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Research article

Muscle Activation during Push-Ups with Different Suspension Training Systems

Joaquin Calatayud [1], Sebastien Borreani [1], Juan C. Colado [1], Fernando Martín F[1], Michael E. Rogers [2]✉, David G. Behm [3] and Lars L. Andersen [4]

[1] Research Group in Sport and Health, Laboratory of Physical Activity and Health, Department of Physical Education and Sports, University of Valencia, Valencia, Spain; [2] Department of Human Performance Studies, Wichita State University, Wichita, Kansas, USA; [3] School of Human Kinetics and Recreation, Memorial University of Newfoundland, St. John's, Newfoundland, Canada; [4] National Research Centre for the Working Environment, Copenhagen, Denmark

Abstract

The purpose of this study was to analyze upper extremity and core muscle activation when performing push-ups with different suspension devices. Young fit male university students (n = 29) performed 3 push-ups each with 4 different suspension systems. Push-up speed was controlled using a metronome and testing order was randomized. Average amplitude of the electromyographic root mean square of Triceps Brachii, Upper Trapezius, Anterior Deltoid, Clavicular Pectoralis, Rectus Abdominis, Rectus Femoris, and Lumbar Erector Spinae was recorded. Electromyographic signals were normalized to the maximum voluntary isometric contraction (MVIC). Electromyographic data were analyzed with repeated-measures analysis of variance with a Bonferroni post hoc. Based upon global arithmetic mean of all muscles analyzed, the suspended push-up with a pulley system provided the greatest activity (37.76% of MVIC; $p < 0.001$). Individually, the suspended push-up with a pulley system also provided the greatest triceps brachii, upper trapezius, rectus femoris and erector lumbar spinae muscle activation. In contrast, more stable conditions seem more appropriate for pectoralis major and anterior deltoid muscles. Independent of the type of design, all suspension systems were especially effective training tools for reaching high levels of rectus abdominis activation.

Key words: EMG, unstable, core, trunk, exercise.

Introduction

The use of unstable devices is a popular option in the fitness world (Behm and Colado, 2012). This training modality is recommended for individuals aiming to achieve functional resistance training and health benefits (Behm et al., 2010). It is well established that use of unstable devices can increase core activation (Behm et al., 2010). Since decreased core muscle strength is associated with low back pain, there is a large emphasis on strengthening the trunk muscles (McGill, 2001). Instability resistance training can also increase limb muscle activation (Anderson and Behm, 2005) and co-contractions (Behm et al., 2002). In addition, a recent review found that instability resistance training programs achieved on average 22% gains in functional performance measures (Behm and Colado, 2012).

Whereas many unstable devices (e.g., Swiss balls, BOSU balls, rocker boards) provide an unstable base, suspension training can provide alternative instability to upper and lower limbs and the core. Although suspension training is portrayed as an innovative training technique, the historical use of these devices is related to the classic gymnastics rings (Beach et al., 2008).

One of the functional exercises that can be performed with suspension devices is the push-up which is a traditional exercise that has been used to train trunk, arm and shoulder musculature (Youdas et al., 2010). The push-up is also recommended in upper extremity rehabilitation programs for advanced training of the scapular stabilizers (Lear and Gross, 1998).

While muscle activation comparing push-ups using stable and unstable platforms or surfaces has been investigated (Behm et al., 2002, Freeman et al., 2006; Lehman et al., 2006), there are only two articles (Beach et al., 2008; McGill et al., 2014) using suspension training systems. Beach et al. (2008) reported greater activation of the abdominal muscles with suspended push-ups in comparison with standard push-ups. Nevertheless, while this study compared a single suspension system with parallel bands to a stable position, no previous studies have compared different types of suspension systems with different anchors and characteristics which may possess varying degrees of stability and muscle activation. Further, no data are available in regard to the muscle activity differences for the primary muscles involved in the suspended push-up exercise. It is also important to know whether differences in muscle activation with these devices are different between core/trunk and limbs.

Despite the wide variety of suspension training systems that are available and the increasing use of these devices, there is a lack of scientific evidence about the muscle activity that may be induced by the different system characteristics, hindering an optimal training tool selection. Thus, the purpose of this study was to compare the muscle activation while performing a push-up with four different conditions/suspension training systems such as V configuration systems (i.e., V-Shaped) with one anchor (i.e., TRX Suspension Trainer and Flying), one-anchor V-Shaped system with a pulley (i.e., AirFit Trainer Pro) and a parallel band system with two independent anchors (i.e., Jungle Gym XT). It was hypothesized that the highest core and upper extremities muscle activation would be induced by the suspension system with the pulley, except for the pectoralis major and anterior deltoid, which were expected to show similar muscle activation in stable and unstable conditions.

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Methods

Subjects

Young fit male university students (n = 29; age: 23.5 ± 3.1 years; height: 1.78 ± 0.06 m; body mass: 75.2 ± 8.5 kg; body fat percentage: 10.0 ± 2.5 % and biacromial (shoulder) width: 39.1 ± 1.5cm) voluntarily participated in this study. The number of participants chosen was calculated and based on effect size 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 experience, performing at least 2 sessions per week and a minimum of 4 months of suspension training experience, using this kind of training at least 1 time per week. No participant included in this study had musculoskeletal pain, neuromuscular disorders, or any form of joint or bone disease. All participants signed an institutional informed consent form before starting the protocol, and the institution's review board approved the study. All procedures described in this section comply with the requirements listed in the 1975 Declaration of Helsinki and its amendment in 2008.

Experiment procedures

Each participant took part in 2 sessions: familiarization and experimental sessions both at the same hour during the morning. The first session occurred 48-72 h before the 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 h before the sessions and no physical activity more intense than daily activities 12 h before the exercises. They were instructed to sleep more than 8 hours the night before data collection. All measurements were made by the same investigators during the morning and the procedures were always conducted in the same sportive facility (with temperature at 20º C). The study was conducted during April.

Familiarization session

During the familiarization session, the participants were familiarized with the push-up exercise, suspension training equipment, 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 participant felt confident and the researcher was satisfied that the form had been achieved. Moreover, 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 exercise performance. Hair was removed with a razor 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 et al., 1998) on the Triceps Brachii (TRICEP), Upper Trapezius (TRAPS), Anterior Deltoid (DELT), Clavicular Pectoralis (PEC), Rectus Abdominis (ABS), Rectus Femoris (FEM), and Lumbar Erector Spinae (LUMB) 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 with an interelectrode distance of 25 mm. The reference electrode was placed between the active electrodes, approximately 10 cm away from each muscle, according to 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 1kHz, 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 exercise, an ME6000P8 (Mega Electronics, Ltd., Kuopio, Finland) biosignal conditioner was used.

Prior to the dynamic exercises described below, two 5 s MVICs were performed for each muscle and the trial with the highest EMG was selected (Jakobsen et al., 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 maximal muscle activation. Positions for the MVICs were performed according to standardized procedures, chosen based on commonly used muscle testing positions for the (1) TRICEP (Kendall et al., 2005) , (2) PEC (Snyder and Fry, 2012), (3) DELT (Ekstrom et al., 2005), (4) TRAPS (Ekstrom et al., 2005), (5) ABS (Vera-García et al., 2010), (6) LUMB (Jakobsen et al., 2013), (7) FEM (Jakobsen et al., 2013) and were performed against a fixed immovable resistance (i.e., Smith machine). Specifically: (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 with an erect posture with no back support (4) deltoid abduction at 90º in a seated position with an erect posture with no back support (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, and (7) static knee extension with the participant positioned in a Biodex dynamometer: knee angle: 70º and hip angle: 110º.

The participants started the push-ups in an extended arm (up) position with forearms and wrists pronated, feet at biacromial (shoulder) width, and fingers flexed. In the down position, the forearm and wrists were kept pronated, whereas the elbow was flexed 90º and the shoulder abducted 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 and hands grasping the handles at 10 cm from the floor during all the repetitions. Each participant performed three consecutive repetitions in all conditions to avoid the influence of fatigue on the subsequent condition (Jakobsen et al., 2013). A 2:2 ratio (i.e., 2-second rate for descent and 2-second rate for ascent) was maintained by a 30-Hz metronome (Ableton Live 6, Ableton AG, Berlin, Germany) to standardize speed of movement (Freeman et al., 2006). Each participant 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.

Exercise equipment

The suspended push-ups were performed with 4 different suspension training systems: TRX Suspension Trainer ™ (TRX®, San Francisco, CA, USA), Jungle Gym XT (LifelineUSA®, Madison, WI, USA), Flying (Sidea, Cesea, Italy), AirFit Trainer Pro (PurMotion™, Pelham, AL, USA). The main characteristic of the suspension equipment is that two bands or cables are suspended from the ceiling or other support. Each device has unique characteristics (see Figure 1). TRX Suspension Trainer ™ is quite common in fitness centers. This equipment has a main band and on the bottom of this band there is a main carabineer and a stabilizing loop where another band is locked, forming a V with handles on the bottom. Flying equipment is very similar to the TRX Suspension Trainer, except that there are two V bands instead of one band with a stabilizing loop in the middle. 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 it allows greater unilateral motion. Greater unilateral movements provide disruptive torques that contribute to instability (Behm and Colado, 2012) and thus this equipment is considered the most unstable. Finally, Jungle Gym XT provides a more stable condition than the other suspension devices due to a neutral suspension system with two parallel bands (similar to Olympic rings) and two independent anchors, in contrast to traditional V-shaped suspension systems.The band length for all devices was adjusted for the hands to be at 10 cm from the floor during all repetitions. The order of conditions was performed randomly with a 2-min interval rest time between them.

Data analysis

All surface EMG signal analyses were performed 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

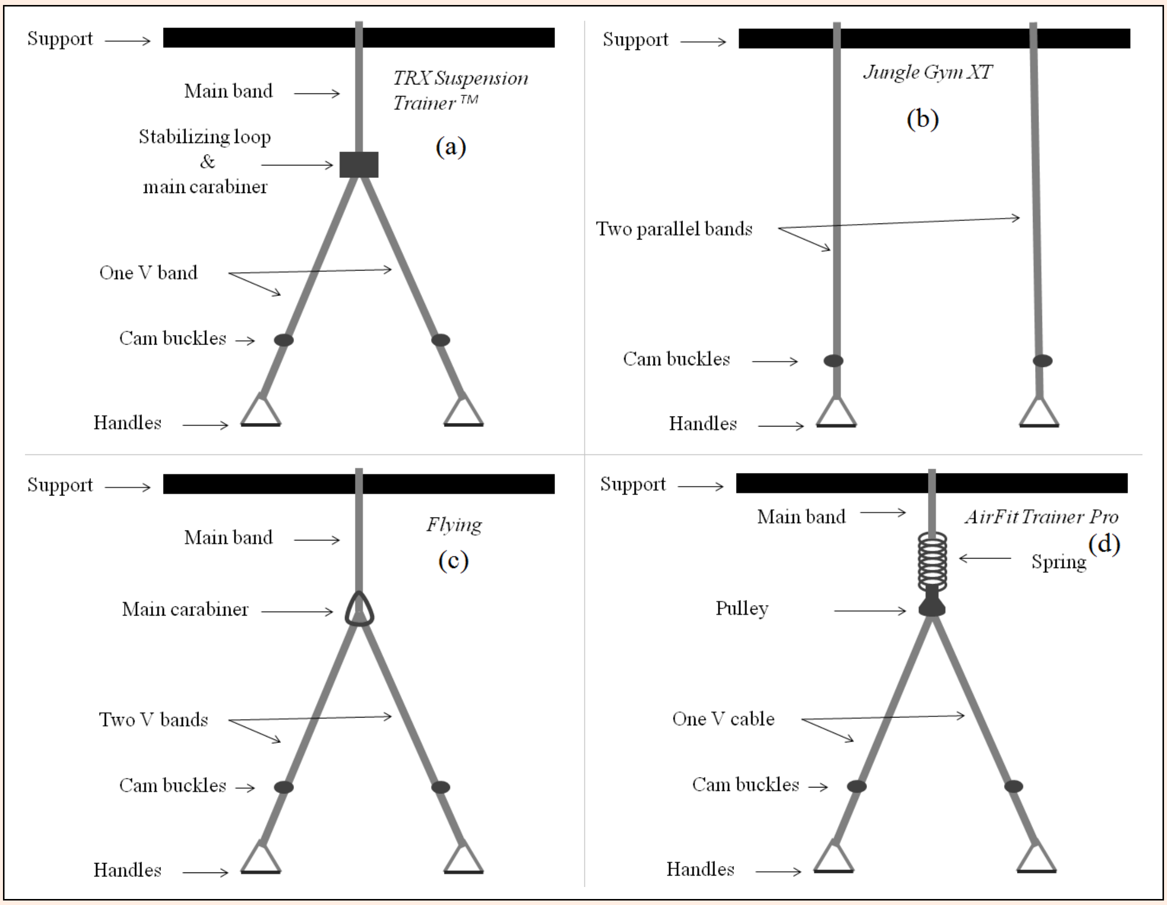

Figure 1. Suspension training equipments: (a) TRX Suspension Trainer, (b) Jungle Gym XT, (c) Flying and (d) AirFit Trainer Pro.

Table 1. Mean (standard error) EMG for each muscle and exercise expressed as percent of each muscle's MVIC (n = 29).

	Floor	TRX Suspension trainer	Jungle Gym XT	Flying	AirFit Trainer Pro	
Triceps Brachii	17.14 (1.31)†‡§‖	37.04 (180)‡‖	24.40 (1.68)*†§‖	34.93 (1.78)*‡‖	47.82 (2.54)*†‡§	F(4,108)=114.212 p<0.001
Upper Trapezius	5.90 (.56)†§‖	15.73 (2.10)*‡§‖	6.35 (.77)†§‖	10.97 (1.54)*†‡‖	20.39 (2.65)*†‡§	F(4,92)=27.184 p<0.001
Anterior Deltoid	26.22 (1.46)†§‖	19.08 (.91)*	22.18 (1.41)§	17.70 (.95)*‡	18.46 (1.24)*	F(4,96)=14.125 p<0.001
Clavicular Pectoralis	29.60 (1.88)‡	31.68 (2.53)‡	41.60 (2.88)*†§‖	30.59 (2.28)‡	27.69 (2.41)‡	F(4,112)=16.504 p<0.001
Rectus Abdominis	23.85 (2.80)†‡§‖	87.98 (8.98)*‖	87.13 (9.27)*‖	97.11 (10.54)*	105.53 (9.84)*†‡	F(4,100)=51.771 p<0.001
Rectus Femoris	7.45 (.72)†‡§‖	11.86 (1.28)*‖	13.43 (1.43)*‖	12.36 (1.21)*‖	19.23 (2.20)*†‡§	F(4,100)=22.013 p<0.001
Erector Lumbar Spinae	2.03 (.14)†‡§‖	3.21 (.24)*‖	3.26 (.23)*‖	3.31 (.24)*‖	4.32 (.32)*†‡§	F(4,112)=50.535 p<0.001
Global	16.75 (.67)†‡§‖	30.50 (1.75)*‖	29.03 (1.72)*‖	30.62 (1.91)*‖	37.76 (2.27)*†‡§	F(4,108)=51.007 p<0.001

Global = mean of the 7 muscles. * =Significant differences compared to the Floor; †= Significant differences compared to the TRX Suspension trainer; ‡=Significant differences compared to the Jungle Gym XT; § =Significant differences compared to the Flying; ‖ =Significant differences compared to the AirFit Trainer Pro

400-Hz cutoff frequency with a fourth-order Butterworth filter. Surface EMG amplitude in the time domain was quantified by using RMS and processed every 100 ms. Mean RMS values were selected for every trial and normalized to the maximum EMG (%MVIC). Global mean of all muscles (i.e., TRICEP, TRAPS, DELT, PEC, ABS, FEM and LUMB) was also calculated (arithmetic mean) and analyzed.

Statistical analyses

Statistical analysis was accomplished 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. Results are reported as mean±SE. Statistical comparisons for each muscle among the conditions were performed using Analysis of Variance (ANOVA) with repeated measures. 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-main effects. Significance was accepted when $p \leq 0.05$.

Results

Statistically significant differences were found for muscle activation (%MVIC) among the different conditions for all muscles. TRICEP and TRAPS EMG signal was significantly greater during the suspended push-up with the pulley system compared to all other conditions. DELT EMG signal was significantly greater with the standard push-up compared to all conditions except the two-anchor suspended push-up. PEC muscle activation was significantly greater with the two-anchor suspended push-up compared to all other conditions. LUMB, FEM and ABS muscle activation was significantly greater during the suspended push-up with the pulley system compared to all other conditions. Complete differences among conditions are represented in Table 1. Graphical representations of the EMG signals for each muscle, ranked from highest to lowest among all exercises, are shown in Figures 2 to 9.

Discussion

In accordance with the hypothesis, the greatest core muscle activation was achieved with the suspension device with a pulley system (i.e., AirFit Trainer Pro), which was considered the most unstable device. However, partly in accordance with the hypothesis, the stable condition only provided the highest muscle activation for the DELT. Suspended push-ups induced greatest activation than standard push-up on the floor, which presented the lowest TRICEP activation, while individually, the suspended

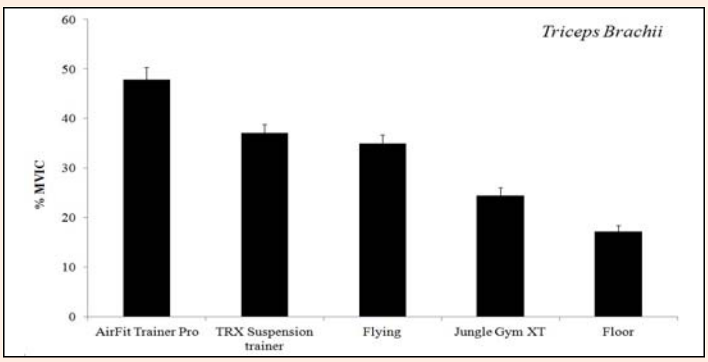

Figure 2. Percentage of maximum voluntary isometric contraction (%MVIC) of triceps brachii under different conditions.

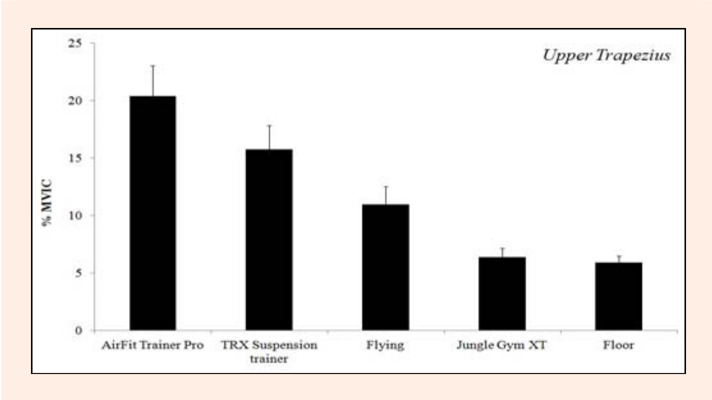

Figure 3. **Percentage of maximum voluntary isometric contraction (%MVIC) of upper trapezius under different conditions.**

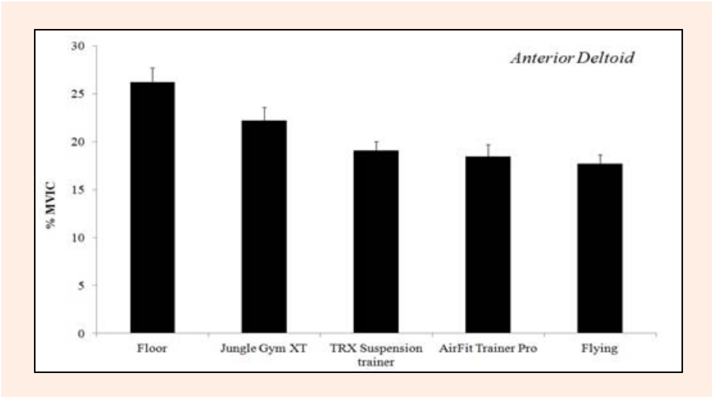

Figure 4. **Percentage of maximum voluntary isometric contraction (%MVIC) of anterior deltoid under different conditions.**

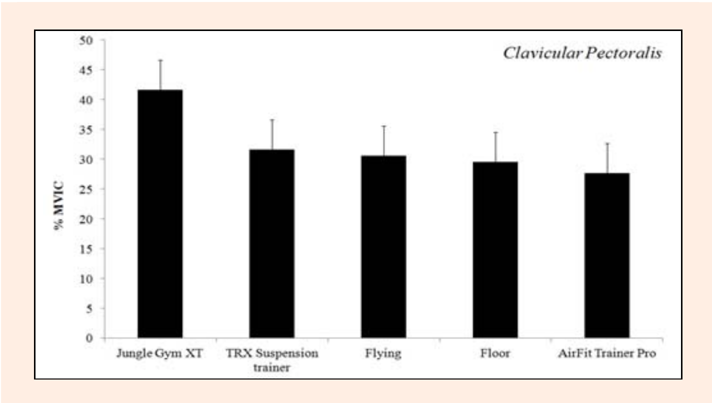

Figure 5. **Percentage of maximum voluntary isometric contraction (%MVIC) of clavicular pectoralis under different conditions.**

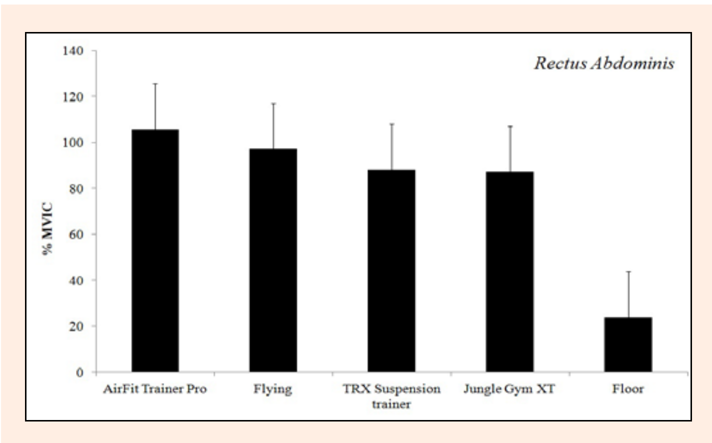

Figure 6. **Percentage of maximum voluntary isometric contraction (%MVIC) of rectus abdominis under different conditions.**

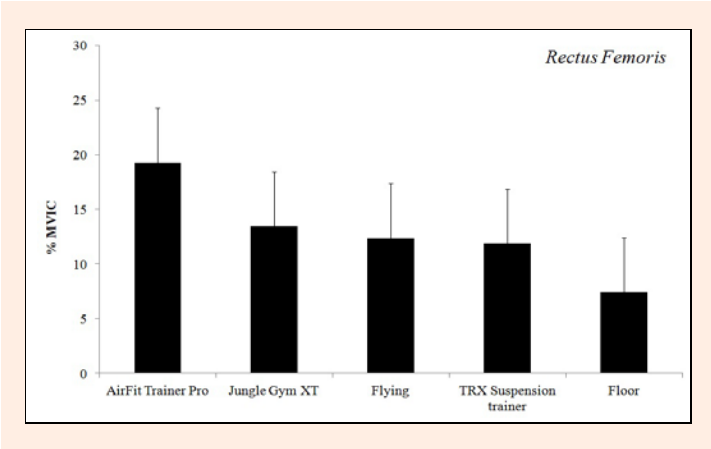

Figure 7. **Percentage of maximum voluntary isometric contraction (%MVIC) of rectus femoris under different conditions.**

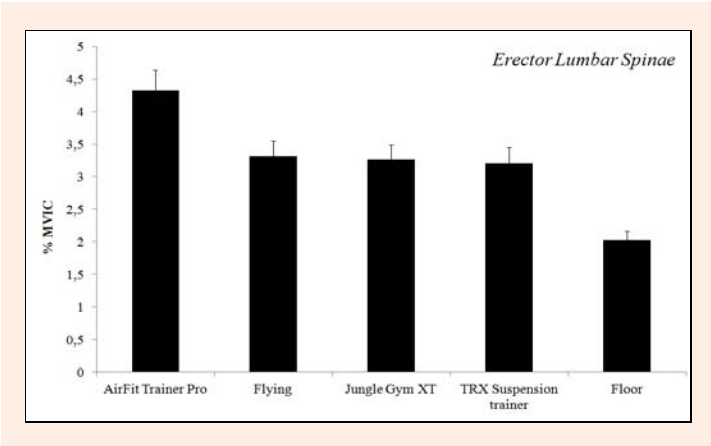

Figure 8. **Percentage of maximum voluntary isometric contraction (%MVIC) of erector lumbar spinae under different conditions.**

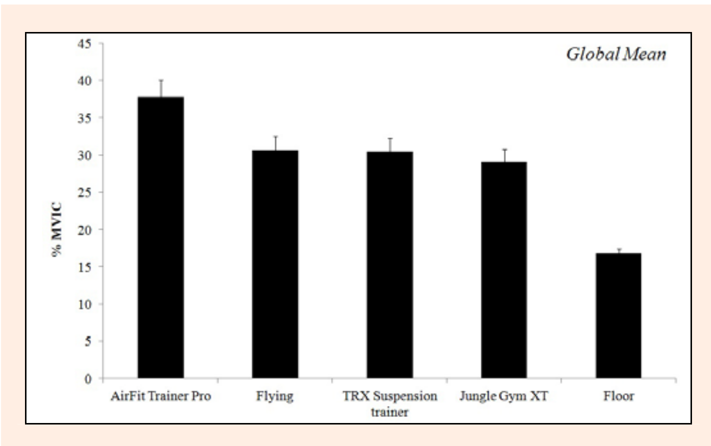

Figure 9. **Percentage of maximum voluntary isometric contraction (%MVIC) of global mean of all muscles (i.e. triceps brachii, upper trapezius, anterior deltoid, clavicular pectoralis, rectus abdominis, rectus femoris and lumbar erector spinae)**

device with a pulley system induced the greatest TRICEP activation. In this line, Lehman et al. (2006) and Anderson et al. (2013) found that TRICEP activation during unstable push-ups was superior to the stable condition. On the other hand, Freeman et al. (2006) showed that performing the push-up with two hands on two balls provoked the same activation levels as a stable push-up. However, it is possible that extent of instability in that study was insufficient to elicit significant differences.

Similar activation patterns were apparent for TRAPS where it seems that unstable conditions may provide a greater challenge than stable conditions. The suspended device with a pulley system elicited over triple TRAPS activation compared with the two parallel band system with independent anchors and the standard push-up on the floor, probably due to the greater unilateral movement allowed and the scapular synergist stabilizer role of this muscle (Lear and Gross, 1998). In accordance, unilateral maintained push-up on a medicine ball showed greater activation of the TRAPS compared to a stable surface (de Oliveira et al., 2008).

Despite there being no significant DELT activation differences between the standard push-up on the floor and the two-anchor suspended push-up, the condition provided by the stable push-up was the only one that caused greater activation than the condition induced by the one-anchor devices (i.e., Flying, TRX Suspension Trainer and the Airfit Trainer Pro). Thus, results suggest that for DELT, a more stable condition may provide a greater or similar extent of activation as more unstable conditions. Consistent with this affirmation, Freeman et al. (2006) found that push-ups on the ground provide similar DELT activation as the same exercise performed with hands on two balls.

The PEC muscle showed significantly increased activation with the two-anchor suspended push-up in comparison with the other conditions. A 20% of MVIC higher activation has been reported for a two ball push-up versus a standard version (Freeman et al., 2006). In contrast, no significant differences were found in favour of pectoralis major activation during push-up exercises on a Swiss ball compared with a stable condition (Lehman et al., 2006). Authors stated that absence of changes in muscle activation of the pectoralis major may be due to its role as prime mover and to a less extent as stabilizer (Lehman et al., 2006), and suggested that moderate, rather than excessive levels of instability, are required to increase activation in pectoralis major muscle (Behm and Colado, 2012; Behm et al., 2010). Other reasons that may lead to different muscle activity is the height of the feet during the exercise and the use of shoulder width or wider hand positions, although recent research does not show any difference in pectoralis major activation during a push-up with these hand positions (Youdas et al., 2010). In addition, it is noteworthy that participants' characteristics such as training experience may play an important role in muscle activation levels (Wahl and Behm, 2008).

If we take into consideration the DiGiovine´s scheme (DiGiovine et al., 1992), LUMB and FEM activation levels are classified as low (i.e., <20% of MVIC). Previous studies reported low LUMB activation rates during push-ups on unstable conditions (Freeman et al., 2006; Beach et al., 2008; Anderson et al., 2013) and during similar exercise positions such as a press-up (Marshall and Murphy, 2005) or prone bridge (Lehman et al., 2005, Kang et al., 2012). These findings suggest that suspended devices provoke a safe amount of muscle activation for the lumbar spine (Escamilla et al., 2010) since excessive muscle activity in the lumbar paraspinals has been related to high compressive and shear forces in this zone (Juker et al., 1998). Low activation levels may be appropriate for LUMB muscle (Behm and Colado, 2012) due to their high type I fiber proportion (Behm et al., 2010) and the prevalent role of muscular endurance for daily functional tasks (McGill, 2001). Higher FEM activation has been suggested to cause greater lumbar lordosis (Sundstrup et al., 2012) and may increase the risk of low back pain (Youdas et al., 2008). In our study, the suspended device with the pulley system achieved the greater FEM activation, perhaps due to greater strength requirements to avoid falling and maintain adequate posture and exercise technique. Although it is unknown how much FEM muscle activity is related to greater anterior tilt and an increased lumbar lordosis, caution should be used with some individuals because of the increased low-back injury risk with suspended push-ups (Beach et al., 2008; McGill et al., 2014).

The greatest muscle activity of all muscles was achieved for the ABS muscle. The suspended device with the pulley system showed greater activation levels than all conditions but did not differ from Flying. Nevertheless, ABS activation levels were very high during all suspended conditions according to DiGiovine´s (1992) classification. Similarly, Beach et al. (2008) reported greater ABS activation during the suspended push-ups compared with regular push-ups. Likewise, results showing instability-induced higher activation were demonstrated when performing push-ups (Freeman et al., 2006; Anderson et al., 2013), push-up variations such as a press up on top (Marshall and Murphy, 2005) or a push-up plus (Lehman et al., 2006), and a different exercise with similar position to a prone bridge (Lehman et al., 2005, Kang et al., 2012).

Conclusion

Coaches, athletes and fitness enthusiasts can use the present information to select the optimal suspension training device and to establish an intensity push-up progression based on the reported extent of muscle activation. It should be noted that greater activation of the TRICEP, TRAPS, LUMB and FEM can be achieved with more unstable suspension devices as a one-anchor system with a pulley. However, if greater activation is sought for the DELT and PEC, it can be achieved with more stable conditions. In fact, a parallel band system with two anchors is the best option to increase PEC muscle activation whereas the suspended push-ups do not suppose an additional advantage to increase DELT muscle activity. All the tested push-up suspension systems effectively enhance ABS activation.

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Key points

- Compared with standard push-ups on the floor, suspended push-ups increase core muscle activation.
- A one-anchor system with a pulley is the best option to increase TRICEP, TRAPS, LUMB and FEM muscle activity.
- More stable conditions such as the standard push-up or a parallel band system provide greater increases in DELT and PEC muscle activation.
- A suspended push-up is an effective method to achieve high muscle activity levels in the ABS.

AUTHORS BIOGRAPHY

Joaquin CALATAYUD

Employment

Research Fellow, Department of Physical Education and Sport, University of Valencia, Spain.

Degree

PhD student

Research interests

Strength and conditioning, measurement and evaluation.

E-mail: ximo86@hotmail.com

Sebastien BORREANI

Employment

Research Fellow, Department of Physical Education and Sport, University of Valencia, Spain.

Degree

PhD student

Research interests

Strength and conditioning, measurement and evaluation.

E-mail: sborreani@yahoo.es

Juan C. COLADO

Employment

Tenured Professor, Department of Physical Education and Sport, University of Valencia, Spain.

Degree

PhD

Research interests

Strength and conditioning, measurement and evaluation.

E-mail: juan.colado@uv.es

Fernando MARTÍN

Employment

Assistant Professor, Department of Physical Education and Sport, University of Valencia, Spain.

Degree

PhD

Research interests

Strength and conditioning, measurement and evaluation.

E-mail: f_martin_r@yahoo.es

Michael E. ROGERS

Employment

Professor and Chair, Department of Human Performance Studies, Wichita State University, Wichita, Kansas, USA.

Degree

PhD

Research interests

Strength and balance training.

E-mail: michael.rogers@wichita.edu

David G. BEHM

Employment

Associate Dean; School of Human Kinetics and Recreation, Memorial University of Newfoundland, St. John's Newfoundland, Canada

Degree

PhD

Research interests

Neuromuscular responses to exercise

E-mail: dbehm@mun.ca

Lars L. ANDERSEN

Employment

Professor, National Research Centre for the Working Environment, Copenhagen, Denmark

Degree

PhD

Research interests

Musculoskeletal disorders, health promotion

E-mail: lla@nrcwe.dk

✉ **Michael E. Rogers**

Department of Human Performance Studies, Wichita State University, Wichita, Kansas, USA