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# Muscle Activity of Core Muscles During Plank Exercise on Different Surfaces

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**Abstract**

Determining the effects of different instability devices on core muscle activation gives important information for practitioners when prescribing strength exercise. This study aimed to compare electromyographic responses of core muscles during plank exercise performed with and without instability devices. Twenty-five subjects (age = 21.5 ± 2.66 years; height 179 ± 0.5 cm; weight 74.28 ± 4.27 kg; Body Mass Index (BMI) = 22.98 ± 1.11 kg/m2) performed plank exercise on stable surface, BOSU ball, Swiss ball, and TRX Suspension Trainer (TRX) in a crossover design. Plank exercise consisting of isometric contractions was performed two times. Surface electromyography (sEMG) was used to determine the amplitude of rectus abdominis (RA), external oblique (EO), erector spinae (ERS) muscles during the exercise. The sEMG amplitude has been normalized against the maximum voluntary contraction (MVC) trial that yielded the highest peak torque value during isometric contractions of the related muscles. In the RA and EO muscles, significantly higher normalized sEMG amplitude (%MVC) values were detected in TRX and Swiss ball compared to a stable surface and BOSU ball ($p<0.05$). On the other hand, TRX exhibited more sEMG amplitude than on Swiss ball ($p<0.05$). A significantly higher sEMG amplitude value was detected on TRX than the Swiss ball in the ERS muscle ($p<0.05$). However, there was no significant difference between the BOSU ball and the Stable surface. In conclusion, the TRX may be a good option for those who want more challenges for the anterior and lateral core muscles. However, plank exercise, whether on a stable surface or an instability device, seems trivial for strengthening the ERS muscle.

**Keywords:** EMG, Instability, BOSU Ball, TRX, Swiss Ball, Core Muscle

## INTRODUCTION

The importance of the core region muscles in daily activities and athletic performance has increased in recent years. Thus, core training has begun to be commonly performed in strength exercises (1,3,4,6,8). Core training provides benefits in daily life, such as preventing and rehabilitating low back pain and reducing the risk of fall-related injuries. It also supports force production by providing trunk stabilization and plays a vital role in transferring the generated force to the extremities in athletic performance (1,21,31). According to its regions and attachment points, the core muscle is called as the global and local core muscle (2). The local core muscle is located close to the spine and takes part in precise spinal movements, and helps the global core muscle to produce more force. In contrast, the global core muscle is the sizeable superficial muscle responsible for both spine stability and actions of the trunk and extremities (6). Being the surface and large size of these muscles provides ease of measurement, and the activation measurement of these muscles was preferred in previous core region muscle activation studies (2). It was stated that the enhanced function and strength of the rectus abdominis (RA), external oblique (EO), and erector spinae (ERS) muscles, which are among the most important global core muscles, improve stability and muscle coordination, thus reducing the risk of injury (10).

Since it is claimed that spinal flexion exercises (i.e., Sit-ups) performed in core training may cause deformations due to overloading the lumbar region, plank exercise, an isometric exercise, has become more preferred in core training (23–25). The traditional plank exercise is an important bodyweight exercise that puts minimal load on the spine, designed to increase the muscle strength, endurance, and stability of the core muscles (28). In recent years, the frequent use of the Plank exercise has led to the manipulation of the Plank exercise by the trainers who demand more muscle development. One of the most trend manipulation techniques is plank exercise carried out with instability devices (13,21,22,29).

One of the most important usage purposes of instability devices is to activate more muscles by creating a less and unbalanced contact area, thus increasing the training intensity (29). Although a few studies examining the effects of instability on training stated that instability did not affect core muscle activation (17,32), some studies reported opposite results (5,7,15,28,33). The most used instability devices are BOSU ball, Swiss ball (4), and TRX Suspension Trainer (TRX), which has been popular recently (3,7,13). Previous studies have mainly focused on comparing exercise on an instability device with exercise on a stable surface. In plank studies comparing Swiss ball and TRX with a stable surface, it was stated that core muscle activation was higher in instability devices (6,13). However, the number of studies comparing instability devices in plank exercise is limited in the literature. To the best of our knowledge, only one study compared instability devices in plank exercise, and the BOSU ball was not included in that study (28). Significant differences were found in the different exercises performed with the BOSU ball compared to the stable ground. In addition, in exercises performed on the floor with body weight, such as Plank exercise, muscle activations may vary according to the angle of the body to the ground. As far as we know, angular differences caused by the height of the instability devices were ignored in previous studies (3,28).

This study aims to compare the electromyographic activations of RA, EO, and ERS muscles during plank exercise carried out with and without different instability devices. Based on previous studies, firstly, it was hypothesized that plank exercise performed on instability devices would generate more activation than on a stable surface. Secondly, among the instability devices, it was thought that due to the structure of the suspension device, it was composed of two independent parts so that it would generate more movement area, which would cause more mechanical stress. Therefore, it was hypothesized that the most significant muscle activation would be in TRX.

## METHOD

### Experimental Approach

In this study, a repeated measurement method was used to examine the changes in muscle activation during plank exercise applied on four different surfaces (Stable, BOSU ball, Swiss ball, TRX). Surface electromyography (sEMG) was used to determine the amplitude of rectus abdominis [RA], external oblique [EO], erector spinae [ERS] muscles. The sEMG amplitude has been normalized against the maximum voluntary contraction (MVC) trial that yielded the highest peak torque value during isometric contractions of the related muscles. The plank exercise carried out on each surface consists of two repetitions lasting five seconds with a rest interval of 120 seconds. All details of this study are described in the subsequent sections.

### Subjects

The sample size was calculated by analyzing the G Power 3.1.2 (Franz Faul, University of Kiel, Kiel, Germany) program. The analysis indicated that a minimum of 24 participants were required to achieve f = 0.25, $\alpha = 0.05$ (5% probability of type 1 error) and $\beta = 0.80$ (80% power) values. In case of possible exclusion of participants during the study, a 25 % larger sample size (n = 30) than specified in the power analysis was planned. Since 5 of the participants left the study for various reasons, the study was completed with 25 male volunteer athletes. The participants' mean age, height, weight, body mass index (BMI), and body fat was 21.5 ± 2.66 years, 179 ± 0.5 cm, 74.28 ± 4.27 kg, 22.98 ± 1.11 kg/m2 and 10.72 ± 2.07 %, respectively (Table 1). Participants who had a sports background between 1-5 years and continued training and competitions related to the branch they are interested in (football, wrestling, athletics) were selected for the study. Those who had any pain, injury, or illness that could affect the exercises were excluded from the study.

A meeting was held with the participants one week before the start of the study to introduce the exercises and give information about the study. An "Informed Voluntary Consent" form was collected from each subject during the meeting. The research was conducted with the approval of the Bursa Uludağ University Clinical Research Ethics Committee.

**Table 1.** Descriptive characteristics of subjects

| Variable | Mean± *SD* |
|---|---|
| Age (yr) | 21.5 ± 2.66 |
| Height (cm) | 179 ± 2.05 |
| Mass (kg) | 74.28 ± 4.27 |
| BMI (kg/m$^2$) | 22.98 ± 1.11 |

**Procedures**

The research consists of two sessions, an introduction, and an experimental session. In the introduction session, after measuring height, weight, BMI, and fat percentages (Tanita model BF-350; Tanita Corp., Tokyo, Japan), the participants were familiarized with the exercises and devices they would use in the research. In the experimental session, the participants were prepared for EMG measurements first. All electrodes were attached to the dominant side of the participants. Electrodes were attached parallel to the direction of the muscle fibers, where the muscles were most prominent, according to the recommendations of SENIAM. Before the electrodes were placed, the hairs on the skin were shaved and cleaned with isopropyl alcohol. The skin was sanded with sandpaper to keep the inter-electrode impedance below 2000 Ω and to minimize the skin impedance. Bipolar Ag-AgCl coated surface electrodes (Kendall-Arbo electrodes with 1 cm silver-silver chloride discs; Tyco Healthcare, Neustadt/Donau, Germany) were used to obtain EMG recordings from the muscles. The distance between the centers of the electrodes was determined as 20 mm. All EMG data were collected using a portable 8-channel surface EMG instrument (ME6000, Mega Electronics, Kuopio, Finland). Raw EMG data were sampled at 1,000 Hz and analyzed by calculating the Root Mean Square (RMS) with MegaWin v3.1 software. MVC measurements of the RA, EO, and ERS muscles were performed to normalize the EMG data amplitude after the electrodes were attached. Muscle activations in the exercises applied in the study were expressed as the percentage of the MVC reference value (%MVC). During MVC measurements, participants were asked to contract with a maximum effort against a manual resistance applied by the researchers. The MVCs consisted of two isometric contractions, each lasting for 5 seconds, and 180 seconds resting between contractions.

• Rectus abdominis: Subjects were placed in a supine position on a mat with the arms crossed over the chest and the knees flexed to 90 degrees. Subjects performed a sit-up movement against the researcher's manual resistance to generate isometric force.

• External Oblique: Subjects performed lateral spinal flexion against the researcher's resistance in the side-lying position with their hips and legs stabilized.

• Erector Spinae: Subjects performed a back extension movement against manual resistance applied from the scapula region in the prone position with their legs stabilized.

Following the MVC measurements, the participants performed the plank exercise on four different surfaces in a randomized block design (Figure 1). The plank exercise carried out on each surface consists of two repetitions lasting five seconds with a rest interval of 120 seconds. During plank exercise, subjects were asked to get a plank position with their elbows flexed to 90 degrees with only the forearms and toes in contact with the surface. Subjects were asked to rigidly lift the whole body to form a straight line with equal width of shoulders and both feet. Participants were asked to contract their core and gluteal muscles to stay stable. In instability devices, the elbows were placed on the devices, and the feet were placed on a stand adjusted at the height of the devices.

**Statistical Analysis**

SPSS version 23.0 (Armonk, NY: IBM Corp) package program was used to analyze the data. Shapiro-Wilk test was used to test the normality of the data distribution. Repeated measures analysis of variance (ANOVA) test was used to examine the differences in EMG activation in RA, EO, and ERS muscles in plank exercises performed on four different surfaces. Statistical significance level was determined as $p<0.05$. A Bonferroni post hoc was used for a follow-up procedure. Cohen's d effect size (ES) values were determined to assess the magnitude of changes in muscle activation. ES were evaluated according to <0.40 small, 0.40–0.70 medium, and >0.70 large effect criteria.


**Figure 1.** Plank on 4 different surfaces. A: Plank on Stable Surface, B: Plank on BOSU Ball, C: Plank on Swiss Ball, D: Plank on TRX

**RESULTS**

All participants (n=25) successfully completed the exercise trials, and all data were included in the statistical analysis process. The normalized EMG amplitude values (%MVC), p values, and effect sizes of muscle activations during the plank exercise applied on four different surfaces are shown in Table 2. The %MVC values of the RA, EO, and ERS muscles are shown in detail in Figures 2, 3, and 4, respectively.

**Table 2.** Comparison of the normalized EMG activity (%MVC) of RA, EO, and ERS muscles during plank on four surfaces.

| | Mean ± *SD* | *p*, ES | | |
|---|---|---|---|---|
| | RA (%MVC) | Stable | BOSU Ball | Swiss Ball |
| Stable | 31.8 ± 17.4 | | | |
| BOSU Ball | 35.3 ± 17.0 | 1.000, 0.205 Small | | |
| Swiss Ball | 63.4 ± 32.6 | 0.000, 1.211 Large | 0.000, 1.081 Large | |
| TRX | 88.3 ± 37.3 | 0.000, 1.942 Large | 0.000, 1.827 Large | 0.000, 0.710 Medium |
| | EO (%MVC) | | | |
| Stable | 40.0 ± 21.5 | | | |
| BOSU Ball | 49.2 ± 21.8 | 0.080, 0.426 Medium | | |
| Swiss Ball | 66.8 ± 33.0 | 0.000, 0.960 Large | 0.002, 0.626 Medium | |
| TRX | 83.3 ± 38.3 | 0.000, 1.396 Large | 0.000, 1.094 Large | 0.000, 0.463 Medium |
| | ERS (%MVC) | | | |
| Stable | 7.6 ± 2.4 | | | |
| BOSU Ball | 7.8 ± 2.4 | 1.000, 0.066 Small | | |
| Swiss Ball | 7.6 ± 2.6 | 1.000, 0.016 Small | 1.000, 0.080 Small | |
| TRX | 8.5 ± 2.4 | 0.211, 0.382 Medium | 0.278, 0.316 Small | 0.041, 0.388 Medium |

MVC: Maximum Voluntary Contraction; ES: Effect Size

In the RA and EO muscles, significantly higher normalized muscle amplitude (%MVC) was detected in TRX and Swiss ball compared to a stable surface and BOSU ball ($p<0.05$). Furthermore, a significantly higher normalized muscle amplitude was found in TRX than on Swiss ball ($p<0.05$). However, no significant difference was found between the BOSU ball and the Stable Surface (Figure 2 and 3) ($p<0.05$).

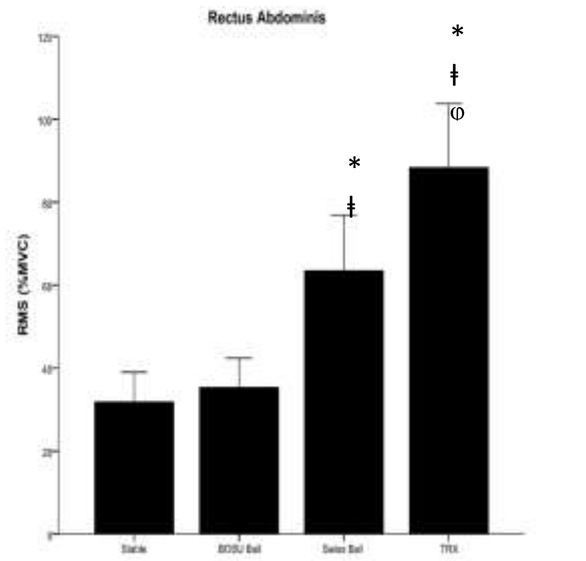


**Figure 2.** Normalized electromyographic activity (%MVC) of the rectus abdominis on stable surface and instability devices.

*Significantly greater compared with stable surface (p<0.05), ł Significantly greater compared with BOSU Ball (p<0.05), φ Significantly greater compared with Swiss Ball (p<0.05).

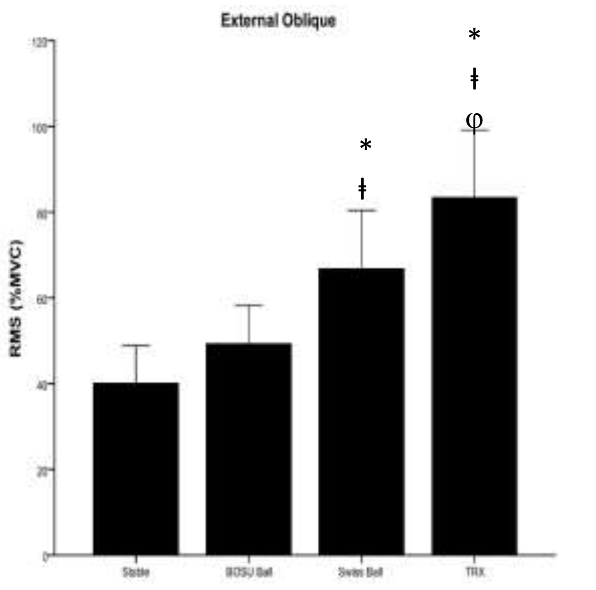


**Figure 3.** Normalized electromyographic activity (%MVC) of the external oblique on stable surface and instability devices.

*Significantly greater compared with stable surface (p<0.05), ł Significantly greater compared with BOSU Ball (p<0.05), φ Significantly greater compared with Swiss Ball (p<0.05).

In the ERS muscle, a significantly higher normalized muscle amplitude (%MVC) was detected in TRX compared to the Swiss ball (p<0.05). However, no significant difference was found between the other surfaces (Figure 4).

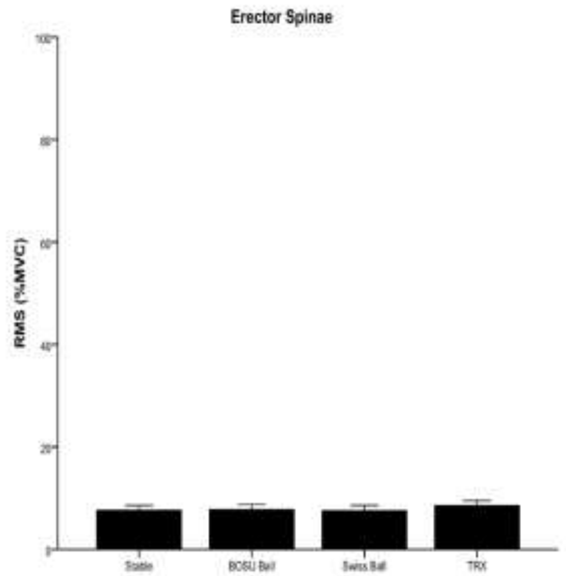


**Figure 4.** Normalized electromyographic activity (%MVC) of the erector spinae on stable surface and instability devices.

φ Significantly greater compared with Swiss Ball (p<0.05).

## DISCUSSION

In recent years, instability devices have been trendy in the fitness industry. Determining muscle activation levels during core exercises on these devices can guide the selection of the appropriate surface for practitioners. Therefore, the aim of this study was to determine the electromyographic responses of RA, EO, and ERS muscles during plank exercise performed on a stable surface or various instability devices. The main findings of this study were: a) Instability devices like Swiss ball and TRX generated more activation in RA and EO muscles than the stable surface and BOSU ball, b) BOSU ball and stable surface exhibited no significant difference, c) the most muscle amplitude in all the muscle groups was in TRX among the instability devices, d) the muscle amplitude was not significantly different in the ERS muscle between the instability devices and stable surface, e) muscle amplitude in the ERS muscle was higher in TRX than in the Swiss ball. Thus, our hypothesis that there is more muscle activity in the instability devices than in the stable surface was partially confirmed in the RA and EO muscles. Our second hypothesis that the most activation among the instability devices was in the TRX, was also confirmed.

Many studies reported that muscle activities for the core region in different exercises such as Crunch, push up, etc., are higher in instability devices compared to a stable surface (13,22). In the same way, our findings were similar to the results of the studies in the literature comparing the stable surface and instability devices in plank exercise. In a study performed with the suspension device in different variations, significant increases were found in the activities of the RA and EO muscles in all three different suspension variations in the front plank exercise compared to the stable surface (6). Similarly, it has been reported that RA and EO muscles are more activated during plank exercise in Swiss ball and TRX than on a stable surface (27). Another study presented significant increases in RA in the TRX compared to the stable surface during prone plank exercise (20). In the study by Czaprowski et al. (11), although muscle activities were not significantly different in any abdominal muscle group (RA, EO, Internal oblique (IO)) between BOSU ball and stable surface during prone plank exercise, muscle activities in all these muscle groups increased significantly in Swiss ball compared to the stable surface. Similar to these studies, no significant difference was found between BOSU ball and stable surface in our study. The fact that the BOSU ball is structurally stable on one side limits instability during exercises performed on this device. However, a study suggests that having the dome side of the BOSU ball on the floor during exercise may increase instability (30). In the study of Czaprowski et al. (11), subjects performed the plank exercise with the elbows on the BOSU ball and the stable side of the BOSU ball on the ground. In our study, exercise was carried out with the dome side of the BOSU ball on the floor. Muscle activity responses were similar in both studies. Thus, the claim that the dome side of the BOSU ball on the ground causes more instability may be limited for plank exercises. However, in different exercises, a significant increase was found in the BOSU ball with the dome side on the ground compared to the stable surface (29). These results show that different muscle activity responses occur in different exercises performed with the BOSU ball compared to the stable surface.

When instability devices were compared, the results of the present study demonstrated that the Swiss ball and TRX cause more muscle activity in RA and EO muscles than the BOSU ball. In addition, significantly more muscle activation was detected in TRX than Swiss Ball in all muscles. Czaprowski et al. (11) reported that the Swiss ball produces significantly more muscle activation in all the muscle groups than the BOSU ball during elbow plank exercise. Another study determined more muscle activity in the RA, EO, and ERS muscles with TRX than Swiss ball during plank exercise where elbows were placed on the instability devices (28). Nevertheless, the designs of these three instability devices were different. The instability level in the BOSU ball is less than the Swiss ball and TRX due to one side stability of the BOSU ball. While the Swiss ball is a single unit and provides instability with its rolling tendency, the TRX provides instability with its structure consisting of 2 independent straps that can move in different directions. It is emphasized that the TRX has fewer degrees of freedom in which the upper body can move so that the focus is on the RA to resist spinal movement (28). While agreeing with this consideration, it was suggested in another study that the activity of synergist abdominal muscles is necessary to keep the whole body in a stable and correct position in instability devices (7). In the present study, the primary muscle of the core area, RA, and its synergist EO muscle might have been more active to provide spinal straightness on the Swiss ball and TRX.

One of the unusual findings of our study was that the ERS muscle, which is of great importance for general postural stabilization (2,16), showed a low activity response during plank exercise regardless of surfaces. However, our findings are similar to previous studies (8,18,27). Although the elbow plank is used to develop the entire core region, it should not be forgotten that it is more suitable for the anterior core muscles as an "anti-extension" exercise (26). Our findings showed a statistically significant increase in TRX compared to Swiss ball. Besides, although more activation was in TRX than the stable surface and the other instability devices, the activation in TRX remained at a low activity level according to the muscle activation classification (12). Thus, this exercise is considered unsuitable for strengthening the ERS muscle, and the activity increase in TRX is practically worthless.

There were some limitations in the study. Firstly, BOSU, Swiss ball, and TRX were used as instability devices. Nevertheless, in the fitness industry, Dyna disk, balance board, etc., are other popular devices, and study findings should not be warranted to these devices. There is a need to prefer other instability devices that are frequently used in the fitness industry in future studies. Likewise, how the position of the feet on the devices affects EMG activity should also be evaluated in future studies. Secondly, EMG measurements were performed while only the elbows were placed on the device. It is also necessary to investigate and determine how the situation where the feet are placed on the device affects muscle activity. Thirdly, healthy young men were included in this study, and the sample size was small. Therefore, our results may not be generalizable to other populations like elderly, females, with low back pain, etc. Finally, muscle activities were measured on the dominant side of the participants in the RA, EO, and ERS muscles. We recommended that the activity of other core muscles, non-dominant side muscles, and other auxiliary muscles can be measured in the future.

## CONCLUSION

We compared electromyographic activities of RA, EO, and ERS muscles during plank exercise performed on stable and three different instability devices. The activity of the RA and EO muscles was more prominent in the TRX than on the other devices and stable surface. Therefore, the TRX may be a good choice for those who want more challenges for the anterior and lateral muscles of the core area. However, it should be noted that Swiss ball, which creates another high activity in areas where TRX cannot be used, can also generate significant difficulty for the abdominal muscles. On the other hand, plank exercise may not be the right choice in training sessions to strengthen the ERS muscle, whether on a stable surface or instability device.

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## REFERENCES

1. Anderson, K and Behm, DG. The impact of instability resistance training on balance and stability. Sports Medicine 35: 43–53, 2005.
2. Arokoski, JP, Valta, T, Airaksinen, O, and Kankaanpaa, M. Back and abdominal muscle function during stabilization exercises. Archives of Physical Medicine and Rehabilitation 82: 1089–1098, 2001.
3. Atkins, SJ, Bentley, I, Brooks, D, Burrows, MP, Hurst, HT, and Sinclair, JK. Electromyographic response of global abdominal stabilizers in response to stable-and unstable-base isometric exercise. Journal of Strength and Conditioning Research 29: 1609–1615, 2015.
4. Behm, D and Colado, JC. The effectiveness of resistance training using unstable surfaces and devices for rehabilitation. International Journal of Sports Physical Therapy 7: 226, 2012.
5. Behm, DG, Leonard, AM, Young, WB, Bonsey, WAC, and MacKinnon, SN. Trunk muscle electromyographic activity with unstable and unilateral exercises. Journal of Strength and Conditioning Research 19: 193–201, 2005.
6. Bergmark, A. Stability of the lumbar spine. A study in mechanical engineering. Acta orthopaedica Scandinavica Supplementum 230: 1–54, 1989.
7. 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. Journal of Strength and Conditioning Research 28: 3049–3055, 2014.
8. Choi, JH, Kim, DE, and Cynn, HS. Comparison of trunk muscle activity between traditional plank exercise and plank exercise with isometric contraction of ankle muscles in subjects with chronic low back pain. Journal of Strength and Conditioning Research 35: 2407–2413, 2021.
9. Cholewicki, J, Juluru, K, and McGill, SM. Intra-abdominal pressure mechanism for stabilizing the lumbar spine. Journal of Biomechanics 32: 13–17, 1999.
10. Cissik, JM. Programming Abdominal Training, Part I. National Strength & Conditioning Association 24: 9–15, 2002.
11. Czaprowski, D, Afeltowicz, A, Gebicka, A, Pawłowska, P, Kedra, A, Barrios, C, et al. Abdominal muscle EMG-activity during bridge exercises on stable and unstable surfaces. Physical Therapy in Sport 15: 162–168, 2014.
12. DiGiovine, NM, Jobe, FW, Pink, M, and Perry, J. An electromyographic analysis of the upper extremity in pitching. Journal of Shoulder and Elbow Surgery 1: 15–25, 1992.
13. Duncan, M. 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, 2009.
14. Fowles, JR. What I always wanted to know about instability training. Applied physiology, nutrition, and metabolism 35: 89–90, 2010.
15. Gamble, P. An Integrated Approach to Training Core Stability. Strength and Conditioning Journal 29: 58–68, 2007.
16. Goodman, CA, Pearce, AJ, Nicholes, CJ, Gatt, BM, and Fairweather, IH. No difference in 1RM strength and muscle activation during the barbell chest press on a stable and unstable surface. Journal of Strength And Conditioning Research 22: 88–94, 2008.
17. Jin, L, Kwang-hyun, J, Hyun-a, L, Jae-yeon, S, Jae-lim, C, Seung-beom, K, et al. Comparison of three different surface plank exercises on core muscle activity. Physical Therapy Rehabilitation Science 5: 29–33, 2016.
18. Kibler, W ben, Press, J, and Sciascia, A. The role of core stability in athletic function. Sports medicine (Auckland, NZ) 36: 189–198, 2006.
19. Lehman, GJ, Hoda, W, and Oliver, S. Trunk muscle activity during bridging exercises on and off a Swissball. Chiropractic & Osteopathy 13: 14, 2005.

20. Luk, J. T., Kwok, F. K., Ho, I. M., & Wong, D. P. (2021). Acute Responses of Core Muscle Activity during Bridge Exercises on the Floor vs. the Suspension System. International Journal of Environmental Research and Public Health, 18(11), 5908.

21. Marshall, P and Murphy, B. Changes in muscle activity and perceived exertion during exercises performed on a swiss ball. Applied Physiology, Nutrition and Metabolism 31: 376–383, 2006.

22. McGill, S. Core training: Evidence translating to better performance and injury prevention. Strength and Conditioning Journal 32: 33–46, 2010.

23. McGill, S. Low Back Disorders (3rd ed.). Champaign, IL: Human Kinetics, 2007.

24. Peterson, DD. Proposed performance standards for the plank for inclusion consideration into the navy's physical readiness test. Strength and Conditioning Journal 35: 22–26, 2013.

25. Schoenfeld, B and Contreras, B. Strategies for optimal core training program design. NSCA's Performance Training Journal 10, 2011.

26. Schoenfeld, BJ, Contreras, B, Tiryaki-Sonmez, G, Willardson, JM, and Fontana, F. An electromyographic comparison of a modified version of the plank with a long lever and posterior tilt versus the traditional plank exercise. Sports Biomechanics 13: 296–306, 2014.

27. Snarr, RL and Esco, MR. Electromyographical comparison of plank variations performed with and without instability devices. Journal of Strength and Conditioning Research 28: 3298–3305, 2014.

28. Snarr, RL, Hallmark, A v., Nickerson, BS, and Esco, MR. Electromyographical comparison of pike variations performed with and without instability devices. Journal of Strength and Conditioning Research 30: 3436–3442, 2016.

29. Snarr, RL, Wirbiezcas, M, Colbert, A, Langford, E, and Hogan, G. Bodyweight BOSU Ball Exercises. Strength & Conditioning Journal 43: 117–126, 2021.

30. Tan, S, Cao, L, Schoenfisch, W, and Wang, J. Investigation of core muscle function through electromyography activities in healthy young men. Journal of Exercise Physiology 16: 45–52, 2013.

31. Uribe, BP, Coburn, JW, Brown, LE, Judelson, DA, Khamoui, A v., and Nguyen, D. Muscle activation when performing the chest press and shoulder press on a stable bench vs. a Swiss ball. Journal of Strength And Conditioning Research 24: 1028–1033, 2010.

32. Vera-Garcia, FJ, Grenier, SG, and McGill, SM. Abdominal muscle response during curl-ups on both stable and labile surfaces. Physical Therapy 80: 564–569, 2000.

33. Wahl, MJ and Behm, DG. Not all instability training devices enhance muscle activation in highly resistance-trained individuals. Journal of Strength and Conditioning Research 22: 1360–1370, 2008.