

Original article

Muscle activation during push-ups performed under stable and unstable conditions

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Abstract

Background/Objective: The purpose of this study was to analyze muscle activation when performing push-ups under different stability conditions.

Methods: Physically fit young male university students ($N = 30$) performed five push-ups under stable conditions (on the floor) and using four unstable devices (wobble board, stability disc, fitness dome, and the TRX Suspension Trainer). The push-up speed was controlled using a metronome, and the testing order was randomized. The average amplitudes of the electromyographic (EMG) root mean square of the anterior deltoid (DELTA), serratus anterior (SERRA), lumbar multifidus (LUMB), and rectus femoris (FEM) were recorded. The electromyographic signals were normalized to the maximum voluntary isometric contraction (MVIC).

Results: No significant differences were found for the DELTA [$F(4,112) = 1.978$; $p = 0.130$] among the conditions. However, statistically significant differences were found among the different conditions for the SERRA [$F(4,60) = 17.649$; $p < 0.001$], LUMB [$F(4,76) = 12.334$; $p < 0.001$], and FEM [$F(4,104) = 24.676$; $p < 0.001$] muscle activation. The suspended device was the only condition that elicited higher LUMB and FEM activation compared to the other conditions. Push-ups performed on the floor showed lower SERRA activation than those performed with all unstable devices.

Conclusion: Not all unstable devices enhance muscle activation compared to traditional push-ups.

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Keywords: Core; EMG; Instability

Introduction

Push-up exercise is normally used to strengthen the torso or upper body.¹ In contrast to the classic push-up performed on the floor, the use of unstable devices during exercise may lead to the recruitment of different muscle patterns. During the past

few years, various unstable devices, such as stability balls or Swiss balls,² suspended devices,³ and basketball balls,¹ have been used to perform the push-up exercise. However, only a few studies have compared the muscle activation using suspension equipment with other typical unstable bases.

The use of unstable devices has been reported to increase the activation of specific muscles compared to a push-up performed on a stable surface.^{1–3} Concretely, a significant increase has been reported in the activation of muscles in the abdominal wall during suspended push-ups in comparison with those performed under stable conditions.³ Furthermore,

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greater triceps brachii activation during push-ups on a Swiss ball and greater upper trapezius activation during a one-arm maintained push-up on a medicine ball have also been reported.^{2,4} On the contrary, for the deltoid, push-ups on the floor showed similar or significantly higher activation in comparison with those performed on unstable surfaces.²

Some unstable devices have been investigated during push-ups and were shown to induce higher muscle activation of core stabilizers, prime movers, and lower body stabilizers.^{1–5} In addition, dual instability provoked greater muscle activation than single instability or the stable condition.⁵ However, it is unknown if suspension equipment leads to greater or smaller muscle activation in comparison to other commonly used unstable devices that can be selected to perform push-ups with unstable bases, such as the stability disc, wobble board, and fitness dome.

Push-up studies usually consider the primary muscles involved in the action as the pectoralis major,^{1,2} anterior deltoid,^{1,4} and triceps brachii,^{1,2,5} although the first two muscles do not seem to be greatly affected by an unstable condition.^{1,2} Less is known regarding the effects of performing push-ups with these devices on the recruitment of other stabilizer muscles, such as the rectus femoris and the anterior serratus, or core muscles, such as the lumbar multifidus. Unstable conditions seem to enhance the activation of core muscles, especially when dual instability is compared to single instability.⁵ It has been demonstrated that unstable devices can increase muscle activation and that efficient exercises are needed for rehabilitation and athletic conditioning programs,^{2,4,6} therefore, the purpose of the present study was to compare the activity levels of the aforementioned muscles during stable push-ups on the floor with push-ups performed using different types of unstable devices (i.e., the stability disc, wobble board, fitness dome and TRX Suspension Trainer).

Increases in the muscle electromyographic (EMG) signal are associated with increases in muscle force or strength output.^{6,7} Exercises that produce higher EMG signal amplitudes are assumed to yield greater strengthening effects.^{8,9} Hence, changes in muscle activation would be associated with changes in muscle force output. We hypothesized that the use of unstable devices would significantly increase the activation of all muscles, except for the anterior deltoid muscles, which were expected to show similar muscle activation under both unstable and stable conditions.

Methods

Participants

Young fit male university students ($n = 30$; age: 23 ± 1.13 years; height: 178.87 ± 8.21 cm; body mass: 78.01 ± 8.5 kg; body fat percentage: $11.48 \pm 3.18\%$; and biacromial (shoulder) width: 42.22 ± 12.81 cm) voluntarily participated in this study. Participants had a minimum of 1 year of resistance training experience, performing at least two sessions/wk at moderate to vigorous intensity. No participant included in this

study had musculoskeletal pain, neuromuscular disorders, or any form of joint or bone disease. The present study was performed during the spring. All participants signed an institutional informed consent form before starting the protocol, and the institutions' review board of the University of Valencia (Spain) 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.

Procedures

Each participant took part in two types of sessions: (1) familiarization and (2) experimental sessions, both at the same time in the morning. The first session occurred 48–72 hours 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 hours before the sessions and no physical activity more intense than daily activities 12 hours before the exercises. They were instructed to sleep >8 hours the night before data collection.

During the familiarization session, participants were familiarized with the push-up exercise, unstable devices, movement amplitude, body positioning, and the cadence of movement that would later be used during data collection. Participants practiced the exercises one to three times each. The participants' height (IP0955, Invicta Plastics Limited, Leicester, England), body mass, body fat percentage (Tanita model BF-350; Tanita Corp., Tokyo, Japan), and biacromial width were obtained according to the protocols used in previous studies.¹⁰

The protocol started with the preparation of the participants' skin and was followed by electrode placement, determination of the maximum voluntary isometric contraction (MVIC), and exercise performance. Hair was removed from the skin overlying the muscles of interest, and the skin was then cleaned by rubbing with cotton wool dipped in alcohol for the subsequent electrode placement. The electrodes were positioned according to the recommendations of Cram et al.¹¹ on the anterior deltoid (DELTA), serratus anterior (SERRA), rectus femoris (FEM), and lumbar multifidus (LUMB), on the dominant side of the body.

In detail, distal and proximal pregelled bipolar silver/silver chloride surface electrodes (Blue Sensor M-00-S, Medicotest, Olstykke, Denmark) were placed with an interelectrode distance of 25 mm on the following muscle groups: (1) DELTA (on the anterior aspect of the arm, ~4 cm below the clavicle, parallel to the muscle fibers); (2) SERRA (horizontally, just below the axillary area, at the level of the inferior tip of the scapula, and just medial and anterior to the latissimus dorsi; the electrodes were anterior to the latissimus dorsi muscle); (3) LUMB (parallel to the spine, ~2 cm from the L-3 vertebra over the muscle mass); and (4) 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). A reference electrode was placed 10 cm away from the midpoint of the two electrodes of each muscle, according to the manufacturer's specifications. All signals were acquired at a

sampling frequency of 1 kHz and were 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, a ME6000P8 (Mega Electronics, Ltd., Kuopio, Finland) biosignal conditioner was used.

The MVIC was determined using fixed immovable resistance for all muscle groups before the exercises. A 5 second MVIC was performed for each muscle in order to estimate the maximum surface electromyographic amplitude according to the recommendations of Kendall et al.¹² and Konrad.¹³ Verbal encouragement was provided to motivate all participants to achieve their maximum.

The participants started the push-ups in an extended arm (up) position with forearms and wrists pronated and feet at the biacromial (shoulder) width. In the down position, the forearm and wrists were kept pronated, whereas the elbow was flexed at $\sim 90^\circ$ and the shoulder was abducted at $\sim 45^\circ$. These positions were always confirmed using a goniometer (Standard silver finger goniometer. Smith & Nephew Inc., Germantown, WI). The hip and spine were maintained neutral during all repetitions; this was verified using a laser device during the execution of the repetitions (Black & Decker, series LZR6TP9). Each participant performed five consecutive repetitions under 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 the speed of movement.¹ Each participant used a standardized grip at biacromial width (based on the distance in centimeters between the tips of the 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.

The push-ups were performed under five conditions, on the floor and using four unstable devices (Figure 1): a wobble board (Theraband, Akron, OH, USA), stability disc (Theraband), fitness dome (SportWorld Research Ltd., Moncada, Valencia, Spain), and a TRX Suspension Trainer (TRX, San Francisco, CA, USA). The TRX Suspension Trainer was suspended from a support and comprised a main band, which had the main carabineer on the bottom, and a stabilizing loop, where another band was locked, forming a V with handles on the bottom. The wobble board is a round plastic surface with a hemisphere that provides multiple planes of instability. The stability disc is an inflatable polyvinyl chloride (PVC) disc, which also provides multiple planes of instability. The fitness dome is an inflatable device, which is a combination of a PVC dome and rigid molded plastic (similar to a BOSU ball), and the flat side was positioned on the floor. The participants' feet were placed on an adjustable platform in order to maintain a horizontal body position. The order of conditions was performed randomly, with a 2-minute interval between them.

Data analysis

All surface EMG signal analyses were performed using the MATLAB 7.0 software program (Mathworks Inc., Natick, MA, USA). Surface EMG signals related to isometric exercises were analyzed by using the middle 3 seconds of the 5-second isometric contraction. The average EMG values during the middle three repetitions of a total of five performed push-ups were analyzed. All signals were bandpass filtered at a 20- to 400-Hz cutoff frequency with a fourth-order Butterworth filter. The surface EMG amplitude in the time domain was quantified using the root mean square (RMS) and was processed every 100 ms. The mean RMS

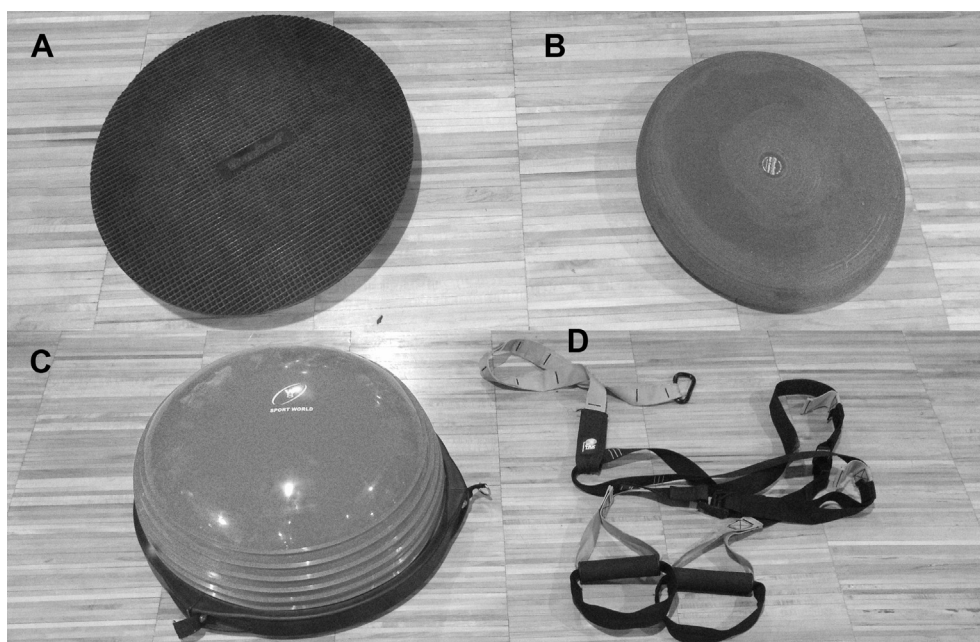


Figure 1. The unstable devices used in the present study: (A) wobble board, (B) stability disc, (C) fitness dome, and (D) TRX Suspension Trainer.

values were selected for every trial. The data obtained were normalized by using the maximum RMS values obtained during the MVIC and were expressed as a percentage of the maximum EMG (% MVIC).

Statistical analysis

Statistical analysis was carried out using the SPSS version 17 software program (SPSS Inc., Chicago, IL, USA). All variables were confirmed to be normally distributed (Shapiro-Wilk's normality test) before data analysis. The results are reported as the means $\pm$ standard error (SE). Statistical comparisons for each muscle among the conditions were performed using a repeated measures analysis of variance (ANOVA). Greenhouse–Geisser correction was used when the assumption of sphericity (Mauchly's test) was violated. A *post hoc* analysis with the Bonferroni correction was used in cases where there were significant effects. Significance was accepted for values of $p \leq 0.05$.

Results

No significant differences were found for the DELT [$F(4,112) = 1.978$; $p = 0.130$] among the conditions. However, statistically significant differences were found for muscle activation among the different conditions for the SERRA [$F(4,60) = 17.649$; $p < 0.001$], LUMB [$F(4,76) = 12.334$; $p < 0.001$], and FEM [$F(4,104) = 24.676$; $p < 0.001$]. The TRX Suspension Trainer provided the highest FEM and LUMB EMG values among the conditions. All unstable conditions provided higher EMG signals than push-ups on the floor. The complete mean differences between statistically significant conditions are shown in Table 1.

Discussion

As we hypothesized, the DELT showed similar activation during push-ups performed under both stable and unstable conditions. This result is in accordance with a previous study that reported a similar amount of activity in this muscle during push-ups with hands on two balls compared with push-ups on the floor.¹ The literature suggests that the addition of unstable devices does not increase the DELT activation.¹⁴ By contrast, a different level of muscle recruitment was shown in the SERRA,

where all unstable devices provoked a significant increase in muscle activation compared with push-ups on the floor. Interestingly, several previous studies did not find any increases in the activation of the SERRA with the addition of unstable devices.^{4,15} However, in those studies, de Oliveira et al⁴ performed a different exercise: a one-arm isometric push-up on a medicine ball, and Lehman et al¹⁵ only used an exercise ball as the unstable equipment. Therefore, it is possible that the different degrees of instability may have led to the differences in SERRA muscle activation. Moreover, different electrode placements may lead to different results,¹⁶ as was established in the study conducted by Park and Yoo¹⁶ who showed that the lower SERRA fibers exhibited greater activation values than the upper SERRA fibers during unstable push-ups.

The LUMB is associated with the segmental stability of the lumbar spine.^{5,17} In the current study, only the push-ups performed with the TRX Suspension Trainer enhanced the LUMB activation more than stable push-ups, although the activity levels were relatively low during all five types of exercise. Similar to our results with the wobble board, Anderson et al⁵ showed similar erector spinae muscle activation in participants performing push-ups in a stable condition and with hands on a balance board.⁵ In addition, they also found that dual (hands and feet) instability generated greater lumbar activation than the stable condition.⁵ In a study conducted by Imai et al,¹⁸ a similar body position, the elbow-toe exercise, showed greater LUMB activation during the unstable condition in comparison with the stable condition. However, in that study, the participants placed their feet on a raised balance disk, which may have increased the disturbances and coactivations of the muscles.¹⁸ Other studies of exercises performed in a standing bipedal position showed that greater stability conditions provoked greater LUMB activation than performing the same exercise on an unstable surface.^{19,20}

Similar recruitment results were found for the FEM muscle, where suspended push-ups provoked greater activation than the other devices and the stable condition. Push-ups performed with the TRX Suspension Trainer may require a greater extent of effort to control and maintain the posture due to the nature of the device, where the hands are suspended during the exercise. As a hip flexor, higher FEM activation levels are known to be related to a greater anterior pelvic tilt.²¹ Additionally, suspended push-ups were shown to induce higher compressive loads on the intervertebral joint than standard push-ups.³

Table 1

Mean and standard error (SE) electromyographic signal for each muscle and exercise expressed as a percent of each muscle's MVIC ($n = 30$).

	Floor		Wobble board		Stability disc		Fitness dome		TRX Suspension Trainer		<i>p</i>
	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	
Anterior deltoid	78.54	4.39	91.17	5.25	84.58	6.66	83.19	4.56	83.74	5.96	0.130
Serratus anterior	29.07	3.76	95.83 ^a	13.24	84.22 ^a	10.39	95.12 ^a	11.68	75.48 ^a	9.42	<0.001
Lumbar multifidus	3.97 ^b	0.43	5.03 ^b	0.59	4.70 ^b	0.52	4.40 ^b	0.51	7.35	0.66	<0.001
Rectus femoris	20.55 ^b	1.69	19.86 ^b	1.71	25.41 ^b	0.18	24.76 ^b	0.27	37.86	3.65	<0.001

MVIC = maximum voluntary isometric contraction.

^a Significant differences compared to the floor.

^b Significant differences compared to the TRX Suspension Trainer.

Therefore, inexperienced practitioners and/or those with low back problems should be cautious when performing suspended push-ups.

In the study by Anderson et al.,⁵ other muscles were measured during the performance of push-ups under stable and unstable conditions. The authors found that push-ups performed with the hands on a balance board generated significantly greater muscle activation in triceps brachii than stable push-ups. However, for the soleus, rectus abdominus, and internal oblique muscles, no significant differences were found between these two conditions.

Conclusion

Practitioners may use different devices to add variation in their training programs, although they should be aware that not all unstable devices enhance muscle activation compared to traditional exercises. Devices that provide an unstable base, such as the stability disc, fitness dome, and wobble board, showed similar muscle activity levels and did not show additional benefits in comparison with a stable push-up, except for the activation of the SERRA. Moreover, the addition of an unstable device did not increase the DELT muscle activation, and thus, this muscle may respond positively to a traditional stable push-up. The use of a suspension device provides higher muscle activation in the SERRA, LUMB, and FEM than stable push-ups and also provides higher LUMB and FEM activation levels than all of the other unstable bases. Professionals and practitioners should select different unstable devices based on their objective and following an adequate progression of training.

Conflicts of interest

The authors declare no conflicts of interest.

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