and core muscles. Our second hypothesis was that for the clavicular pectoralis and anterior deltoid similar muscle activation in stable and unstable conditions would be achieved.

METHOD

Participants

Twenty nine healthy university students (n= 29; mean ± SD - age: 23.5 ± 3.1 years; height: 178.2 ± 5.9 cm; body mass: 75.2 ± 8.5 kg; body fat percentage: 10.0 ± 2.5 % and biacromial width: 39.1 ± 1.5 cm) volunteered to take part in this study. The number of subjects chosen was calculated using G Power Software (University of Kiel, Germany) and was based on effect size of 0.25 SD with an α level of 0.05 and power at 0.80. Participants had a minimum of 1 year of resistance training, performing at least 2 sessions per week of moderate to vigorous intensity. No subject included in this study presented musculoskeletal pain, neuromuscular disorders or any form of joint or bone disease. This study was carried out in the spring. All participants signed an institutional informed consent form before starting the protocol and Institutional Review Board approval was obtained before the study. All procedures described in this section comply with the requirements listed in the 1975 Declaration of Helsinki and its 2008 amendment.

Procedures and Instruments

Each subject took part in 2 sessions: familiarization and experimental sessions - both at the same time in the morning. The first session took place 48-72 hrs before data collection in the experimental session. Several restrictions were imposed on the volunteers: no food, drinks or stimulants (e.g., caffeine) to be consumed 3-4 hrs before the sessions and no physical activity more intense than normal daily activities 12 hrs before the exercises. They were instructed to sleep more than 8 hours the night before data collection. The same investigators made all measurements, during the morning and the procedures were always conducted in the same sportive facility (with temperature at 20° C). The study was done during April.

Familiarization Session

During the familiarization session, the participants were familiarized with the push-up exercise, the stable conditions, suspension device, movement amplitude, body position and cadence of movement that would later be used during data collection. Participants practiced the exercises typically 1-3 times each until the subject felt confident and the researcher was satisfied that the form had been achieved. In addition, height (IP0955, Invicta Plastics Limited, Leicester, England), body mass, body fat percentages (Tanita model BF-350) and biacromial width were obtained according to the protocols used in previous studies (García-Massó et al., 2011).

Experimental Session

The protocol started with the preparation of participants' skin, followed by electrode placement, MVIC collection and performance of the exercise. 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, 1998) on the Triceps Brachii (TRICEP), Upper Trapezius (TRAPS), Anterior Deltoid (DELT), Clavicular Pectoralis (PEC), Rectus Abdominis (ABS), Rectus Femoris (FEM), Lumbar Erector Spinae (LUMB) and Gluteus Maximus (GLUT) on the dominant side of the body. Pre-gelled bipolar silver/silver chloride surface electrodes (Blue Sensor M-00-S, Medicotest, Olstykke, DNK) were placed on the following muscle groups with an inter-electrode distance of 25 mm: a) TRICEP (parallel to the muscle fibers, 2 cm medial from midline of the arm, approximately 50% of the distance between the acromion and the olecranon or elbow), b) TRAPS (parallel to the muscle fibers of the upper trapezius, along the ridge of the shoulder, slightly lateral to and one-half the distance between the cervical spine at C-7 and the acromion), c) DELT (on the anterior aspect of the arm, approximately 4 cm below the clavicle, parallel to the muscle fibers), d) PEC (on the chest wall at an oblique angle toward the clavicle, approximately 2 cm below the clavicle, just medial to the axillary fold), e) ABS (3 cm apart and parallel to the muscle fibers so that they are located approximately 2 cm lateral and across from the umbilicus over the muscle belly), f) FEM (on the center of the anterior surface of the thigh, approximately half the distance between the knee and the iliac spine, parallel to the muscle fibers), g) LUMB (parallel to the spine, approximately 2 cm from the L-3 vertebra over the muscle mass), and h) GLUT (in the middle of the muscle clearly below the level of the trochanter, 2 to 3 cm above the gluteal fold). The reference electrode was placed between the active electrodes, approximately 10 cm away from each muscle, in accordance with the manufacturer's specifications. Once the electrodes were placed, participants performed 2 standard push-ups on the floor in order to check signal saturation. 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. An ME6000P8 (Mega Electronics, Ltd., Kuopio, Finland) biosignal conditioner was used to acquire the surface EMG signals produced during exercise.

Prior to the dynamic exercises described below, two 5s MVICs were performed for each muscle and the trial with the highest EMG was used (Jakobsen, Sundstrup, Andersen, Aagaard, & Andersen, 2013). Participants performed 1 practice trial to ensure that they understood the task, 1-minute rest was given between each MVIC and standardized verbal encouragement was provided to motivate all participants to achieve their maximum. Positions for the MVICs were performed according to standardized procedures, chosen based on commonly used muscle testing positions for the (1) TRICEP (Kendall, McCreary, Provance, Rodgers, & Romani, 2005), (2) PEC (Snyder & Fry, 2012),(3) DELT (Ekstrom, Soderberg, & Donatelli, 2005), (4) TRAPS (Ekstrom et al., 2005), (5) ABS (Vera-García, Moreside, & McGill, 2010), (6) LUMB (Jakobsen et al., 2013), (7) GLUT (Distefano, Blackburn, Marshall, & Padua, 2009), (8) FEM (Jakobsen et al., 2013) and were performed against a fixed immovable resistance (i.e., Smith machine). Concretely: (1) forearm extension with elbows at 90º in a seated position an erect posture with no back support (2) bench press with a grip at 150% of biacromial width, the shoulder abducted at 45º and feet flat on the bench (3) deltoid flexion at 90º in a seated position an erect posture with no back support (4) deltoid abduction at 90º in a seated position an erect posture with no back support and (5) curl up at 40º with arms on chest and pressing against the bar with the participant lying on the bench and feet flat on the bench, (6) trunk extension (with the participant lying on the bench and pelvis fixated, the trunk was extended against the bar), (7) resisting maximum-effort hip extension, performed with the subject lying prone on a treatment table, with the knee flexed 90° and (8) static knee extension (with the participant positioned in a Biodex dynamometer: knee angle: 70º and hip angle: 110º).

The participants performed the 3 push-ups under 4 conditions (see Figure 1) in a random order to reduce threats to the study's internal validity, with 2 min interval between them. Stable and suspension equipment (AirFit Trainer Pro, PurMotion™, Pelham, AL, USA) conditions were performed at 10 cm and 65 cm from the floor. AirFit Trainer Pro has a main band supported by a spring and a V cable with a pulley in the middle. Therefore, friction is reduced and greater unilateral motion is allowed. Greater unilateral movements provide disruptive torque that contributes to instability (Behm & Colado, 2012), thus this equipment is considered very unstable. The participants started the push-ups in an extended arm (up) position with forearms and wrists pronated, feet at biacromial (shoulder) width. The arm was positioned perpendicular to the floor. In the down position, the forearm and wrists were kept pronated, while the elbow was flexed at approximately 90º and the shoulder abducted at approximately 45º. A Cross Line Auto Laser Level was fixated with a tripod (Black & Decker LZR6TP, New Britain, CT, USA) and used as a visual feedback for researchers in connection to requested elbow and shoulder joint positioning during exercises. Hip and spine were maintained neutral during all repetitions. Push-ups at 10 cm and 65 cm under stable condition were performed with each hand placed on a box and with both hands grasping a bar in a Smith machine, respectively. Push-ups at 10 cm and 65 cm with suspension equipment were performed with each hand grasping a handle. Each subject performed three consecutive repetitions in all conditions. A 2-second rate for descent and ascent of an individual push-up cycle was maintained by a 30-Hz metronome (Ableton Live 6, Ableton AG, Berlin, Germany) to standardize speed of movement (Freeman et al., 2006). Each subject used a standardized grip width of 150% of biacromial width (distance in centimeters between the tips of right and left third digits). Visual feedback was given to the participants in order to maintain the range of movement and hand distance during the data collection. A trial was discarded and repeated if participants were unable to perform the exercise with the correct technique.

Data analysis

Surface EMG signal analyses were perfor-

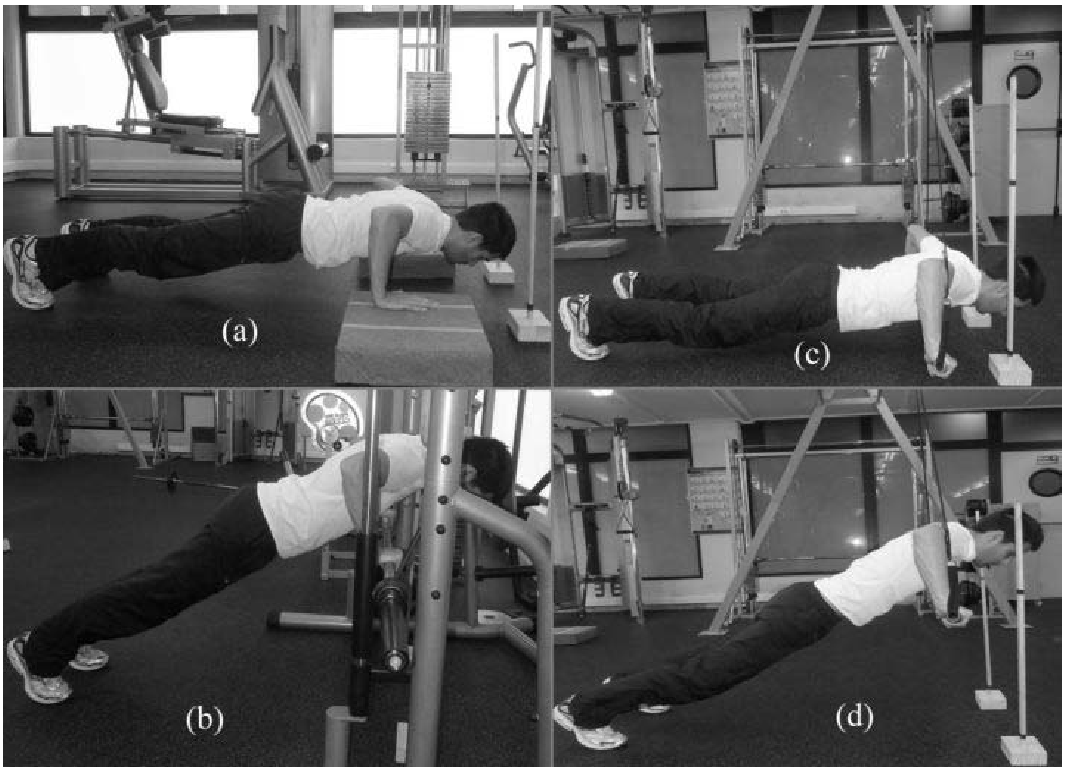

Figure 1. Push-ups performed in 4 different conditions: (a) stable, hands at 10 cm from the floor; (b) stable, hands at 65 cm from the floor; (c) suspension equipment, hands at 10 cm from the floor and (d) suspension equipment, hands at 65 cm from the floor

med formed using Matlab 7.0 (Mathworks Inc., Natick, MA, USA). Surface EMG signals related to isometric exercises were analyzed by using the 3 middle seconds of the 5-second isometric contraction. The EMG signals of the dynamic exercises were analyzed by taking the average of the entire three repetitions. All signals were bandpass filtered at a 20- to 400-Hz cutoff frequency with a fourth-order Butterworth filter. Surface EMG amplitude in the time domain was quantified by using the root mean square (RMS) and processed every 100 ms. Mean RMS values were selected for every trial. The data obtained were normalized by using the maximum RMS values during the MVIC and expressed as a percentage of the maximum EMG (%MVIC). Mean values of the %MVIC of the upper extremities muscles (i.e. TRICEP, TRAPS, DELT and PEC); of the core muscles (i.e., ABS, FEM, LUMB and GLUT) and global mean of all muscles (i.e., TRICEP, TRAPS, DELT, PEC, ABS, FEM, LUMB and GLUT) were also calculated and analyzed.

Statistical Analyses

Statistical analysis was carried out using SPSS version 17 (SPSS inc., Chicago, IL, USA). All variables were found to be normally distributed (Shapiro-Wilk's normality test) before data analysis. The results are reported as mean ± *SE*. Statistical comparisons for each muscle were performed using a two-way (Stability [stable, suspension equipment] × Height [10 and 65 cm]) repeated measures analysis of variance (ANOVA). Greenhouse–Geisser correction was used when the assumption of sphericity (Mauchly's test) was violated. Post hoc analysis with Bonferroni correction was used in the case of significant effects. Effect sizes are reported as partial eta-squared (η_p^2), with cut-off values of 0.01, 0.06, and 0.14 for small, medium, and large effects, respectively

(Cohen, 1988). Significant interaction effects were followed by simple effect analyses using Student t-tests. Significance was accepted when $p \leq 0.05$.

RESULTS

In the TRAPS, PEC, FEM, GLUT, Mean core and Global mean there was a significant stability *vs*. height interaction. Therefore, the main effects of equipment and position were not examined for these muscles.

An analysis of simple effects revealed that suspended push-ups elicit higher TRAPS, FEM, GLUT, Mean core and Global mean muscle activation than stable push-ups at 10 cm and 65 cm, except for PEC where no significant differences were found at 10 cm and the stable condition leads to significantly higher muscle activation at 65 cm. For all muscles which did not show significant interaction, the push-ups performed with suspension equipment showed significantly higher TRICEP, ABS, LUMB and Mean upper extremities muscle activation than those performed in a stable condition except for DELT where push-ups performed on the floor led to higher muscle activation than

Table 1
Mean and SE of the percentage of maximal muscle activation (%EMG)

	Position	Stable		Suspension equipment		Interaction effect	η_p^2
		Mean	SE	Mean	SE	*p*	
Triceps Brachii	10	17.82*†	1.43	49.33*†	2.88	0.779	0.003
	65	11.19*†	1.03	43.25*†	2.22		
Upper Trapezius	10	5.90*	0.56	20.39*†	2.65	< 0.001	0.432
	65	7.27*	1.02	14.62*†	1.98		
Anterior Deltoid	10	26.41*†	1.42	18.49*†	1.19	0.084	0.114
	65	18.26*†	1.01	12.81*†	0.97		
ClavicularPectoralis	10	29.60†	1.88	27.69†	2.41	0.029	0.160
	65	25.48*†	1.55	20.09*†	1.79		
Rectus Abdominis	10	23.84*†	2.80	105.53*†	9.84	0.490	0.019
	65	9.36*†	1.34	87.54*†	8.37		
Rectus Femoris	10	7.10*†	0.65	18.97*†	2.73	0.010	0.244
	65	4.47*†	0.58	11.74*†	1.33		
Erector Lumbar Spinae	10	2.03*†	0.14	4.32*†	0.32	0.074	0.110
	65	1.37*†	0.09	3.23*†	0.25		
Gluteus Maximus	10	0.83*†	0.06	2.65*†	0.27	0.002	0.343
	65	0.64*†	0.05	1.96*†	0.20		
Upper extremities	10	21.29*†	1.22	30.32*†	1.77	0.312	0.037
	65	16.10*†	0.82	23.90*†	1.30		
Core	10	8.10*†	0.70	38.65*†	3.95	0.045	0.136
	65	4.08*†	0.40	24.43*†	2.38		
Global	10	14.54*†	0.59	34.52*†	2.19	0.016	0.190
	65	10.17*†	0.46	24.43*†	1.32		

*Note: Upper extremities = mean of triceps brachii, upper trapezius, anterior deltoid and clavicularpectoralis; Core = mean of rectus abdominis, rectus femoris, erector lumbar spinae and gluteus maximus; Global = mean of the 8 muscles (i.e., 4 upper extremities and 4 core muscles); * Significant differences between stable condition and suspension equipment; † Significant differences between the 2 different positions (i.e., 10 and 65 cm)* performed with the suspension equipment.

Simple effect analysis also revealed that stable push-ups at 10 cm led to higher PEC, FEM, GLUT, Mean core and Global mean muscle activation than stable push-up at 65 cm. However, the TRAPS showed no significant differences during the stable condition. In addition, suspended push-ups at 10 cm lead to higher TRAPS, PEC, FEM, GLUT, Mean core and Global mean than suspended push-up at 65 cm. For all muscles which did not show significant interaction, the push-ups performed with a body position at 10 cm showed significantly higher TRICEP, DELT, ABS, LUMB and Mean upper extremities muscle activation than those performed with a body position at 65 cm. Complete results are indicated in Table 1.

DISCUSSION

The results of this study supported the first hypothesis: greater global muscle activation was found when using a suspension device. However, in regard of the second hypothesis, we expected that stable and unstable conditions would lead to similar PEC and DELT muscle activation and our results showed that higher or similar muscle activation was achieved under stable condition.

TRICEP showed more than double the activation with the suspension device in the two positions when compared with a stable condition. These findings are in accordance with authors who reported greater TRICEP activation with push-ups on a Swiss ball (Lehman et al., 2006) than on the floor. On the other hand, Freeman et al. (2006) found no differences between conditions, although the unstable device used in this study consisted of two basketballs that probably lacked the appropriate degree of instability to lead to changes in muscle activation.

A substantial increase occurred for TRAPS using the suspension device, especially at 10 cm where push-ups elicited more than triple the activation levels when compared with a stable condition. De Oliveira, de Morais Carvalho, and de Brum (2008) found greater TRAPS activation when participants performed a one arm maintained push-up on the medicine ball compared with the same exercise on the floor. In addition, push-up plus (protracting and retracting scapula) on the floor showed similar TRAPS activation to push-up plus with feet elevated and hands placed on a mini-trampoline (Lear & Gross, 1998). However, as the authors stated, changes in body weight that vary load magnitude and an insufficient instability degree of the mini-trampoline may explain the insignificant changes (Lear & Gross, 1998). Probably due to the scapular synergist stabilizer role of the TRAPS (Lear & Gross, 1998), it seems that a push-up exercise under higher instability doses provides higher TRAPS amount of activation.

Different muscle activation patterns were found for the DELT where standard push-ups on the floor lead to significantly higher activation. Other studies reported similar DELT activation during push-ups with the hands on two separate balls (Freeman et al., 2006) in comparison with a stable surface. Despite variations in gleno-humeral joint position during the exercise and different instability degrees may change muscle activity results. Literature findings suggest that DELT activation do not increase during unstable conditions, which corresponds with our results.

We found that push-ups performed on the floor led to higher PEC activation than push-ups with suspension equipment at 65 cm, whereas similar activation was found at 10 cm. De Oliveira et al. (2008) reported that a mantained one-arm push-up on medicine ball decreased PEC activation when compared with a stable surface. Other studies showed no significant differences for the pectoralis major during stable push-ups in comparison with push-ups on a Swiss ball (Lehman et al., 2006). However, Freeman et al. (2006) found that greater pectoralis major activity occurred when participants performed the exercise with hands on two separate balls, compared with the stable condition. Due to the primary movement of the pectoralis major in the push-up and a smaller stabilizer role (Lehman et al., 2006), it was possible that less instability was required to increase muscle activation as has been suggested by some authors (Behm & Colado, 2012). At 65 cm, probably due to the same cause and the less body weight load supported during the flexion, stable push-ups reported greater PEC activation than unstable push-ups.

On the other hand, the instability elicited by the suspension device greatly increased the activation of core muscles. More specifically, suspended push-ups were very efficient at promoting ABS activation compared with the stable push-up. Similar results were found in favour of unstable conditions to elicit ABS muscle activity during push-ups (Freeman et al., 2006) and other similar positions such as the push-up plus (Lehman et al., 2006), press up on top (Marshall & Murphy, 2005), prone bridge (Lehman, Hoda, & Oliver, 2005), and prone bridge with feet raised on an unstable device (Imai et al., 2010). The greater activation of FEM when push-ups were performed with the suspension device in comparison with the floor was probably due to the additional effort required to sustain the posture and perform the exercise. Care should be taken due to the possible greater lumbar lordosis when participants show higher FEM activity (Sundstrup, Jakobsen, Andersen, Jay, & Andersen, 2012). Thus, our results and others (Sundstrup et al., 2012; Beach et al., 2008) suggest that standard floor push-ups may be safer for those with low back injury risk. Suspension equipment provoked double the LUMB activation of floor push-ups, although activity levels were low. In the same vein, a low activation rate in the same muscle was found during suspended push-ups (Beach et al., 2008) and push-ups with hands on two balls (Freeman et al., 2006). In addition, no differences were reported between stable and unstable conditions during a prone bridge (Lehman et al., 2005) and during a press up on top (Marshall & Murphy, 2005). In contrast, with a similar exercise, Imai et al. (2010) found differences between the stable and unstable conditions for LUMB, although the authors used an additional unstable device to keep their feet raised and LUMB activation was also lower than 20%MVIC. It appears that LUMB may achieve significant differences with the correct degree of instability. GLUT also showed higher activation during suspended push-ups than with standard push-ups. It should be noted that activation levels were also low in both exercises. Improving GLUT strength and activation is a relevant rehabilitation factor and may reduce the risk of injury (Distefano et al., 2009). The literature includes attempts to find the most efficient exercises to target the gluteal muscles (Distefano et al., 2009; Ayotte, Stetts, Keenan, & Greenway, 2007; Boren et al., 2011).

Generally, our results showed that higher intensity was achieved for upper extremity muscles when more body weight was supported by the hands (i.e., 10 cm) except for TRAPS, which showed different recruitment patterns to all the other muscles in a stable condition. The scapular stabilizer role of TRAPS (Lear & Gross, 1998) in a stable condition might not be as relevant as in an unstable condition and therefore any changes were found in the different stable body positions. In order to stabilize the body and resist external imbalances (Anderson & Behm, 2005), a greater amount of core muscle activation occurred when greater body weight was supported by the hands and therefore higher instability levels were reached.

CONCLUSIONS

In conclusion, if the push-up is performed in order to recruit the pectoralis major muscle, the suspended version of the exercise provides no additional benefit. Performing push-ups at 65 cm from the floor decreases exercise intensity and muscle activity in comparison with the 10 cm position. Intensity progression may be performed using both heights. It should be pointed out that performing suspended push-ups may change the recruitment patterns of the muscles involved. Practitioners must evaluate training goals and be aware that suspended push-ups increase activation of all muscles (except for PEC and DELT), reaching high and very high activity levels for TRICEP and ABS, respectively, compared with the classic push-up.

Acknowledgments:
The authors wish to thank the participants for their contribution to this study. In addition, the authors thank specially Aerobic & Fitness S. L. (Sant Salvador de Guardiola, Barcelona, Spain) for the donation of the suspension equipment employed.

Conflicts of Interest
Nothing to declare.

Funding:
Nothing to declare.

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