MUSCLE ACTIVATION IN SUSPENSION TRAINING: A SYSTEMATIC REVIEW

Joan Aguilera-Castells [a]

e-mail: joanac1@blanquerna.url.edu

Bernat Buscà [a]

e-mail: bernatbs@blanquerna.url.edu

Azahara Fort-Vanmeerhaeghe [a]

e-mail:azaharafv@blanquerna.url.edu

Alicia M. Montalvo [b]

e-mail: amontal@fiu.edu

Javier Peña [c]

e-mail: javier.pena@uvic.cat

[a] Department of Sports Sciences, Ramon Llull University, FPCEE Blanquerna, Barcelona, Spain

c/ Císter, 34, 08022 Barcelona, Spain Phone: +34 93 253 30 00

[b] Department of Athletic Training, Nicole Wertheim College of Nursing and Health Sciences, Florida International University, Miami, FL, USA

11200 SW 8th St, Miami, FL 33199, USA

Phone: 305 348 7716

[c] Sport Performance Analysis Research Group, University of Vic—Central University of Catalonia, Vic, Barcelona, Spain

C/ Dr. Antoni Vilà Cañellas, s/n 08500 Vic

Phone: +34 93 881 61 64

Corresponding author: Dr. Bernat Buscà, c/ Císter, 34, 08022 Barcelona, Spain. Tel. +34 93 253 30 00 Fax: +34 93 253 30 31

E-mail: bernatbs@blanquerna.url.edu

Funding:

This work was supported by *Secretaria d'Universitats i Recerca del Departament d'Empresa i Coneixement de la Generalitat de Catalunya i als Fons Socials Europeus* under Grant [2018 FI_B 00229]; and *Ministerio de Educación, Cultura y Deporte* (*Beca de Colaboración*) under Grant [311327].

Abstract

Suspension training is an adjunct to traditional strength and conditioning. The effect of added instability on muscle activation during traditional exercises is unclear and depends on the exercise and type of instability. The purpose of this review was to compare the activations of different muscles in suspension training exercises and their traditional counterparts. A search of the current literature was performed without language restrictions using the electronic databases PubMed (1969 – January 12, 2017), SPORTDiscus (1969 – January 12, 2017) and Scopus (1969 – January 12, 2017). The inclusion criteria were: (1) descriptive studies; (2) physically active participants; and (3) studies that analysed muscle activation using normalised electromyographic signals during different suspension training exercises. Eighteen studies met the inclusion criteria. For the push-up, inverted row, prone bridge and hamstring curl in suspension, the activation of upper-body and core muscles ranged between moderate (21%-40% maximum voluntary isometric contraction (MVIC)) and very high (>60% MVIC). Muscle activation in these same muscle groups was greater with suspension exercises relative to comparable traditional exercises, except for the inverted row. Muscle activation in the upper extremity and core muscles varied greatly amongst studies.

Keywords:

Electromyography

Instability

Muscular activity

Revision

Introduction

Traditional external load strength training focuses on working specific muscle groups with an emphasis on primary movers. However, advancements in knowledge about sport-specific demands have resulted in the development of training methodologies that involve new functional conditions. Thus, new trends in training have emerged to develop and enhance muscle activation during sport-specific movements (Lawrence & Carlson, 2015), and to improve the strength of accessory muscles by emphasising multiplanar movements. These movements result in improvements to agility, core strength, and posture (DiStefano, DiStefano, Frank, Clark, & Padua, 2013).

In recent years, the addition of instability to traditional exercises has become a popular method for increasing sport-specificity. The ability to maintain balance and the desired posture during sport-specific movements requires activation of core muscles, including the abdominal, back, and hip muscles. Instability resistance training increases the activation of core muscles essential to force production by the large primary movers (eg. hamstrings, quadriceps) (Behm & Colado, 2012). Furthermore, an unstable resistance training environment stresses the neuromuscular system and may promote greater strength gains and increases in cross-sectional area (Behm & Anderson, 2006; Cormie, McGuigan, & Newton, 2011). Unstable training may also increase motor unit recruitment and improve neuromuscular coordination without an increase in the mechanical load when performing push-ups under unstable conditions (Anderson, Gaetz, Holzmann, & Twist, 2013).

Traditionally, tools that create unstable surfaces have been used to progress the difficulty of exercises by stimulating increased motor unit recruitment. These tools include the Swiss ball, Balance Board®, Wobble Board®, and BOSU® exercises (Anderson et al., 2013; Duncan, 2009; Norwood, Anderson, Gaetz, & Twist, 2007; Vera-Garcia, Grenier, & McGill, 2000), and exercises with basketballs (Freeman, Karpowicz, Gray, & McGill, 2006). A newer method available to increase activation is suspension training. Suspension training uses body weight and force momentum principles to enhance motor unit recruitment. The difficulty of the suspension training exercise and the number of motor units recruited depend on the amount of instability caused by the suspension device and the body position (Dawes & Melrose, 2015; Maté-Muñoz, Monroy, Jodra Jiménez, & Garnacho-Castaño, 2014). Although we cannot measure the amount of instability or the effect of the body position on instability during suspension training, we can measure electromyography (EMG) during exercise. Thus, EMG can be used to quantify the 'load' (Atkins et al., 2015; Borreani et al., 2015a; Snarr & Esco, 2013a).

Typically, muscle activation is presented as a percent of the maximum voluntary isometric contraction (%MVIC). Once MVIC is obtained, the EMG signal can processed several different ways: 1) by using high-pass filtering, 2) by rectifying and smoothing, or 3) by calculating the root mean square of the signal. The peak value registered after the signal processing constitutes the reference value of the normalised EMG signal (Halaki & Ginn, 2012). However, the same EMG signal may vary depending on the technique used to process it. Currently, there is no consensus about which technique should be used to process EMG signals. Studies comparing suspension training to traditional training utilise similar/the same exercises, but the results are difficult to reconcile unless there is an understanding on the differences in EMG signal processing techniques.

While activation of each muscle used to maintain stability has been studied for the most popular suspension training exercises, such as push-ups, inverted rows and prone bridges, to our knowledge, a review of this literature does not currently exist. The results of this review might be used to encourage the use of suspension exercises in place of traditional exercises in sport-specific resistance training. Choosing exercises that better suit an athlete's goals could enhance the effects and the quality of training programs. Therefore, the main purpose of this study was to perform a systematic review of studies that analysed the activation (% MVIC) of stabilising muscles involved in the most studied suspension training exercises in physically active populations. The secondary purpose of this study was to compare the muscle activation of the suspension training exercises with their traditional counterparts.

Methods

A Preferred Reporting Items for Systematic Reviews and Meta-Analysis (PRISMA) statement guidelines provided by Moher, Liberati, Tetzlaff, and Altman (2009) were used to conduct the present systematic review. Additionally, the study quality of all eligible cross-sectional studies was assessed by the first author and was checked by the second and the third co-authors using the Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) criteria (Vandenbroucke et al., 2007). The following scale was used to classify study quality: a) good quality (>14 points, low risk of major or minor bias), b) fair quality (7-4 points, moderate risk of major bias), and c) poor quality (< 7 points, high risk of major bias). The score was obtained through the 22 items of the STROBE checklist.

A search of the current literature was performed without language restrictions using the electronic databases PubMed (1969 – January 12, 2017), SPORTDiscus (1969 – January 12, 2017) and Scopus (1969 – January 12, 2017). The search strategy for each database is listed in Table 1. MeSH terms were not used. The inclusion criteria were: a) studies that had a descriptive design, b) studies that utilised physically active participants, and c) studies that analysed muscle activation using normalised EMG signals during different suspension training exercises. Randomised control trials and clinical trials were excluded if they did not analyse muscle activation. Additionally, articles with insufficient discussion, poor data presentation, and unclear or vague descriptions of the applied protocols were excluded (see the flowchart of the search and study selection in Figure 2).

Table 1 near here

The first author performed the data analysis. First, a pre-reading was conducted to familiarise with terminology, Then, each article was re-read and the following information was extracted: 1) study design, 2) sample size, 3) gender, 4) age, 5) types of intervention (objective, exercise, measuring instruments), 6) EMG activation (expressed as %MVIC from normalised EMG), and 7) differences in EMG activation between traditional and suspension training exercises. Only the exercise type and the EMG activation differences between traditional and suspension training exercises (expressed as %MVIC from normalised EMG) were included in Tables 3 and 4. With regard to EMG signal, all analysed articles reported the MVIC protocol used. These protocols utilised isometric contraction against a matched resistance for each examined muscle. Similarly, all articles included used surface EMG. To facilitate the comparison of the muscle activation in different suspension training exercises, activation (% of MVIC) was categorised into four levels as described in previous studies: >60%, very high; 41-60%, high; 21-40%, moderate and <21%, low (Calatayud et al., 2014b; Escamilla et al., 2010; Mok et al., 2014).

All studies reported the muscle activation of each analysed muscle. Some authors examined the muscle activation of transversus abdominis and internal oblique together (Mok et al., 2014; Fong et al., 2015), while others only reported internal oblique activation (Beach, Howarth, & Callaghan, 2008; McGill, Cannon, & Andersen, 2014a, 2014b). For this reason transversus abdominis and internal oblique, and internal oblique activations were included in the analysis.

The suspension training exercises reported in the included studies were performed using three different suspension devices (Figure 1). The traditional suspension device has a main strap. On the bottom of this strap there are both, a main carabineer and a stabilising loop where another strap is locked, forming a V with handles on the bottom. The TRX® is an example of a traditional suspension device (Calatayud et al., 2014c). The pulley suspension device has a main strap supported by a spring and a V-rope with a pulley in the middle. The pulley's function is to reduce friction and increase unilateral motion (Calatayud et al., 2014c). Finally, Beach and colleagues (2008) used a suspension device with two parallel chains (similar to Olympic rings) and two independent anchors.

Figure 1 near here

Results

Search results

Three independent reviewers identified a total of 218 articles in the initial search. Sixty-eight articles were duplicates, which left 150 unique articles. Following title/abstract and full-text screening, 132 articles were eliminated because they did not meet the inclusion criteria (75 articles without EMG analysis, 5 clinical trials or randomised control trials and 52 articles that did not use a suspension device). A total of 18 articles were selected for final review (Figure 2).

Figure 2 near here

From the 18 studies reviewed, the suspension exercises described were: push-ups (Beach et al., 2008; Borreani et al., 2015a; Borreani et al., 2015b; Calatayud et al., 2014b; Calatayud et al., 2014a; Calatayud et al., 2014c; Fong et al., 2015; McGill et al., 2014a; Mok et al., 2014; Snarr, Esco, Witte, Jenkins & Brannan, 2013; Snarr & Esco, 2013b), inverted row (Fong et al., 2015; McGill et al., 2014b; Mok et al., 2014; Snarr & Esco, 2013a; Snarr, Nickerson & Esco, 2014), prone bridge (Atkins et al., 2015; Byrne et al., 2014; Fong et al., 2015; Mok et al., 2014; Snarr & Esco, 2014), and hamstring curl (Fong et al., 2015; Malliaropoulos et al., 2015; Mok et al., 2014).

Of the 18 included studies, only Fong and colleagues (2015) and Mok and colleagues (2014) were excluded from the secondary analysis. Fong and colleagues (2015) and Mok and colleagues (2014) only compared muscle activation during different suspension training exercises. Of the 16 remaining studies, nine compared muscle activation during suspension training and traditional exercise (Beach et al., 2008; Borreani et al., 2015b; Byrne et al., 2014; Calatayud et al., 2014a; McGill et al., 2014a, 2014b; Snarr & Esco, 2013a, 2013b; Snarr, Nickerson, et al., 2014), five compared muscle activation during suspension training exercise with traditional exercise performed on an unstable surface (eg. prone bridge on a Swiss ball)(Atkins et al., 2015; Borreani et al., 2015b; Calatayud et al., 2014a; Calatayud et al., 2014b; Snarr & Esco, 2014), and two compared muscle activation during suspension training exercise with different traditional exercises (Malliaropoulos et al., 2015; Snarr et al., 2013). The differences in activity (expressed as % of MVIC) of the muscles involved in push-ups, inverted row, prone bridge and hamstring curl exercises are described in the following paragraph. Results are presented below according to primary objective (muscle activation of the suspension training exercises) and secondary objective (muscle activation comparison between suspension training exercises and traditional strength training counterparts). Table 2 shows the descriptive characteristics and the quality of all studies revised.

Table 2 near here

Muscle activation during suspension exercises

Suspension push-up

Muscle activation during suspension push-ups is reported in Figure 3. For suspension push-ups, activation of triceps brachii, serratus anterior, and rectus abdominis were high (41%-60% MVIC). Activations of pectoralis major, anterior deltoid, transversus abdominis and internal oblique, external oblique, and rectus femoris were moderate (21%-40% MVIC). Activations of upper trapezius, posterior deltoid, latissimus dorsi, internal oblique, erector spinae, lumbar multifidus, and gluteus maximus were low (<21% MVIC).

Figure 3 near here

Suspension inverted row, prone bridge and hamstring curl

Muscle activations during suspension inverted rows, suspension prone bridges and suspension hamstring curls are reported in Figures 4, 5 and 6 respectively. For suspension inverted row, activations of latissimus dorsi, middle trapezius, posterior deltoid, and biceps brachii were very high (>60% MVIC). Activations of core muscles (transversus abdominis and internal oblique, rectus abdominis, external oblique, internal oblique, lumbar multifidus) were low (<21% MVIC). In suspension prone bridge, activations of some core muscles (transversus abdominis and internal oblique, rectus abdominis, external oblique) ranged from high to very high (>41% MVIC), while activations of other core muscles (serratus anterior, lumbar multifidus, erector spinae, rectus femoris) ranged from moderate to low (< 40% MVIC). For suspension hamstring curl, activations of biceps femoris and semitendinosus were very high (> 60% MVIC). Activations of some core muscles (transversus abdominis and internal oblique, and lumbar multifidus) were high (41-60% MVIC) while others (external oblique and rectus abdominis) ranged from moderate to low (<40% MVIC).

Figure 4 near here

Figure 5 near here

Figure 6 near here

Muscle activation in suspension exercises compared to traditional exercises

Suspension push-up

Differences in activations between suspension push-ups and push-ups for each muscle are reported in Table 3. Activations of pectoralis major, anterior deltoid, upper trapezius, triceps brachii, latissimus dorsi, serratus anterior, rectus abdominis, external oblique, internal oblique, lumbar multifidus and rectus femoris were significantly greater in suspension push-up compared to push-up (Beach et al., 2008; Borreani et al., 2015a; Borreani et al., 2015b; Calatayud et al., 2014a; McGill et al., 2014a; Snarr & Esco, 2013b). The use of a suspension device with pulley, a type of suspension training device that uses a pulley to further increase instability, caused significant increases in activation of upper trapezius, triceps brachii, posterior deltoid, rectus abdominis, external oblique, erector spinae, rectus femoris and gluteus maximus relative to traditional push-up (Calatayud et al., 2014b; Calatayud et al., 2014a; Calatayud et al., 2014c). The traditional push-up resulted in significantly higher activations of pectoralis major and anterior deltoid compared to suspension push-up with pulley (Borreani et al., 2014a). However, for certain muscles, like pectoralis major (Borreani et al., 2015b), anterior deltoid (Borreani et al., 2015b; Calatayud et al., 2014b; Calatayud et al., 2014c) and serratus anterior (Borreani et al., 2014b; McGill et al., 2014a), significantly greater activation was found in traditional push-up in comparison with suspension push-up in the aforementioned studies.

** Table 3 near here**

Suspension inverted row, prone bridge and hamstring curl

Differences in activations between suspension and traditional inverted row, prone bridge and hamstring curl for each muscle are reported in Table 4. Activations of middle trapezius, posterior deltoid, rectus abdominis, internal oblique, external oblique and erector spinae were greater in suspension inverted row compared to inverted row; however, the increases were not statistically significant (McGill et al., 2014b; Snarr & Esco, 2013a; Snarr, Nickerson et al., 2014). Activation of latissimus dorsi was significantly greater in inverted row compared to suspension inverted row, but biceps brachii activity was significantly higher in suspension inverted row compared to inverted row (Snarr, Nickerson et al., 2014). Activations of core muscles (rectus abdominis, external oblique, erector spinae and rectus femoris) were significantly greater in suspension prone bridge compared to prone bridge (Atkins et al., 2015; Byrne et al., 2014; Snarr & Esco, 2014). Activations of biceps femoris and semitendinosus were significantly greater in suspension hamstring curl compared to traditional exercise with and without destabilising devices (Malliaropoulos et al., 2015).

** Table 4 near here**

Discussion and implications

Muscle activation during suspension exercises

The primary aim of this study was to identify muscle activation during execution of different suspension training exercises. We found both similarities and differences in the activations of the same muscles amongst the exercises. Any differences may be attributed to differences in body position and conditioning parameters (range of motion, suspension height, type of grip, type of suspension training device, etc.). Each type of exercise will be discussed in detail below.

Suspension push-up

Some studies found the pectoralis major activation to be moderate (Borreani et al., 2015b; Calatayud et al., 2014a; Calatayud et al., 2014c; Calatayud et al., 2014b), but Snarr and Esco (2013b) found that the pectoralis major activation was very high. This difference may be explained by differences in the types of suspension device used. Several studies used a traditional suspension devices (Borreani et al., 2015b; Snarr & Esco, 2013b), while other studies used a pulley suspension devices (Calatayud et al., 2014a; Calatayud et al., 2014c; Calatayud et al., 2014b). Additionally, there were differences in the height of the suspension device. The activation of the pectoralis major decreased as the trunk-legs inclination, or the angle between the body and the floor, increased and the hip flexion decreased (Borreani et al., 2015b). Similarly, the wide range of the anterior deltoid activation can be attributed to these same two factors (suspension device type and length). These results suggest that the anterior deltoid is inhibited as a synergist of the pectoralis major, thus reducing the anterior deltoid's activation under highly unstable conditions. The stabilising function of core muscles (rectus abdominis and external oblique) using a pulley suspension device is more demanding (Calatayud et al., 2014a; Calatayud et al., 2014c; Calatayud et al., 2014b), in contrast to the lower activation of the serratus anterior (Calatayud et al., 2014b). The differences in the rectus abdominis and external oblique activations amongst studies could be partially explained by differences in suspension device height and the trunk-legs inclination (Dawes & Melrose, 2015) and by changes caused by increased instability. Despite changes in activation of the other muscles, the activation of the triceps brachii during push-ups did not vary by suspension device type (Borreani et al., 2015b; Calatayud et al., 2014a; Calatayud et al., 2014c; Calatayud et al., 2014b); however, it did vary by the trunk-legs inclination (Snarr & Esco, 2013b).

With regard to back muscles, the activation of the erector spinae was reduced with the use of a pulley suspension device (Calatayud et al., 2014a; Calatayud et al., 2014c). This is because suspension push-ups increase the activation of the latissimus dorsi to stabilise the shoulder joint. Additionally, the use of a suspension device requires the abdominal muscles and latissimus dorsi to be sufficiently activated to achieve mechanical equilibrium around the lower back (Beach et al., 2008).

The differences between the muscle activity of the pectoralis major, anterior deltoid and upper trapezius as reported by Snarr and Esco (2013b) and the other studies can be explained by the use of a traditional suspension device that did not inhibit its activation and the body inclination having supported the major part of the body mass, in accordance with the vector resistance and stability fundamental principles (Bettendorf, 2010). Again, the differences in the muscle activation of the anterior deltoid, serratus anterior and rectus femoris, between Borreani and colleagues (2015a) and the other studies, could be explained by the use of the traditional suspension device, which produces a degree of instability to increase the activity of the aforementioned musculature. The differences in the activation of the rectus abdominis were provoked by the type of suspension device and for modified the vector resistance and stability fundamental principles. Thus, by reducing the body angle inclination and performing the push-ups exercise with the suspension device with pulley, the participants in the study by Calatayud and colleagues (2014a, 2014c) achieved an increase of muscle demands and very high activations (>60% MVIC) from the rectus abdominis.

Suspension inverted row, prone bridge and hamstring curl

The differences in activations of the latissimus dorsi and middle trapezius between suspension inverted row studies can be explained by handgrip type. Snarr and Esco (2013a) and Snarr, Nickerson, and colleagues (2014) used pronated and supinated handgrips, respectively, while McGill and colleagues (2014b) used a neutral handgrip. The pronated handgrips demand a higher activation of the posterior deltoid, whereas the supinated handgrips demands a higher activation of the biceps brachii (Snarr, Nickerson, et al., 2014). The prone handgrip could be enhanced the extensor role of the posterior chain musculature. The biceps brachii activity observed by Snarr, Nickerson and colleagues (2014) differed to the other studies. This could be because they used a supine handgrip, which increases the recruitment of the biceps brachii during elbow flexion. Additionally, the trunk-legs inclination and the hip flexion angle influence the latissimus dorsi and middle trapezius activation. Activations of core muscles (rectus abdominis, external oblique and lumbar multifidus) were low in suspension inverted row, as the instability created by traditional suspension devices does not engage the trunk muscles, even though instability increases with the variation of the trunk-legs inclination and the hip flexion angle. The included suspension inverted row studies showed that the variations in the suspension training fundamental principles (Bettendorf, 2010) were insufficient to offer a challenge to the recruitment of the core muscles.

In the suspension prone bridge, the variation in rectus abdominis, external oblique and erector spinae activations may be due to the additions of hip abduction (Fong et al., 2015; Mok et al., 2014), arms extension (Atkins et al., 2015), suspension of feet or arms (Snarr & Esco, 2014), or suspension of feet and arms (Byrne et al., 2014). Additionally, the modification in the fundamental principles of stability and pendulum (Bettendorf, 2010) by Mok and colleagues (2014) were insufficient to increase the degree of instability, especially in the rectus abdominis, which activation was lower compared to the aforementioned studies.

The suspension hamstring curl technique utilised by Fong and colleagues (2015) in chronic back pain patients, which entails positioning the supine trunk with a lumbopelvic retroversion, could explain the differences in the activation of trunk muscles (transversus abdominis and internal oblique, rectus abdominis and external oblique) in comparison with Mok and colleagues (2014).

Muscle activation in suspension exercises compared to traditional exercises

Studies that compared muscle activation during suspension and traditional exercises utilised physically active participants between 15 and 28 years of age. Most studies presented activations as

%MVIC; however, these studies used different procedures to obtain the MVIC. For example, Malliaropoulos and colleagues (2015) performed three five-second MVICs with an isokinetic dynamometer whereas other studies performed MVIC trials against a matched resistance (Beach et al., 2008; Byrne et al., 2014; Borreani et al., 2015a), with trial lengths ranging from three to ten seconds (Atkins et al., 2015; Byrne et al., 2014; Mok et al., 2014). The MVIC trials for each analysed muscle differed in accordance with the protocol used (e.g. the protocols described by Konrad (2005) compared to Escamilla and colleagues (2010)).

Suspension push-up

All the reviewed studies showed a greater activation of suspension push-ups compared to traditional push-ups, regardless of the use of stabilising loop. The use of a suspension device without a stabilising loop significantly improved the activation of the pectoralis major (Calatayud et al., 2014c). However, suspension push-ups performed under highly unstable conditions provoked a lower activation of the pectoralis major (Calatayud et al., 2014a) and anterior deltoid (Borreani et al., 2015b). This is because the triceps brachii acts as a stabiliser under unstable conditions, especially when instability is lateral (Borreani et al., 2015b; Calatayud et al., 2014a; Calatayud et al., 2014c; Calatayud et al., 2014b; Snarr & Esco, 2013b). Furthermore, lateral instability of the pulley suspension device results in greater activation of the trunk muscles (rectus abdominis, internal oblique and external oblique). This is especially true for the rectus abdominis, which acts as a grater stabiliser during suspension push-ups compared to traditional push-ups (Beach et al., 2008; Calatayud et al., 2014a; Calatayud et al., 2014c; Calatayud et al., 2014b; McGill et al., 2014a; Snarr et al., 2013). Thus, the activation of the rectus abdominis during suspension push-ups with a pulley substantially increases (around 20%) in comparison with traditional suspension push-ups. This is an important finding for clinicians looking for a way to more thoroughly engage the abdominals during sports-specific upper extremity movements. In contrast, there was no consensus in the included studies for the serratus anterior on the effects of instability during push-ups; however, variations in the suspension device height suggested that the higher the position of the suspension device, the greater the activation of the serratus anterior. (Borreani et al., 2015b; Calatayud et al., 2014a; Calatayud et al., 2014c; Calatayud et al., 2014b).

Suspension inverted row, prone bridge and hamstring curl

Variations in the grip type used in studies investigating inverted row exercise make it difficult to compare muscle activations. Along with the grip type, variations in trunk-legs inclination and the hip flexion angle result in variations in the activation of the involved muscles (latissimus dorsi, middle trapezius, posterior deltoid, and biceps brachii), which cause significant differences in activations between suspension inverted row and inverted row (McGill et al., 2014b; Snarr & Esco, 2013a; Snarr, Nickerson, et al., 2014). As such, it is difficult to tell if this difference is due to the addition of instability to the exercise. However, for the suspension prone bridge, compared with the traditional prone bridge, the variations in execution (arms or legs suspended) increases the activation of muscles used to maintain body position (rectus abdominis, external oblique, rectus femoris, serratus anterior and erector spinae) (Byrne et al., 2014; Snarr & Esco, 2014). Furthermore, instability of the arms may increase the difficulty of the exercise more than instability of the legs, which may cause higher rectus abdominis activation (Byrne et al., 2014). In contrast, the activation of trunk muscles reported by Atkins and colleagues (2015) differ from other studies because they studied elite swimmers who have particular neuromuscular characteristics. Finally, although there is little evidence in the literature, the hamstring musculature was more activated during the suspension hamstring curl than other bilateral hamstring exercises (Malliaropoulos et al., 2015).

Methodological considerations

There is no consensus about the protocol used to normalise the EMG signal for calculating MVIC. The procedures used to produce the MVIC, which can be achieved progressively or explosively, were not provided by most authors. Compared to the use of rapid movement, the use of isometric and slow dynamic movements for achieving a maximal contraction results in more reliable and easy-to-compare EMG signals (Alizadehkhaiyat & Frostick, 2015). Only three studies (Atkins et al., 2015; Byrne et al., 2014; Malliaropoulos et al., 2015) followed the European Recommendation for Surface ElectroMyoGraphy (SENIAM) (Hermens, Freriks, Disselhorst-Klug, & Rau, 2000) guidelines, which warn clinicians to be cautious when making comparisons of muscle activations. Regardless, all reviewed studies reported the electrode placement in detail.

The majority of the reviewed studies used the metronome for pace control in push-ups, except for Beach and colleagues (2008), Fong and colleagues (2015) and Snarr and colleagues (2013), and for prone-bridge studies, except for Mok and colleagues (2014). As such, it is possible that the differences in muscle activity amongst studies for suspension push-ups exercises may have been caused by the type of muscle contraction and the execution velocity. This may be true for dynamic suspension push-up protocols (Beach et al., 2008; Borreani et al., 2015a; Borreani et al., 2015b; Calatayud et al., 2014a; Calatayud et al., 2014c; Calatayud et al., 2014b; Snarr & Esco, 2013b; Snarr et al., 2013), dynamic suspension push-up protocols combining isometric contraction while maintaining movement during the eccentric phase (McGill et al., 2014a; Mok et al., 2014), and isometric suspension push-up protocols (Fong et al., 2015). Research has indicated that muscle activation is highest for dynamic suspension push-ups compared to isometric suspension push-ups or protocols combining both types of contractions. Furthermore, studies with dynamic suspension inverted row protocols (Snarr & Esco, 2013a; Snarr, Nickerson, et al., 2014) demonstrated higher muscle activation compared to studies that used a combination of dynamic and isometric contractions during the concentric phase (McGill et al., 2014b). In addition, the protocol conducted to analyse the core musculature (transversus abdominis and internal oblique, rectus abdominis, external oblique, and lumbar multifidus) in the suspension hamstring curl was similar in Mok and colleagues (2014) and Fong and colleagues (2015). These findings suggest that the protocol (pace control and type of contraction) is not responsible for the differences in muscle activation. Instead, differences may be due to variations in the study populations and procedures used to normalise the EMG signals.

Limitations

In this review, most of the references are from 2013 or later, which indicates that the study of muscle activation during suspension training exercises is a new topic in strength and conditioning. In fact, the manufacturer of the most popular suspension devices patented its first device in 2006. There were certain variations in the execution of the exercises, the muscles assessed for activation, the methods used to assess muscle activity and the EMG signal normalisation procedures. As a result, readers should be cautious in interpreting the magnitudes of muscle activations between the same muscles and amongst exercises. Moreover, the participants in a majority of the studies were physically active male non-athletes, which makes it difficult to generalise findings to both females and athletes.

Suggestions for future research

Athletes differ functionally and morphologically from non-athletes and unhealthy patients. They have more advanced muscular development and their muscles are trained to sport-specific tasks. These differences may result in variations in muscle activation patterns during execution of suspension exercises. Future research should consider this type of population and focus on identifying muscle activations patterns for a greater variety of suspension exercises, including exercises involving the lower extremity, and comparing bilateral and unilateral suspension training exercises. In addition, more research is needed to determine the effectiveness of the inclusion of suspension training exercises during the return-to-play phase of rehabilitation. Finally, Genevois and colleagues (2014); Janot and colleagues (2013) and Maté-Muñoz and colleagues (2014) all recommended longitudinal research and interventional research that measures muscle activity using EMG.

Conclusion

After a detailed systematic review of studies analysing muscle activity during different suspension training exercises (push-ups, inverted row, prone bridge and hamstring curl), we can conclude that there are differences in muscle activation between the exercises using suspension devices and their traditional counterparts. The suspension device increased activation in the most of the muscle groups participating in suspension training exercises (push-ups, inverted row, prone bridge and hamstring curl) compared to traditional. However, certain muscles (middle trapezius, posterior deltoid and biceps brachii) did not differ with regard to activation by exercise type, concretely during suspension inverted row. Depending on the conditioning goals and the strength demands for a given sport, a mixture of traditional exercises, suspension exercises and other conditioning methods can be used to maximise performance.

Clinicians and practitioners should consider the use of push-ups and suspended push-ups to improve the activation of pectoralis major, serratus anterior and anterior deltoid. The use of a pulley suspension device inhibits the aforementioned muscles, which make these exercises less demanding. Likewise, the use of a suspension device with pulley is a challenge for the core muscles in suspension push-ups, prone bridge and hamstring curl. Moreover, when the participant tries to strengthen the triceps brachii, the use of a suspension device with pulley is appropriate in suspension push-ups. In addition, the supine grip when performing the suspension inverted row exercise is recommended for higher demands on the biceps brachii.

The use of different suspension devices and the body position in the most highly practised exercises in suspension training are crucial factors for exercise prescription in clinics and rehabilitation. The different set-ups in these exercises have an influence on the situations during which a high muscle activation is required. This is the case when suspension training becomes an interesting method in injury prevention and other clinical programs, such as those designed in the different phases of the rehabilitation and return-to-play protocols. Another clinical application of the different variation of suspension training exercises might guide the low back pain prevention programs and other postural pains.

Disclosure statement

The authors have no conflicts of interest to disclose.

References

Alizadehkhaiyat, O., & Frostick, S. P. (2015). Electromyographic assessment of forearm muscle function in tennis players with and without lateral epicondylitis. *Journal of Electromyography and Kinesiology*, *25*, 876–886. doi:10.1016/j.jelekin.2015.10.013

Anderson, G., Gaetz, M., Holzmann, M., & Twist, P. (2013). Comparison of EMG activity during stable and unstable push-up protocols. *European Journal of Sport Science*, *13*, 42–48. doi:10.1080/17461391.2011.577240

Atkins, S. J., Bentley, I., Brooks, D., Burrows, M. P., Hurst, H. T., & Sinclair, J. K. (2015). Electromyographic response of global abdominal stabilizers in response to stable- and unstable-base isometric exercise. *Journal of Strength and Conditioning Research*, *29*, 1609–1615. doi:10.1519/JSC.0000000000000795

Beach, T.A., Howarth, S. J., & Callaghan, J. P. (2008). Muscular contribution to low-back loading and stiffness during standard and suspended push-ups. *Human Movement Science*, *27*, 457–472. doi:10.1016/j.humov.2007.12.002

Behm, D., & Colado, J. (2012). The effectiveness of resistance training using unstable surfaces and devices for rehabilitation. *The International Journal of Sports Physical Therapy*, *7*, 226–241.

Behm, D. G., & Anderson, K. G. (2006). The role of instability with resistance training. *The Journal of Strength and Conditioning Research*, *20*, 716–722. doi:10.1519/R-18475.1

Bettendorf, B. (2010). *TRX suspension training bodyweight exercises: Scientific foundations and practical applications* (pp. 6-7). San Francisco, CA: Fitness Anywhere Inc.

Borreani, S., Calatayud, J., Colado, J. C., Moya-Nájera, D., Triplett, N. T., & Martin, F. (2015a). Muscle activation during push-ups performed under stable and unstable conditions. *Journal of Exercise Science & Fitness*, *13*, 94–98. doi:10.1016/j.jesf.2015.07.002

Borreani, S., Calatayud, J., Colado, J., Tella, V., Moya-Nájera, D., Martin, F., & Rogers, M. (2015b). Shoulder muscle activation during stable and suspended push-ups at different heights in healthy subjects. *Physical Therapy in Sport*, *16*, 248–254. doi:10.1016/j.ptsp.2014.12.004

Byrne, J. M., Bishop, N. S., Caines, A. M., Crane, K., Feaver, A. M., & Pearcey, G. (2014). The effect of using a suspension training system on muscle activation during the performance of a front plank exercise. *Journal of Strength and Conditioning Research*, *28*, 3049–3055. doi:10.1519/JSC.0000000000000510

Calatayud, J., Borreani, S., Colado, J., Martin, F., Batalha, N., & Silva, A. (2014a). Muscle activation differences between stable push-ups and push-ups with a unilateral v-shaped suspension system at different heights. *Motricidade*, *10*, 84–93. doi:10.6063/motricidade.10(4).3395

Calatayud, J., Borreani, S., Colado, J., Martin, F., & Rogers, M. (2014b). Muscle activity levels in upper-body push exercises with different loads and stability conditions. *The Physician and Sportsmedicine*, *42*, 106–119. doi:10.3810/psm.2014.11.2097

Calatayud, J., Borreani, S., Colado, J., Martin, F., Rogers, M., Behm, D., & Andersen, L. (2014c). Muscle activation during push-ups with different suspension training systems. *Journal of Sports Science and Medicine*, *13*, 502–510.

Cormie, P., McGuigan, M., & Newton, R. (2011). Developing maximal neuromuscular power: Biological basis of maximal power production. *Sports Medicine*, *41*, 17–38. doi:10.2165/11537690-000000000-00000

Dawes, J., & Melrose, D. (2015). Resistance characteristics of the TRX ™ suspension training system at different angles and distances from the hanging point. *Journal of Athletic Enhancement*, *4*, 2–5.

doi:10.13140/RG.2.1.4245.1047

DiStefano, L., DiStefano, M., Frank, B., Clark, M., & Padua, D. (2013). Comparison of integrated and isolated training on performance measures and neuromuscular control. *Journal of Strength and Conditioning Research*, *27*, 1083–1090. doi:10.1519/JSC.0b013e318280d40b

Duncan, M. (2009). Muscle activity of the upper and lower rectus abdominis during exercises performed on and off a swiss ball. *Journal of Bodywork and Movement Therapies*, *13*, 364–367. doi:10.1016/j.jbmt.2008.11.008

Escamilla, R. F., Lewis, C., Bell, D., Bramblet, G., Daffron, J., Lambert, S., … Andrews, J. R. (2010). Core muscle activation during swiss ball and traditional abdominal exercises. *Journal of Orthopaedic & Sports Physical Therapy*, *40*, 265–276. doi:10.2519/jospt.2010.3073

Fong, S. M., Tam, Y. T., Macfarlane, D. J., Ng, S. M., Bae, Y.-H., Chan, W. Y., & Guo, X. (2015). Core muscle activity during TRX suspension exercises with and without kinesiology taping in adults with chronic low back pain: Implications for rehabilitation. *Evidence-Based Complementary and Alternative Medicine*, *2015*, 1–6. doi:10.1155/2015/910168

Freeman, S., Karpowicz, A., Gray, J., & McGill, S. (2006). Quantifying muscle patterns and spine load during various forms of the push-up. *Medicine & Science in Sports & Exercise*, *38*, 570–577. doi:10.1249/01.mss.0000189317.08635.1b

Genevois, C., Berthier, P., Guidou, V., Muller, F., Thiebault, B., & Rogowski, I. (2014). Effects of 6-week sling-based training of the external-rotator muscles on the shoulder profile in elite female high school handball players. *Journal of Sport Rehabilitation*, *23*, 286–295. doi:10.1123/JSR.2012-0108

Halaki, M., & Ginn, K. (2012). Normalization of EMG signals: To normalize or not to normalize and what to normalize to?. In G. Naik (Ed.), *Computational intelligence in electromyography analysis - a perspective on current applications and future challenges* (pp. 175-194). InTech. doi:10.5772/49957

Hermens, H. J., Freriks, B., Disselhorst-Klug, C., & Rau, G. (2000). Development of recommendations for SEMG sensors and sensor placement procedures. *Journal of Electromyography and Kinesiology*, *10*, 361–374. doi:10.1016/S1050-6411(00)00027-4

Janot, J., Heltne, T., Welles, C., Riedl, J., Anderson, H., Howard, A., & Myhre, S. (2013). Effects of TRX versus traditional resistance training programs on measures of muscular performance in adults. *Journal of Fitness Research*, *2*, 23–38.

Konrad, P. (2005). *The ABC of EMG: A practical introduction of kinesiological electromyography* (pp. 31-33). Scottsdale, AZ: Noraxon Inc.

Lawrence, M., & Carlson, L. (2015). Effects of an unstable load on force and muscle activation during a parallel back squat. *Journal of Strength and Conditioning Research*, *29*, 2949–2953. doi:10.1519/JSC.0000000000000955

Malliaropoulos, N., Panagiotis, T., Jurdan, M., Vasilis, K., Debasish, P., Peter, M., & Tsapralis, K. (2015). Muscle and intensity based hamstring exercise classification in elite female track and field athletes: Implications for exercise selection during rehabilitation. *Open Access Journal of Sports Medicine*, *26*, 209–217. doi:10.2147/OAJSM.S79189

Maté-Muñoz, J., Monroy, A., Jodra Jiménez, P., & Garnacho-Castaño, M. (2014). Effects of instability versus traditional resistance training on strength, power and velocity in untrained men. *Journal of Sports Science & Medicine*, *13*, 460–468.

McGill, S., Cannon, J., & Andersen, J. (2014a). Analysis of pushing exercises: Muscle activity and spine load while contrasting techniques on stable surfaces with a labile suspension strap training system. *Journal of Strength and Conditioning Research*, *28*, 105–116. doi:10.1519/JSC.0b013e3182a99459

McGill, S., Cannon, J., & Andersen, J. (2014b). Muscle activity and spine load during pulling exercises: Influence of stable and labile contact surfaces and technique coaching. *Journal of Electromyography and Kinesiology*, *24*, 652–665. doi:10.1016/j.jelekin.2014.06.002

Moher, D., Liberati, A., Tetzlaff, J., & Altman, D. G. (2009). Preferred reporting items for systematic reviews and meta-analyses: The PRISMA statement. *Journal of Clinical Epidemiology*, *62*, 1006–1012. doi:10.1016/j.jclinepi.2009.06.005

Mok, N. W., Yeung, E. W., Cho, J. C., Hui, S. C., Liu, K. C., & Pang, C. H. (2014). Core muscle activity during suspension exercises. *Journal of Science and Medicine in Sport*, *18*, 189–194. doi:10.1016/j.jsams.2014.01.002

Norwood, J., Anderson, G., Gaetz, M., & Twist, P. (2007). Electromyographic activity of the trunk stabilizers during stable and unstable bench press. *Journal of Strength and Conditioning Research*, *21*, 343–347.

Snarr, R., & Esco, M. (2013a). Comparison of electromyographic activity when performing an inverted row with and without a suspension device. *Journal of Exercise Physiology*, *16*, 51–58.

Snarr, R., & Esco, M. (2013b). Electromyographic comparison of traditional and suspension push-ups. *Journal of Human Kinetics*, *39*, 75–83. doi:10.2478/hukin-2013-0070

Snarr, R., & Esco, M. (2014). Electromyographical comparison of plank variations performed with and without instability devices. *Journal of Strength and Conditioning Research*, *28*, 3298–3055. doi:10.1519/JSC.0000000000000521

Snarr, R., Esco, M., Witte, E., Jenkins, C., & Brannan, R. (2013). Electromyographic activity of rectus abdominis during a suspension push-up compared to traditional exercises. *Journal of Exercise Physiology*, *16*, 1–8.

Snarr, R., Nickerson, B., & Esco, M. (2014). Effects of hand-grip during the inverted row with and without a suspension device: An electromyographical investigation. *European Journal of Sports and Exercise Science*, *3*, 1–5.

Vandenbroucke, J. P., von Elm, E., Altman, D. G., Gøtzsche, P. C., Mulrow, C. D., Pocock, S. J., … Egger, M. (2007). Strengthening the reporting of observational studies in epidemiology (STROBE):

Explanation and elaboration. *PLoS Medicine*, *4*, 1628-1654. doi:10.1371/journal.pmed.0040297

Vera-Garcia, F. J., Grenier, S. G., & McGill, S. (2000). Abdominal muscle response during curl-ups on both stable and labile surfaces. *Physical Therapy*, *80*, 564–569.

Table 1. Search strategy, filters, and databases used

Database	**Records identified**	**Search strategy**
MEDLINE (PubMed)	n= 54	1 suspen* OR TRX 2 electromyograp* OR ‘muscle activation’ 3 training OR stability OR stable OR instability OR unstable 4 1 AND 2 AND 3
SPORTDiscus	n= 33	1 suspen* OR TRX 2 electromyograp* OR ‘muscle activation’ 3 training OR stability OR stable OR instability OR unstable 4 1 AND 2 AND 3
Scopus	n= 131	1 suspen* OR TRX 2 electromyograp* OR ‘muscle activation’ 3 training OR stability OR stable OR instability OR unstable 4 1 AND 2 AND 3
Total	n= 218	

Filter: References from other articles were consulted

Table 2. Descriptive characteristics and quality assessment of cross-sectional studies describing the effects of suspension training exercises on muscle activity in physically active populations

Author/s (year)	Suspension exercise	Sample Size	Sex	Age (mean)	Resistance training experience	Study quality (STROBE points)
Atkins et al. (2015)	Prone Bridge	18	18 Male	15.9	NA	Good (17)
Beach et al. (2008)	Push-ups	11	18 Male	27.4	NA	Good (16)
Borreani et al. (2015a)	Push-ups	30	30 Male	23	1 year	Fair (14)
Borreani et al. (2015b)	Push-ups	29	29 Male	23.5	1 year	Good (15)
Byrne et al. (2014)	Prone Bridge	21	11 Male, 10 Female	21.9	NA	Fair (14)
Calatayud et al. (2014a)	Push-ups	29	29 Male	23.5	1 year	Good (15)
Calatayud et al. (2014b)	Push-ups	29	29 Male	22..6	1 year	Good (15)
Calatayud et al. (2014c)	Push-ups	29	29 Male	23.5	1 year	Good (15)
Fong et al. (2015)	Push-ups Inverted row Prone bridge Hamstring curl	21	11 Male, 10 Female	21.4	NA	Good (15)
Malliaropoulos et al. (2015)	Hamstring curl	20	20 Female	22.8	NA	Fair (14)
McGill et al. (2014a)	Push-ups	14	14 Male	21.1	NA	Good (15)
McGill et al. (2014b)	Inverted row	14	14 Male	21.1	NA	Good (16)
Mok et al. (2014)	Push-ups Inverted row Prone bridge Hamstring curl	18	8 Male, 10 Female	21.9	NA	Fair (14)
Snarr and Esco (2013a)	Inverted row	15	11 Male, 4 Female	25.4	NA	Fair (14)
Snarr and Esco (2013b)	Push-ups	21	15 Male, 6 Female	25.24	6 months	Fair (14)
Snarr and Esco (2014)	Prone bridge	12	6 Male, 6 Female	23.25	6 months	Fair (14)
Snarr et al. (2013)	Push-ups	15	12 Male, 3 Female	25.27	NA	Fair (14)
Snarr, Nickerson et al. (2014)	Inverted row	20	12 Male, 8 Female	26.6	NA	Fair (14)

NA_Not available

Table 3. Push-ups: Differences in muscle activation between traditional and suspension exercise for each muscle

STUDY	EXERCISE TYPE	RESULTS (% MVIC)
Beach et al. (2008)	SD: Push-ups with chains FL: Push-ups	**Rectus abdominis:** ↑* 25.6% in suspension push-ups vs push-ups **External oblique:** ↑* 8.4% in suspension push-ups vs push-ups **Internal oblique:** ↑* 8.5% in suspension push-ups vs push-ups **Latissimus dorsi**: ↑* 4.2% in suspension push-ups vs push-ups **Erector spinae:** No # in suspension push-ups vs push-ups
Snarr and Esco (2013b)	SD: Push-ups with TRX® FL: Push-ups	**Pectoralis major:** ↑* 5.92% in suspension push-ups vs push-ups **Anterior deltoid:** ↑* 22.22% in suspension push-ups vs push-ups **Triceps brachii:** ↑* 31.51% in suspension push-ups vs push-ups
Snarr et al. (2013)	SD: Push-ups with TRX® FL: Push-ups and abdominal supine crunch	**Rectus abdominis:** ↑* 47% in suspension push-ups vs push-ups No # in suspension push-ups vs supine crunch
McGill et al. (2014a)	SD: Push-ups with TRX® at different angles FL: Push-ups	**Serratus anterior:** ↑61.73% in push-ups vs suspension push-ups ↑19.6% in suspension push-ups scapula vs suspension push-ups angle 2 **Rectus abdominis:** ↑22% in suspension push-ups vs push-ups **External oblique:** ↑8% in suspension push-ups vs push-ups **Internal oblique:** ↑6% in suspension push-ups vs push-ups
Calatayud et al. (2014a)	SD: Push-ups with pulley (AirFit Trainer Pro®) at different heights (10 cm and 65 cm) FL: Push-ups at different heights (10 cm and 65 cm)	**Pectoralis major:** ↑* 3.65% in push-ups vs suspension push-ups with pulley **Anterior deltoid:** ↑* 6.74% in push-ups vs suspension push-ups with pulley **Upper trapezius:** ↑* 10.92% in suspension push-ups with pulley vs push-ups **Triceps brachii:** ↑* 31.79% in suspension push-ups with pulley vs push-ups **Rectus abdominis:** ↑* 79.94% in suspension push-ups with pulley vs push-ups **Rectus femoris:** ↑* 9.57% in suspension push-ups with pulley vs push-ups **Erector spinae:** ↑* 2.08% in suspension push-ups with pulley vs push-ups **Gluteus maximus:** ↑* 1.57% in suspension push-ups with pulley vs push-ups
Calatayud et al. (2014b)	SD: Push-ups with pulley (AirFit Trainer Pro®) and TRX® FL: Push-ups and variations (elastic resistance, bench press and press of cables)	**Pectoralis major:** ↑* 26.78% in press bench (85% 1RM) vs suspension push-ups / No # in suspension push-ups vs push-ups **Anterior deltoid:** ↑* 13.46% in push-ups vs suspension push-ups **Upper trapezius:** ↑* 5.61% in suspension push-ups with pulley vs push-ups **Triceps brachii:** ↑* 27.15% in suspension push-ups with pulley vs push-ups **Rectus abdominis:** ↑* 47.67% in suspension push-ups vs push-ups **External oblique:** ↑* 36.83% in suspension push-ups vs push-ups **Serratus anterior:** ↑* 11.27% in push-ups vs suspension push-ups **Posterior deltoid:** ↑* 7.45% in suspension push-ups with pulley vs push-ups

Calatayud et al. (2014c)	SD: Push-ups with pulley (AirFit Trainer Pro®) and without pulley (TRX®, Flying®, Jungle Gym XT®) FL: Push-ups	**Pectoralis major:** ↑* 12% in suspension push-ups double anchor (Jungle Gym XT®) vs push-ups **Anterior deltoid:** ↑* 7.81% in push-ups vs suspension push-ups No # in push-ups vs suspension push-ups double anchor (Jungle Gym XT®) **Upper Trapezius:** ↑* 14.49% in suspension push-ups with pulley vs push-ups **Triceps brachii:** ↑* 30.68% in suspension push-ups with pulley vs push-ups **Rectus abdominis:** ↑* 81.68% in suspension push-ups with pulley vs push-ups **Rectus femoris:** ↑* 11.78% in suspension push-ups with pulley vs push-ups **Erector spinae:** ↑* 2.29% in suspension push-ups with pulley vs push-ups
Borreani et al. (2015a)	SD: Push-ups with TRX® DM: Push-ups with Wobble board®, Stability disc® and Fitness Dome® FL: Push-ups	**Anterior deltoid:** No # in suspension push-ups vs push-ups, wobble board®, stability disc®, fitness dome® **Serratus anterior:** ↑* 66.76% in wobble board® vs push-ups ↑* 66.05% in fitness dome® vs push-ups ↑* 55.15% in stability disc® vs push-ups ↑* 46.41% in suspension push-ups vs push-ups **Lumbar multifidus:** ↑* 3.38% in suspension push-ups vs push-ups **Rectus femoris:** ↑* 17.31% in suspension push-ups vs push-ups
Borreani et al. (2015b)	SD: Push-ups with TRX® at different heights (10 cm and 65 cm) FL: Push-ups at different heights (10 cm and 65 cm)	**Pectoralis major:** ↑* 4.33% in push-ups (65 cm) vs suspension push-ups (65 cm) No # in suspension push-ups (10 cm) vs push-ups (10 cm) **Anterior deltoid:** ↑* 5.1% in push-ups vs suspension push-ups **Upper trapezius:** ↑* 10.28% in suspension push-ups vs push-ups **Triceps brachii:** ↑* 28.27% in suspension push-ups vs push-ups

SD _ Suspension Device; FL _ Floor; DM _ Destabilizing Material; %MVIC _ percent of maximum voluntary isometric contraction; ↑* _ Significantly increases ($p<0.05$); ↑ _ increases; # _ difference

Table 4. Inverted row, prone bridge and hamstring curl: Differences in muscle activation between traditional and suspension exercise for each muscle

STUDY	EXERCISE TYPE	RESULTS (%MVIC)
Snarr and Esco (2013a)	SD: inverted row with TRX® FL: inverted row	**Latissimus dorsi:** No # in suspension inverted row vs inverted row **Middle trapezius:** No # in suspension inverted row vs inverted row **Posterior deltoid:** No # in suspension inverted row vs inverted row **Biceps brachii:** ↑* 8.8% in inverted row vs suspension inverted row
Snarr, Nickerson et al. (2014)	SD: inverted row with pronated and supinated grip in TRX ® FL: inverted row with pronated and supinated grip	**Latissimus dorsi:** ↑* 8.47% in inverted row (prone grip) vs suspension inverted row (prone grip) / ↑* 11.01% in suspension inverted row (supine grip) vs suspension inverted row (prone grip) / No # in suspension inverted row (supine grip) vs suspension inverted row (neutral grip) **Middle trapezius:** ↓* 29.05% in suspension inverted row (supine grip) vs inverted row (prone grip) / ↓* 28.64% in suspension inverted row (supine grip) vs suspension inverted row (neutral grip) / ↓* 15.1% in suspension inverted row (supine grip) vs suspension inverted row (prone grip) **Posterior deltoid:** ↑* 18.27% in suspension inverted row (neutral grip) vs suspension inverted row (prone grip) / ↑* 23.32% in suspension inverted row (neutral grip) vs suspension inverted row (supine grip) / ↑* 6.17% in suspension inverted row (neutral grip) vs inverted row (prone grip) **Biceps brachii:** ↑* 6.65% in suspension inverted row (supine grip) vs inverted row (prone grip) / ↑* 6.02% in suspension inverted row (supine grip) vs suspension inverted row (prone grip) / ↑* 17.83% in suspension inverted row (supine grip) vs inverted row (supine grip)
McGill et al. (2014b)	SD: inverted row and other pulling exercises with TRX® FL: inverted row and other pulling exercises	**Latissimus dorsi:** No # in suspension inverted row vs inverted row /↑* 16.5% in suspension inverted row vs suspension inverted row (TRX® angle 1 and angle 2) / No # in TRX® ghost vs TRX® one-arm ghost **Rectus abdominis:** No # in suspension inverted row vs inverted row / No # in TRX® ghost vs TRX® one-arm ghost **Internal oblique:** No # in suspension inverted row vs inverted row / No # in TRX® ghost vs TRX® one-arm ghost **External oblique:** No # in suspension inverted row vs inverted row / No # in TRX® ghost vs TRX® one-arm ghost **Erector spinae:** No # in suspension inverted row vs inverted row /↑* 18% in suspension inverted row vs suspension inverted row (TRX® angle 1 and angle 2) / No # in TRX® ghost vs TRX® one-arm ghost

Byrne et al. (2014)	SD: Three conditions of prone bridge in TRX® (arms in suspension, legs in suspension and, arms and legs in suspension FL: prone bridge	**Rectus abdominis:** ↑* 31.6% in suspension prone bridge (legs) vs prone bridge / ↑* 20% in suspension prone bridge (arms) vs suspension prone bridge (legs) / ↑* 20% in suspension prone bridge (arms and legs) vs suspension prone bridge (legs) / No # in suspension prone bridge (arms) vs suspension prone bridge (arms and legs) **External oblique:** ↑* 14% in suspension prone bridge (legs) vs prone bridge / ↑* 15% in suspension prone bridge (arms) vs suspension prone bridge (legs) /↑* 10% in suspension prone bridge (arms and legs) vs suspension prone bridge (legs) / No # in suspension prone bridge (arms) vs suspension prone bridge (arms and legs) **Rectus femoris:** ↑* 8% in suspension prone bridge (arms) vs suspension prone bridge (legs) / ↑* 10% in suspension prone bridge (arms) vs prone bridge **Serratus anterior:** ↑* 12% in suspension prone bridge (legs) vs suspension prone bridge (arms) / ↑* 11% in suspension prone bridge (legs) vs suspension prone bridge (arms and legs)
Snarr and Esco (2014)	SD: Two conditions of prone bridge in TRX® (arms in suspension; legs in suspension) DM: two conditions of prone bridge in swiss ball (arms on swiss ball; legs on swiss ball) FL: Prone bridge	**Rectus abdominis:** ↑* 34.2% in suspension prone bridge (arms) vs prone bridge, and swiss ball prone bridge (legs) **External oblique:** ↑* 42.5% in swiss ball prone bridge (legs) vs prone bridge / ↑* 25.4% in swiss ball prone bridge (legs) vs swiss ball prone bridge (arms) / ↑* 21% in swiss ball prone bridge (legs) vs suspension prone bridge (legs) / No # in swiss ball prone bridge (legs) vs suspension prone bridge (arms) **Erector spinae:** ↑* 4.8% in swiss ball prone bridge (arms) vs suspension prone bridge (legs) / ↑* 8.6% in suspension prone bridge (arms) vs suspension prone bridge (legs) / ↑* 6.5% in swiss ball prone bridge (legs) vs prone bridge / ↑* 2.7% in suspension prone bridge (legs) vs prone bridge /↑* 11.3% in suspension prone bridge (arms) vs prone bridge
Atkins et al. (2015)	SD: Prone bridge (arms in suspension) DM: prone bridge with arms on swiss ball FL: Prone bridge	**Rectus abdominis:** ↑* 34.56% in suspension prone bridge vs swiss ball prone bridge **External oblique:** ↑* 12.03% in prone bridge vs swiss ball prone bridge, and suspension prone bridge **Erector spinae:** No # in prone bridge conditions (SD, DM, and FL)
Malliaropouls et al. (2015)	SD: Hamstring curl with TRX® DM: curl with elastic band and fitball flexion FL: lunge, deadlift, kettlebell swing, bridge, hamstring bridge, hamstring curl, nordic and side leg	**Biceps femoris:** ↑* 69% in suspension hamstring curl vs lunge / ↑* 62% in suspension hamstring curl vs deadlift / ↑* 60% in suspension hamstring curl vs kettlebell swing / ↑* 44% in suspension hamstring curl vs bridge / ↑* 67.37% in fitball flexion vs hamstring curl (SD and FL)/ ↑* 99.37% in side leg vs hamstring curl (SD and FL) / ↑* 28% in suspension hamstring curl vs hamstring bridge /↑* 34% in suspension hamstring curl vs curl and nordic **Semitendinosus:** ↑* 55% in suspension hamstring curl vs lunge / ↑* 45% in suspension hamstring curl vs deadlift /↑* 35% in suspension hamstring curl vs kettlebell swing /↑* 30% in suspension hamstring curl vs bridge / ↑* 41.38% in fitball flexion vs hamstring curl (SD and FL)/ ↑* 91.38% in side leg vs hamstring curl (SD and FL) / ↑* 15% in suspension hamstring curl vs hamstring bridge and nordic / ↑* 16% in suspension hamstring curl vs curl

SD _ Suspension Device; FL _ Floor; DM _ Destabilizing Material; %MVIC _ percent of maximum voluntary isometric contraction; ↑* _ Significantly increases ($p<0.05$); ↓*_ significantly reduces ($p < 0.05$); # _ difference

Figure captions

Figure 1. Suspension training devices and their main features: **a)** traditional suspension device, **b)** pulley suspension device and **c)** suspension device with two parallel chains

Figure 2. PRISMA flowchart of the search and study selection

Figure 3. Percentage of maximum voluntary isometric contraction achieved for each muscle in suspension push-ups studies. REF_1: Beach et al. (2008); REF_2: Snarr and Esco (2013b); REF_3: Snarr et al. (2013); REF_4: McGill et al. (2014a); REF_5: Calatayud et al. (2014a); REF_6: Calatayud et al. (2014b); REF_7: Calatayud et al. (2014c); REF_8: Mok et al. (2014); REF_9: Borreani et al. (2015a); REF_10: Borreani et al. (2015b); REF_11: Fong et al. (2015)

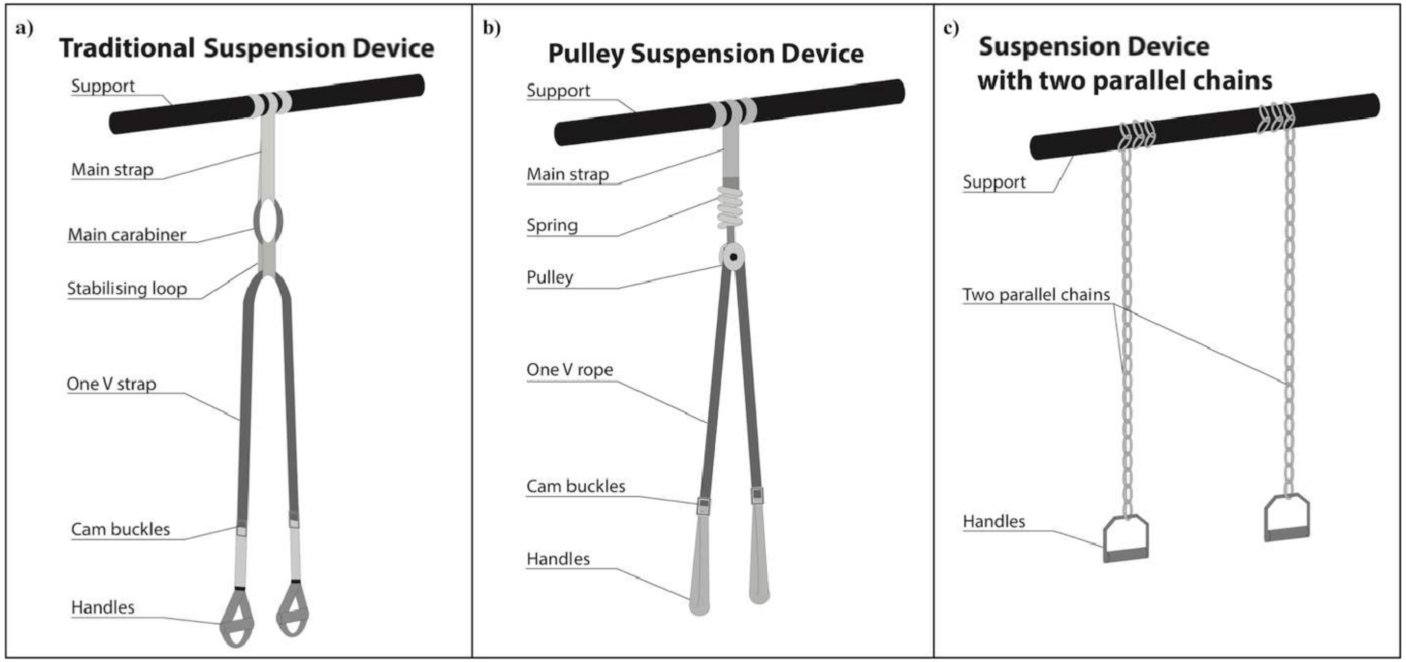
Figure 4. Percentage of maximum voluntary isometric contraction achieved for each muscle in suspension inverted row studies. REF_1: Snarr and Esco (2013a); REF_2: Snarr, Nickerson et al. (2014); REF_3: McGill et al. (2014b); REF_4: Mok et al. (2014); REF_5: Fong et al. (2015)

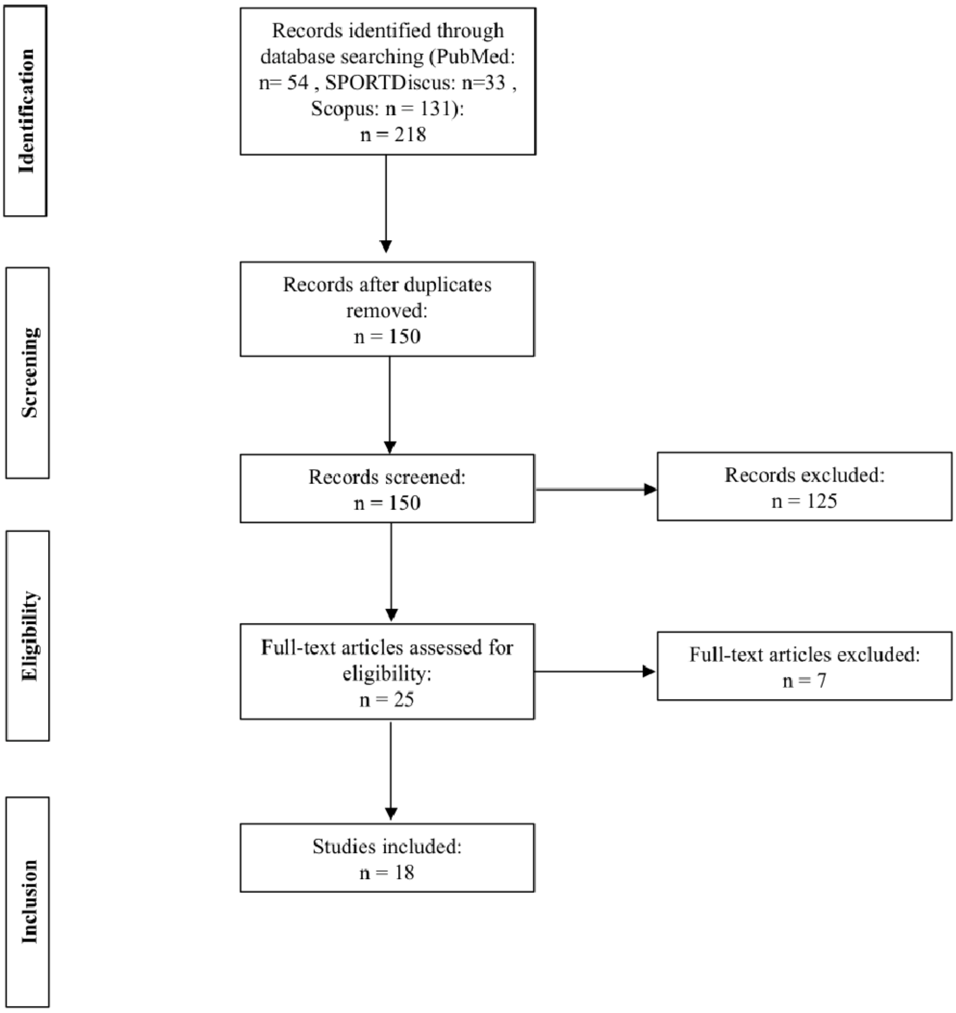
Figure 5. Percentage of maximum voluntary isometric contraction achieved for each muscle in suspension prone bridge studies. REF_1: Byrne et al. (2014); REF_2: Mok et al. (2014); REF_3: Snarr and Esco (2014); REF_4: Atkins et al. (2015); REF_5: Fong et al. (2015)

Figure 6. Percentage of maximum voluntary isometric contraction achieved for each muscle in suspension hamstring curl studies. REF_1: Mok et al. (2014); REF_2: Fong et al. (2014); REF_3: Malliaropoulos et al. (2015)

Published in final edited form as: Aguilera-Castells J, Buscà B, Fort-Vanmeerhaeghe A, Montalvo A.M, Peña J. Muscle activation in suspension training: a systematic review. Sports Biomech, 2020;19:55-75.

DOI: 10.1080/14763141.2018.1472293

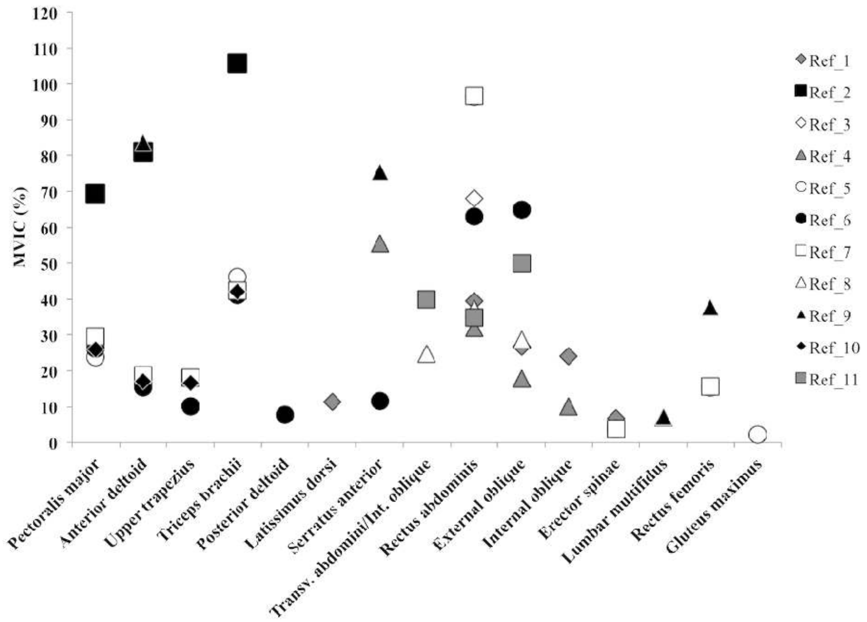


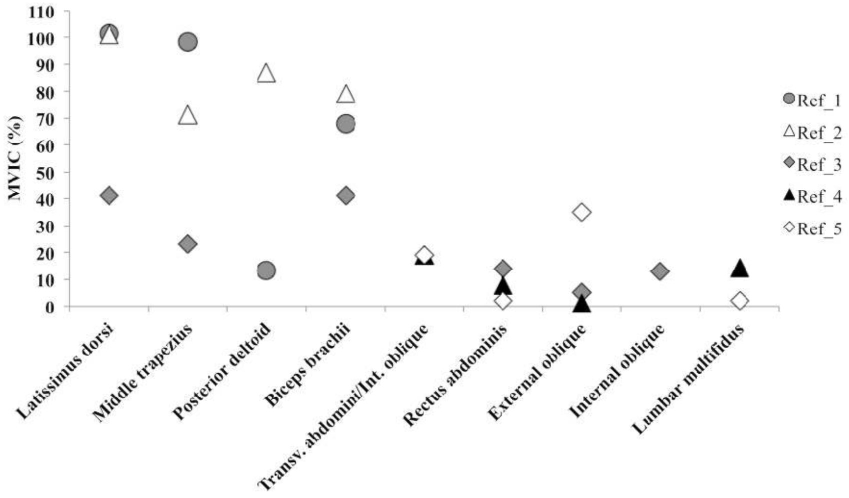

Identification
Screening
Eligibility
Inclusion
Records identified through database searching (PubMed: n= 54 , SPORTDiscus: n=33 , Scopus: n = 131): n = 218
Records after duplicates removed: n = 150
Records screened: n = 150
Records excluded: n = 125
Full-text articles assessed for eligibility: n = 25
Full-text articles excluded: n = 7
Studies included: n = 18

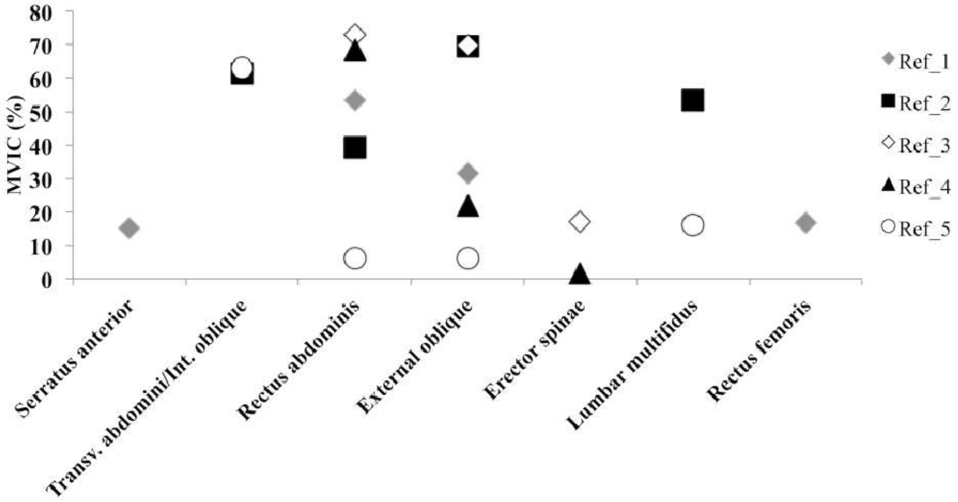
This is a post-print (final draft post-refeering). Published in final edited form as: Aguilera-Castells J, Buscà B, Fort-Vanmeerhaeghe A, Montalvo A.M, Peña J. Muscle activation in suspension training: a systematic review. Sports Biomech, 2020;19:55-75.

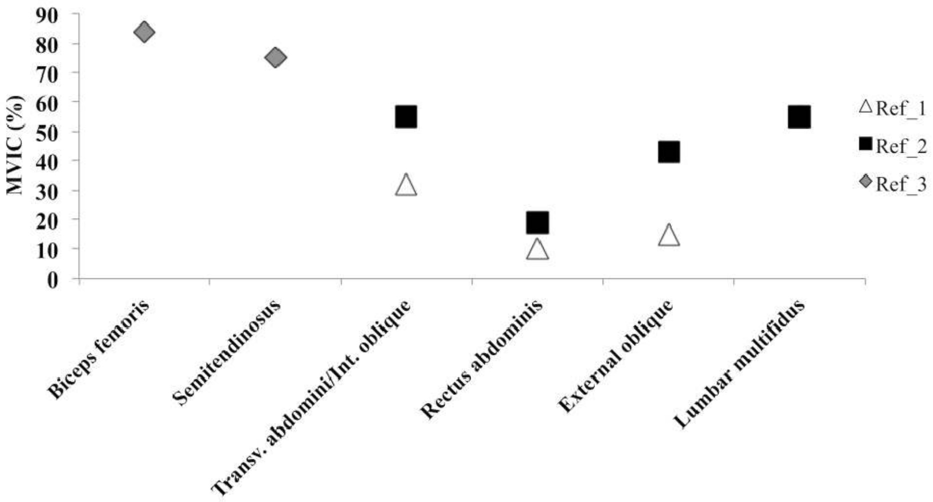
DOI: 10.1080/14763141.2018.1472293

Avalaible in : http://www.dau.url.edu




110
100
90
80
70
60
50
40
30
20
10
0
MVIC (%)
Latissimus dorsi
Middle trapezius
Posterior deltoid
Biceps brachii
Transv. abdomini/Int. oblique
Rectus abdominis
External oblique
Internal oblique
Lumbar multifidus
● Ref_1
△ Ref_2
◆ Ref_3
▲ Ref_4
◇ Ref_5


MVIC (%)
80
70
60
50
40
30
20
10
0
Serratus anterior
Transv. abdomini/Int. oblique
Rectus abdominis
External oblique
Erector spinae
Lumbar multifidus
Rectus femoris
Ref_1
Ref_2
Ref_3
Ref_4
Ref_5


MVIC (%)
90
80
70
60
50
40
30
20
10
0
Biceps femoris
Semitendinosus
Transv. abdomini/Int. oblique
Rectus abdominis
External oblique
Lumbar multifidus
△Ref_1
■Ref_2
◆Ref_3