Progression of Core Stability Exercises Based on the Extent of Muscle Activity

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Objective: The aim of this cross-sectional study was to evaluate a variety of isometric plank exercises.

Design: Twenty university students performed the following eight different variants of plank exercises in random order and with 1-min rest intervals: stable prone plank, suspended prone plank, stable roll-out plank, suspended roll-out plank, unilateral stable prone plank, unilateral suspended prone plank, stable lateral plank, and suspended lateral plank. Surface electromyography signals were recorded for the upper rectus abdominis, lower rectus abdominis, external oblique, lumbar erector spinae, and normalized to the maximum voluntary isometric contraction.

Results: The suspended prone plank and the suspended roll-out plank provided the greatest upper rectus abdominis activity. The greatest lower rectus abdominis activity was induced by the suspended roll-out plank. The highest lumbar erector spinae activity was provided by the suspended and stable lateral planks. The suspended prone plank and the suspended roll-out plank provided the greatest external oblique activity, although not significantly different from the suspended lateral plank.

Conclusions: Muscle activity could be progressed using the different exercises. Although suspended prone plank and the suspended roll-out plank were most efficient for the abdominal muscles, suspended and stable lateral planks were most efficient for the lumbar muscles.

Key Words: Plank, Bridging, Trunk, EMG

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Low back pain is a major public health challenge and socioeconomic burden worldwide.[1] Thus, prevention as well as rehabilitation of low back pain should be a key priority. A recent systematic review showed that physical exercise—either alone or in combination with education—is effective in preventing development of low back pain.[2] Although many types of physical exercises exist, specific training of the low back and abdominal muscles or "core stability training" have become popular during the last decade in injury-prevention programs for athletes[3] and in rehabilitation programs for clinical populations.[4] Core stability training involves the activation of deep and superficial spinal muscles and recently demonstrated greater short-term effectiveness than general exercise in decreasing pain and improving physical function among low back patients.[5]

The isometric plank exercises—lying on the floor with one or both elbows and feet/foot supporting the ground while maintaining an isometric position—have been widely used as core stability exercises.[6–8] Importantly, the isometric plank exercises minimize spine loads[9] and provide muscle tension of longer duration in comparison with dynamic abdominal exercises.[10] Although traditional plank exercises are performed using body weight as load, the actual resistance can be modulated by changing body position. For instance, removing the support of one foot from the floor results in higher levels of muscle activity compared with the bilateral (i.e., full support) version of the exercise.[6] Devices that challenge the stability of the plank exercise, that is, making the supporting ground unstable, are also considered an efficient way to train the core muscles[4] and may be used to improve and restore balance and proprioception.[11]

A relatively new way of making plank exercises even more challenging is by use of suspension devices, providing unexpected perturbations to balance due to the high level of instability. Recent studies demonstrated that the suspended planks provided higher rectus abdominis[12–14] and lumbar activity[14] than traditional stable planks. However, these studies only evaluated the prone plank exercise. Thus, additional studies evaluating a wider range of core stability exercises that allow comparisons between stable and more unstable variations are warranted. Exercises providing greater muscle activity and thus greater challenges to the neuromuscular system may be more effective to improve core muscle strength and stability.[15] However, a thorough evaluation and comparison of different exercises are needed before recommendations can be provided. Thus, evaluating muscle activity during a number of plank exercise variants can provide valuable information to athletes, patients, and therapists, thereby allowing improved decision making in relation to design of core training programs to prevent and rehabilitate back pain.

The purpose of this study is to evaluate a variety of isometric plank exercises on the basis of the extent of muscle activity. Based on biomechanical considerations, we hypothesized that the suspended roll-out plank would provide the

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highest abdominal activity of all the exercises. We also hypothesized that the highest back electromyography (EMG) values would be induced by the suspended lateral plank.

METHODS

Participants

A total of 20 university students (13 men and 7 women) voluntarily participated in the study, which was performed during December 2015. The participants were physically active, performing at least two physical exercise sessions per week at moderate to vigorous intensity. All subjects were free from musculoskeletal pain, neuromuscular disorders, or any form of joint or bone disease. All participants were informed about the purpose and content of the investigation. Informed consent was written from all individual participants included in the study. The study conformed to The Declaration of Helsinki and was approved by the local ethical committee (H1460994903890).

Procedures

Each subject took part in two sessions: familiarization and experimental sessions both at the same hour during the morning and separated by 48 to 72 hrs. Several restrictions were imposed on the volunteers: no food, drinks, or stimulants (e.g. caffeine) to be consumed 2 hrs before the sessions as well as no physical activity more intense than daily activities 24 hrs before the exercises. They were instructed to sleep at least 7 to 8 hrs the night before data collection. All measurements were made by the same two investigators and were conducted in the same facility. Data reported in the present study forms part of a research project investigating muscle activity during different core stability exercises. This article adheres to the STROBE guidelines.

During the familiarization session, height (IP0955; Invicta Plastics Limited, Leicester, England), body mass, and body fat percentages (Tanita model BF-350, Tokyo, Japan) were obtained. Then, subjects were familiarized with the exercise and instructions that would later be used during data collection. Subjects practiced at least three times for each condition, until they felt confident of understanding the task.

At the experimental session, the protocol started with a light warm-up, where each subject performed 3 mins of light walking. Then, the protocol continued with the preparation of subjects' skin, followed by electrode placement, maximum voluntary isometric contractions (MVICs) collection, 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. Electrodes were placed according to established recommendations on the upper rectus abdominis (UP ABS),[16] lower rectus abdominis (LOW ABS),[17] external oblique (OBLIQ),[16] and lumbar erector spinae (LUMB),[16] on the dominant side of the body (Fig. 1). Pregelled bipolar silver/silver chloride surface electrodes (Blue Sensor M-00-S; Medicotest, Olstykke, Denmark) were placed with an inter-electrode distance of 2 cm. The reference electrode was placed between the active electrodes, approximately 10 cm away from each muscle, according to the manufacturer's specifications. All signals were acquired at a sampling frequency of 1 kHz, amplified and converted from analog to digital. All records of myoelectrical activity (in microvolts) were stored on a hard drive for later analysis. To acquire the surface EMG signals produced during exercise, an ME6000P8 (Mega Electronics, Ltd, Kuopio, Finland) biosignal conditioner was used. Before the exercise performance described hereafter, two MVICs of 5-sec duration were performed for each muscle and the trial with the highest EMG was selected. Participants performed a nonmaximal practice trial to ensure that they understood the task. One minute of rest was given between each MVIC and verbal encouragement was provided to motivate all participants to achieve maximal muscle activity. Positions during the

FIGURE 1. Bipolar surface electromyographic electrode placement. A, Upper rectus abdominis: parallel to the muscle fibers of rectus so that they are located approximately 2 cm lateral and across from the umbilicus over the muscle belly. B, Lower rectus abdominis: centered on the muscle belly near the midpoint between the umbilicus and the pubic symphysis and 3 cm lateral from the midline. C, External oblique: lateral to the rectus abdominis and directly above the anterior superior iliac spine, halfway between the crest and the ribs at a slightly oblique angle. D, Lumbar erector spinae: the electrodes are placed approximately 2 cm from the L3 vertebra (determined from the ileac crest) of the spine and over the muscle belly.

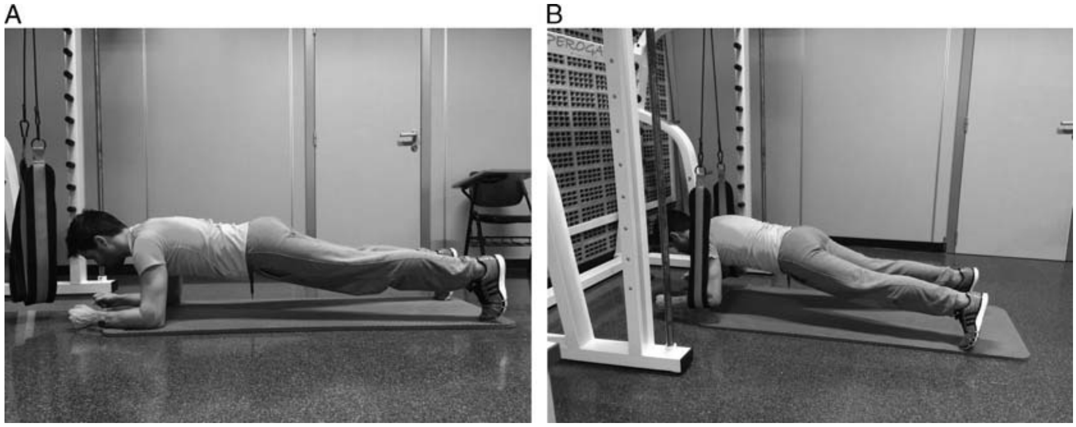

FIGURE 2. A, Stable prone plank. B, Suspended prone plank.

MVICs were based on standardized muscle testing procedures[18] for the (1) UP ABS and LOWS AB, (2) OBLIQ, and (3) LUMB and were performed against a fixed immovable resistance (i.e., Smith machine). Specifically, (1) curling up at 40 degrees with arms on the chest and pressing against the bar with the participant lying on the exercise mat and feet flat on the floor, (2) curling up at 40 degrees with arms on the chest and pressing against the bar in an oblique direction with the participant lying on the exercise mat, with the feet flat on the floor and the knees bent at 90 degrees, and (3) trunk extension with the participant lying on a bench and pelvis fixated, the trunk was extended against the bar.

Each subject performed the following eight different conditions (Figs. 2–5), randomly assigned and with 1-min rest interval: stable prone plank; suspended prone plank (as the previous exercise but with forearms on a suspended device); stable roll-out plank (the subject "rolled out" while maintaining a neutral spine and pelvis until the hip and knee were aligned, with the elbows fully extended and without lifting the feet from the floor); suspended roll-out plank (as the previous exercise but "rolling out" with the suspended device); unilateral stable prone plank (as the stable prone plank but with the dominant leg in a fully extended position); unilateral suspended prone plank (as the previous exercise but with the non-dominant foot suspended at 10 cm from the floor and with the dominant leg fully extended); stable lateral plank (in a sidelying position with the dominant side beneath, with the elbow beneath the shoulder, the other arm perpendicular to the ground, and the pelvis raised); and suspended lateral plank (as the previous exercise but with the feet suspended at 10 cm from the floor). The suspended device consisted of a one-anchor system (AirFit Trainer Pro; PurMotion, Pelham, AL). This device has a main band supported by a spring and a cable with a pulley in the middle, reducing friction and allowing greater unilateral disturbances. The suspension device was anchored to a Smith machine, so the handle straps were placed at 10 cm from the floor.

Subjects started all the prone exercises with feet shoulder width apart. Subjects had 2 to 3 seconds to reach the proper exercise position, and then they have to maintain it during 5 seconds. During the exercise performance, subjects were asked to use minimal lower body and trunk movement. Verbal feedback was given to the subjects to start or end the exercise and to maintain the proper position. The EMG signals of these 5 secs were recorded for later analysis. A trial was discarded and repeated if a participant was not able to maintain the proper position or performed sudden trunk movements.

Data Analysis

During later analysis, all raw EMG signals obtained during the exercises were digitally filtered, consisting of (1) high-pass

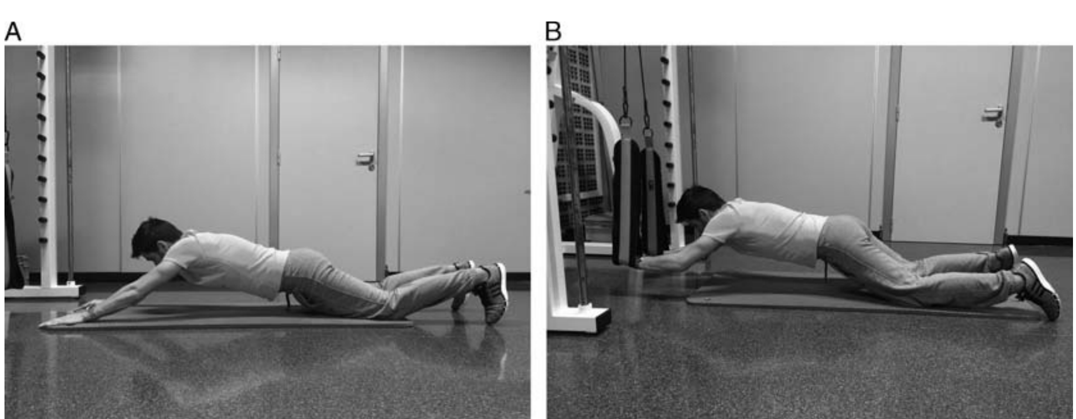

FIGURE 3. A, Stable roll-out plank. B, Suspended roll-out plank.

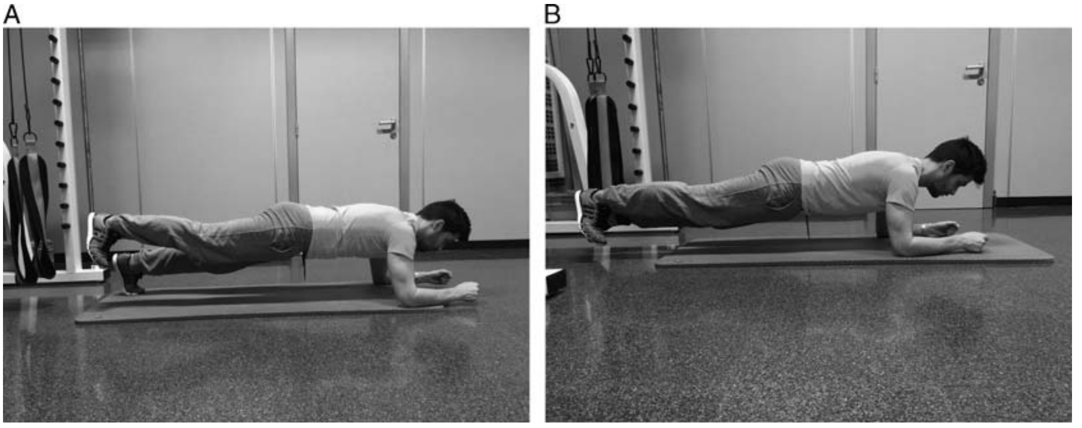

FIGURE 4. A, Unilateral stable prone plank. B, Unilateral suspended prone plank.

filtering at 10 Hz and (2) a moving root-mean-square filter of 500 millisecs. For each individual muscle, peak root-mean-square EMG in each condition was determined and normalized to the maximal root-mean-square EMG obtained during the MVIC collection.

Statistical Analyses

A repeated measures analysis of variance (Proc Mixed, SAS Version 9; SAS Institute, Cary, NC) was used to determine whether differences existed between conditions for each muscle separately. The factor included in the model was *condition (8 conditions)*. Normalized EMG was the dependent variable. Values are reported as least-square means (standard error), unless otherwise stated. *P* values of less than 0.05 were considered statistically significant.

Sample size calculations showed that 20 subjects were sufficient to achieve a statistical power of 80% at a minimal relevant difference of 10% EMG, a type 1 error probability of 1%, and a standard deviation of 10%.[19]

RESULTS

The participants of this current study presented the following demographic characteristics: age, 20(1) yrs; height, 173.4 (7.8) cm; body mass, 73.9(7.7) kg; and body fat percentage, 14.1(4.4%).

Table 1 shows complete data during the different exercises. The suspended prone plank and the suspended roll-out plank provided the greatest UP ABS activity. The greatest LOW ABS activity was induced by the suspended roll-out plank. The highest LUMB activity was provided by the suspended and stable lateral planks. The suspended prone plank and the suspended roll-out plank provided the greatest OBLIQ activity, except when compared with the suspended lateral plank.

DISCUSSION

The main findings of the present study were that the suspended prone plank and the suspended roll-out plank generally provided the highest level of muscle activity for the abdominal muscles, whereas the greatest back muscle activity was generated by the lateral planks.

In agreement with previous literature,[12,14] we found that the rectus abdominis had the greatest activity, whereas the LUMB had the lowest values. Partly in agreement with the first hypothesis, the suspended roll-out plank provided the highest LOW ABS activity. However, UP ABS had comparable EMG during the suspended prone plank and the suspended roll-out plank. Both exercises resulted in higher abdominal muscle activity than during the other exercises. In line with these results, the roll-out exercise on a Swiss Ball[17] or with a power wheel[20] was one of the most effective exercises in activating upper and

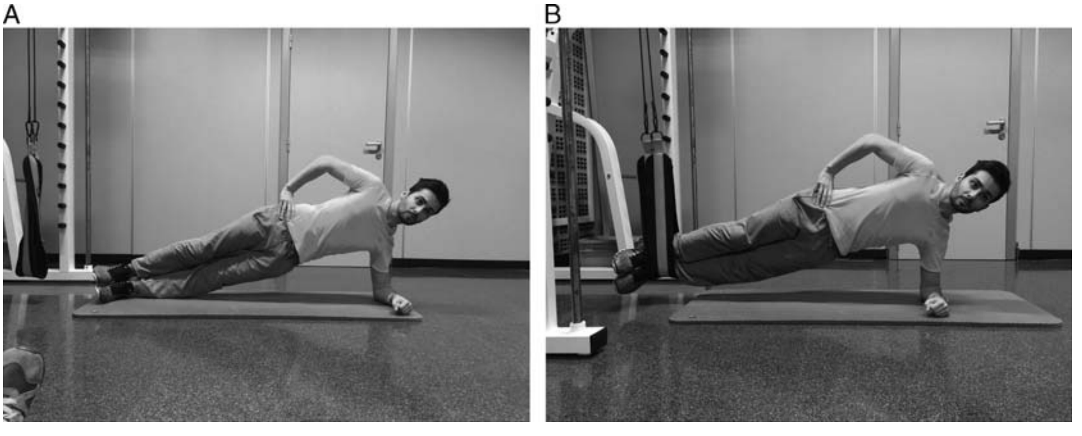

FIGURE 5. A, Stable lateral plank. B, Suspended lateral plank.

TABLE 1. Normalized EMG (standard error) during the different exercises

	Stable Prone Plank	Suspended Prone Plank	Stable Roll-out Plank	Suspended Roll-out Plank	Unilateral Stable Prone Plank	Unilateral Suspended Prone Plank	Stable Lateral Plank	Suspended Lateral Plank
	1	2	3	4	5	6	7	8
UP ABS	32 (4)	131 (15)	100 (12)	145 (22)	30 (5)	43 (9)	26 (4)	31 (5)
	2–4	*1, 3, 5–8*	*1, 2, 4–8*	*1, 3, 5–8*	*2–4*	*2–4*	*2–4*	*2–4*
LOW ABS	30 (4)	93 (10)	74 (11)	122 (32)	28 (7)	37 (8)	20 (3)	30 (4)
	2–4	*1, 4–8*	*1, 4–8*	*1, 2, 3, 5–8*	*2–4*	*2–4*	*2–4*	*2–4*
LUMB	2 (1)	4 (1)	2 (1)	4 (1)	2 (1)	3 (1)	13 (1)	14 (2)
Spinae	*7, 8*	*7, 8*	*7, 8*	*7, 8*	*7, 8*	*7, 8*	*1, 2–6*	*1, 2–6*
OBLIQ	37 (5)	88 (14)	49 (7)	84 (12)	44 (9)	58 (11)	62 (12)	74 (14)
	2, 4, 6–8	*1, 3, 5–7*	*2, 4, 8*	*1, 3, 5–7*	*2, 4, 6–8*	*1, 2, 4, 5*	*1, 2, 4, 5*	*1, 3, 5*

Italic numbers denote statistical differences between the exercises (e.g., italic number 1 means different from the exercise number 1, which is the stable prone plank).

lower parts of the rectus abdominis muscle among different abdominal exercises. Recent studies have shown that the suspended prone planks yielded higher rectus abdominis than the stable counterparts[12–14] or even than the exercise performed on a Swiss ball.[12,14] A previous study found that the use of unilateral variations during different supine planks generally provided a progression respect to the bilateral version in terms of core neuromuscular challenge.[6] In contrast, present findings indicate no advantages of using a suspended device during the unilateral prone plank for the UP ABS and LOW ABS. It is worth mentioning that the stable roll-out plank was the second most effective exercise in providing UP ABS activity and also LOW ABS activity (together with the suspended prone plank exercise).

In a similar way as occurred with the UP ABS and LOW ABS, the suspended prone plank and the suspended roll-out plank provided the greatest OBLIQ activity, except when compared with suspended lateral plank. In contrast, the unilateral stable prone planks together with the stable prone plank were the less challenging exercises for the OBLIQ. In accordance, greater OBLIQ activity has been reported during a suspended prone plank than during the stable version.[13,14] Interestingly, Atkins et al.[12] found that the traditional plank provided greater OBLIQ activity when compared with the suspended counterpart or the same exercise on a Swiss ball. However, the subjects in this study performed the plank position with the elbows in a fully extended position. Greater abdominal activity has been reported during a suspended prone body position at a lower height from the ground, as compared with a higher height.[21] Therefore, it is plausible that the higher position during the study conducted by Atkins et al.[12] explained the absence of OBLIQ activity increments when compared with the present results. The present data show an increased OBLIQ activity during the unilateral suspended plank in comparison with the nonsuspended version of the exercise. This result could be expected because of the rotator and trunk stabilizer role of this muscle[22] and agreed with previous data from a study using different supine planks, where unilateral variations generally provided the greatest neuromuscular challenge.[6]

Not all the suspended planks yielded higher EMG values than stable counterparts. For instance, there were no muscle activity differences during the suspended and the stable lateral planks. Partly supporting the second hypothesis, it was found that either the suspended or the stable lateral plank provided the highest LUMB activity. Indeed, the other exercises showed no LUMB activity differences between them. In accordance with the present results, Atkins et al.[12] reported no LUMB EMG differences between the prone plank performed on the ground, on a Swiss ball, or in suspension. On the contrary, another study reported higher LUMB activity during the suspended prone plank in comparison with the stable version.[14]

In similar way as found in this study, previous data showed that the stable lateral plank provided similar LUMB[8,23] and lumbar multifidus activity whereas the stable supine plank provided greater activity in these muscles than the stable prone plank.[23] As occurred in other studies that used suspended planks,[12,14] the LUMB had the lowest EMG values among all the measured muscles. This is in line with previous studies evaluating different stable planks. Although prone planks provide a more efficient stimulus for the abdominal muscles, supine planks have demonstrated greater muscle activity for the back muscles.[7,8,23] However, the different planks performed at the current study can have some core stability benefits, because only 25% of the maximal voluntary contractions are able to provide maximal joint stiffness.[24] In addition, the EMG levels of abdominal muscle that were found at the present study are more than enough to stiffen the spinal segments.[25] In addition, the postural disruptions provided by some of the exercises performed may challenge proprioception, producing an enhanced trunk muscle response and therefore increasing stability and balance.[4]

The amplitude of the exercise-induced EMG signal normalized to the maximal EMG amplitude has been used to measure intensity of muscle contraction and thereby the potential for stimulating strength gains.[26] This can be the result of greater motor unit recruitment, discharge rates, and synchronization.[27] In terms of core training, a review pointed out that greater challenge to the neuromuscular system may be more effective to improve core muscle strength and stability.[15] Interestingly, biomechanically comparable exercises providing similar muscle activity have resulted in nonstatistical different muscle strength gains after a training period.[26] Moreover, it has been found that regional difference in muscle activation during an exercise can explain regional differences in muscle cross-sectional area after a training intervention.[28] In our article, the variety of exercises provided can be used to challenge different muscles, which can also be trained in different ways (e.g., progressing from lower to higher intensities). It is worth to mention that some core muscles as the multifidus may respond well to low intensities, because 30% to 40% of the MVIC seem sufficient to improve its efficiency.[29] However, greater intensities will be needed to generate further adaptations at long term by providing a progressive stimulus to the neuromuscular system. In addition, higher intensities will be needed for those involved in work-related task or sport participation containing high stresses and torques for the core muscles.

Because proper exercise selection is a basic component of every well-designed training program for preventing or rehabilitating back pain, the present results have high clinical relevance. According to the principles of training physiology, higher intensities of muscle contraction will to a larger extent stimulate strength gains everything else being equal.[30] However, although relatively high levels of muscle activity is beneficial in stimulating strength gains among pain-free individuals, for example, performing suspended prone plank and the suspended roll-out plank, patients with chronic back pain may need to start with exercises providing lower levels muscle activity, for example, stable prone plank and stable lateral plank, and later progress to more intensive exercises when pain subsides. Thus, by using the present results as reference values, clinicians, coaches, athletes, and patients will be able to grade the intensity of muscle contraction depending on the current level of pain, performance, and needs.

Because participants in this study were healthy, the present data may not be directly transferable to patients with low back pain. However, the data provided represent one of the widest varieties of isometric suspended planks until date and can serve as a general guide while no data are available among clinical population. This can have relevant practical applications to improve decision making in core stability programs, facilitating exercise selection, and providing greater possibilities to attend the training principles of variation and progression.

CONCLUSIONS

The suspended roll-out plank is the most effective exercise in activating the LOW ABS. The suspended prone plank and the suspended roll-out plank are the most proper exercises when a higher UP ABS activity is desired and also provided the greatest OBLIQ activity (except when compared with the suspended lateral plank). Both lateral planks (suspended or stable) are the best options to increase LUMB activity.

The following examples can serve as adequate exercise progressions based on the extent of muscle activity:

For the rectus abdominis, these exercises should be performed as a first step (lateral planks, stable prone plank, unilateral stable, and suspended prone planks). After that, the stable roll-out would be the next step. After this, the suspended prone plank could be performed and finally the suspended roll-out plank. Regarding progression to stimulus, the OBLIQ could start with the stable prone plank and the unilateral stable prone plank. Then, a stable roll-out and a unilateral suspended prone plank could be performed. The next step would be the use of the lateral planks and finally the suspended roll-out plank and the suspended prone plank. For a LUMB muscle progression, these exercises should constitute the first step (stable prone plank, stable roll-out plank, unilateral stable prone plank, unilateral suspended prone plank, suspended roll-out plank, and suspended prone plank). Afterward, the stable lateral plank and the suspended lateral plank should be the last exercises.

REFERENCES

1. Balagué F, Mannion AF, Pellisé F, et al: Non-specific low back pain. *Lancet* 2012;379:482–91
2. Steffens D, Maher CG, Pereira LS, et al: Prevention of low back pain: a systematic review and meta-analysis. *JAMA Intern Med* 2016;176:1–10
3. Behm DG, Colado JC: The effectiveness of resistance training using unstable surfaces and devices for rehabilitation. *Int J Sports Phys Ther* 2012;7:226–41
4. Borghuis J, Hof AL, Lemmink KAPM: The importance of sensory-motor control in providing core stability: implications for measurement and training. *Sports Med* 2008;38:893–916
5. Wang XQ, Zheng JJ, Yu ZW, et al: A meta-analysis of core stability exercise versus general exercise for chronic low back pain. *PLoS One* 2012;7: e52082
6. Feldwieser FM, Sheeran L, Meana-Esteban A, et al: Electromyographic analysis of trunk-muscle activity during stable, unstable and unilateral bridging exercises in healthy individuals. *Eur Spine J* 2012;21(Suppl 2):S171–86
7. Imai A, Kaneoka K, Okubo Y, et al: Trunk muscle activity during lumbar stabilization exercises on both a stable and unstable surface. *J Orthop Sports Phys Ther* 2010;40:369–75
8. Lehman GJ, Hoda W, Oliver S: Trunk muscle activity during bridging exercises on and off a Swiss ball. *Chiropr Osteopat* 2005;13:14
9. Axler CT, McGill SM: Low back loads over a variety of abdominal exercises: searching for the safest abdominal challenge. *Med Sci Sports Exerc* 1997;29:804–11
10. Lee BCY, McGill SM: Effect of long-term isometric training on core/torso stiffness. *J Strength Cond Res* 2015;29:1515–26
11. Akuthota V, Nadler SF: Core strengthening. *Arch Phys Med Rehabil* 2004;85(3 suppl 1): S86–92
12. Atkins SJ, Bentley I, Brooks D, et al: Electromyographic response of global abdominal stabilizers in response to stable- and unstable-base isometric exercise. *J Strength Cond Res* 2015;29:1609–15
13. Byrne JM, Bishop NS, Caines AM, et al: Effect of using a suspension training system on muscle activation during the performance of a front plank exercise. *J Strength Cond Res* 2014;28:3049–55
14. Snarr RL, Esco MR: Electromyographical comparison of plank variations performed with and without instability devices. *J Strength Cond Res* 2014;28:3298–305
15. Martuscello JM, Nuzzo JL, Ashley CD, et al: Systematic review of core muscle activity during physical fitness exercises. *J Strength Cond Res* 2013;27:1684–98
16. Criswell E, Cram JR (eds): *Cram's Introduction to Surface Electromyography*, 2nd ed. Sudbury, MA: Jones and Bartlett, 2011
17. Escamilla RF, Lewis C, Bell D, et al: Core muscle activation during Swiss ball and traditional abdominal exercises. *J Orthop Sports Phys Ther* 2010;40:265–76
18. Vera-Garcia FJ, Moreside JM, McGill SM: MVC techniques to normalize trunk muscle EMG in healthy women. *J Electromyogr Kinesiol* 2010;20:10–6
19. Andersen LL, Kjaer M, Andersen CH, et al: Muscle activation during selected strength exercises in women with chronic neck muscle pain. *Phys Ther* 2008;88:703–11
20. Escamilla RF, Babb E, DeWitt R, et al: Electromyographic analysis of traditional and nontraditional abdominal exercises: implications for rehabilitation and training. *Phys Ther* 2006;86:656–71
21. Calatayud J, Borreani S, Colado JC, et al: Muscle activation differences between stable push-ups and push-ups with a unilateral v-shaped suspension system at different heights. *Motricidade* 2014;10:84–93
22. Arokoski JP, Valta T, Airaksinen O, et al: Back and abdominal muscle function during stabilization exercises. *Arch Phys Med Rehabil* 2001;82:1089–98
23. Ekstrom RA, Donatelli RA, Carp KC: Electromyographic analysis of core trunk, hip, and thigh muscles during 9 rehabilitation exercises. *J Orthop Sports Phys Ther* 2007;37:754–62
24. Cresswell AG, Oddsson L, Thorstensson A: The influence of sudden perturbations on trunk muscle activity and intra-abdominal pressure while standing. *Exp Brain Res* 1994; 98:336–41
25. Kibler WB, Press J, Sciascia A: The role of core stability in athletic function. *Sports Med* 2006;36:189–98
26. Calatayud J, Borreani S, Colado JC, et al: Bench press and push-up at comparable levels of muscle activity results in similar strength gains. *J Strength Cond Res* 2015;29:246–53
27. Gabriel DA, Kamen G, Frost G: Neural adaptations to resistive exercise: mechanisms and recommendations for training practices. *Sports Med* 2006;36:133–49
28. Wakahara T, Fukutani A, Kawakami Y, et al: Nonuniform muscle hypertrophy: its relation to muscle activation in training session. *Med Sci Sports Exerc* 2013;45:2158–65
29. Cholewicki J, McGill SM: Mechanical stability of the in vivo lumbar spine: implications for injury and chronic low back pain. *Clin Biomech (Bristol, Avon)* 1996;11:1–15
30. American College of Sports Medicine: American College of Sports Medicine position stand. Progression models in resistance training for healthy adults. *Med Sci Sports Exerc* 2009;41:687–708