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Abstract

Introduction: Deep stabilization system (DSS) strength and endurance are crucial for injury prevention and athletic performance. Training surfaces can influence training outcomes; therefore, this study aimed to compare the impact of performing strength trunk exercises on unstable and stable surfaces with conventional trunk exercises. Materials and Methods: DSS and trunk stability were assessed before and after 10 weeks of three different training interventions among twenty elite futsal players. Each intervention included 25 strength training sessions. Pre- and post-tests encompassed various measurements, including diaphragm, trunk flexion, trunk back extension, hip flexion, intraabdominal pressure, side plank, pronation, and supination tests. Results: Conventional exercises showed a significant improvement only in the side plank test. In contrast, unstable and stable surface conditions exhibited notable enhancements in all tests, displaying superior trunk stability compared to conventional exercises. The stable surface condition demonstrated significantly greater improvements in the pronation and supination tests compared to the unstable surface condition. Conclusions: Except for the side plank test, dynamic conventional exercises did not yield substantial improvements in the assessed tests. Deep stabilization system training enhances trunk stability when performed on both unstable and stable surfaces, with unstable surfaces potentially yielding greater improvements in m. transversus stabilization functions.

Keywords

core training, deep stabilization system, unstable surface training, core muscle activation

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Article

The effectiveness of resistance exercises performed on stable and unstable surfaces in relation to torso activation

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Abstract: Introduction: Deep stabilization system (DSS) strength and endurance are crucial for injury prevention and athletic performance. Training surfaces can influence training outcomes; therefore, this study aimed to compare the impact of performing strength trunk exercises on unstable and stable surfaces with conventional trunk exercises. Materials and Methods: DSS and trunk stability were assessed before and after 10 weeks of three different training interventions among twenty elite futsal players. Each intervention included 25 strength training sessions. Pre- and post-tests encompassed various measurements, including diaphragm, trunk flexion, trunk back extension, hip flexion, intraabdominal pressure, side plank, pronation, and supination tests. Results: Conventional exercises showed a significant improvement only in the side plank test. In contrast, unstable and stable surface conditions exhibited notable enhancements in all tests, displaying superior trunk stability compared to conventional exercises. The stable surface condition demonstrated significantly greater improvements in the pronation and supination tests compared to the unstable surface condition. Conclusions: Except for the side plank test, dynamic conventional exercises did not yield substantial improvements in the assessed tests. Deep stabilization system training enhances trunk stability when performed on both unstable and stable surfaces, with unstable surfaces potentially yielding greater improvements in m. transversus stabilization functions.

Keywords: core training, deep stabilization system, unstable surface training, core muscle activation.

1. Introduction

Strength training of deep trunk muscles which are responsible for spine stability in calm position and during movement, i.e. deep stabilization system (DSS), is an important component of training programs not only for injury prevention but also for maximizing athletic performance [1]. Therefore, many articles [2–4] are trying to analyze which training approach leads to the maximal increase in trunk stability.

Van den Tillaar [5] tried to find out if focused core training (training that is focused on strengthening or conditioning of the middle section of the body – the abdomen, hips, pelvis and lower back) can be replaced with weighted squat exercises. According to the EMG results, the erector spinae muscle showed four times higher activity during squats, while the rectus abdominis muscle, except for the last few repetitions, exhibited approximately 30% higher activity during the plank position. Similar results were found in a study [6] showing that weighted back squat was ineffective in activating m. rectus abdominis, as opposed to sit-ups, where its activity was more than twice higher. Further studies of squatting on unstable surfaces rejected the idea that a weighted squat on an unstable surface provides higher core activity compared to a stable surface [7, 8]. Although complex exercises, like squats or deadlifts, do not seem to be best for activation of m. rectus abdominis, they indicate similar, or better, activity of m. transversus and m. multifidus than most typical core exercises [9]. Therefore, the effect of exercise selection on stabilizer muscles is still unclear.

In sports games, quality activation of the trunk is very important, as it is involved in practically every movement on the field. Yet, in sports games, injuries result mostly from unilateral or excessive loading [10]. Unfortunately, many coaches and athletes start solving the situation only when it occurs, although it is far more practical to perform regular prevention in the form of deep stabilization system (DSS) activation [11, 12]. Therefore, a quality training plan should include repetitive trunk stabilization exercises throughout the whole training cycle. If sports games are dominated by complex movements, then logically, this principle should be preserved for a major part of DSS training [11, 13]. It is also necessary to activate the DSS muscles in different exercise positions and with different exercise equipment during core training. As reported in previous studies, muscles that are involved in DSS activation, such as the pelvic floor, differently respond to different positions [14, 15]. Therefore, in sports practice, alternate positions should be regularly applied.

Testing of strength and strength endurance of the abdominal muscles through repetitive sit-ups for time has been repeatedly recommended to be replaced by curl-ups or half sit-ups [16, 17]. There is almost 60% unexplained variance between sit-ups and curl-ups while being performed for time by adult subjects. The low association between the results of sit-ups and curl-ups may be explained by differences in hip flexor involvement [16]. In addition, the correlation between the number of curl-ups performed and the isometric strength of the abdominal muscles was found to be significant, but not high ($r = 0.38$) [17]. Though it was found that higher static strength endurance of the abdominal muscles could be expected when a high number of crunches were performed continuously ($p < 0.01$), an even higher correlation was found with the ability to perform them in a controlled and slow manner ($p < 0.0001$) [18].

For this reason, a standardized forearm plank position is commonly used for evaluating abdominal muscle strength [19]. Furthermore, another study [20] demonstrated the considerable inadequacy of the sit-up time test to detect the functional level of the deep spinal stabilization system, which is often described as an important component of the body core. However, it is true that a similar deficiency can be expected in the case of the sit-up test and even forearm plank position. Even in these tests, the impaired function of the deep stabilizing system may be masked by excellent fitness levels of the surface abdominal muscles. The DSS can be monitored by MRI technology [21], for example in positions of isometric flexion of the upper or lower limbs. In routine practice, DSS function is diagnosed by breathing stereotype examination and functional tests of trunk flexion and extension [22]. In the diagnosis of DSS, the participation of a qualified physiotherapist who has a good understanding of palpation and aspection is crucial for a correct examination [23, 24].

Exercises focused on trunk strengthening should first teach athletes the correct activation of the trunk with a straight spinal posture in basic positions without movement, which is aimed at improving postural stability and activation of the DSS. For elite athletes, this is a very important activity, especially for improving injury prevention [25, 26], which might significantly affect the performance growth of athletes, especially at a senior sporting age. Therefore, we consider this type of exercise to be beneficial for both younger athletes as a prevention measure and for older athletes as an integral part of their strength training, without which their performance cannot be maintained at peak level in the long term [27, 28].

Most injuries and health problems in athletes are mainly manifested by overloading in the lumbar spine, which is why qualitative activation of the trunk muscles with DSS is offered as one of the most appropriate injury prevention options. Nowadays, many coaches and athletes still believe that the "old" type exercises such as sit-ups and crunches are sufficient to improve trunk stability and consequently DSS. However, these are isolated movements performed largely by swinging and, therefore, a qualitative shift in DSS activation is very improbable. Even more, these exercises are incorporated in various modifications, which are more likely to cause additional overload in the lumbar spine region (due to the different muscle chains) compared to complex and controlled exercises [29]. In the case of speed and speed-strength sports, such as athletics (especially throwing disciplines) or sports games, studies [30, 31] agree on the beneficial aspects of using complex exercises for improving athletes' performance.

2. Materials and methods

2.1. Participants

Power calculations (G*Power 3.1.9.4) indicated that the minimum sample size of 9 participants would be required to detect an effect size of 0.66 collected from the Behm study [32] (repeated measures, within-between interactions ANOVA, power = 0.8, alpha = 0.05, correlation among rep measures = 0.8, number of groups = 3, number of measurements = 2). 20 elite futsal players from the Czech first league (aged 26 ± 8 years, height 182 ± 9 cm, weight 77 ± 17 kg,) participated in the research. All participants had competed in elite teams for at least 6 years, and their current habitual training cycle met the following criteria as a minimum: 6 training sessions per week, 160 min of conditioning work, 120 min of technical-tactical training, 190 min of game time and 130 min of warm-ups. The research and the informed consent form were approved by the institutional ethics committee of Charles University, Faculty of Physical Education and Sport in (no 146/2019) accordance with the ethical standards of the Helsinki Declaration of 2013. A signed written informed consent form was obtained from all participants in this study before measurements.

2.2. Experimental approach

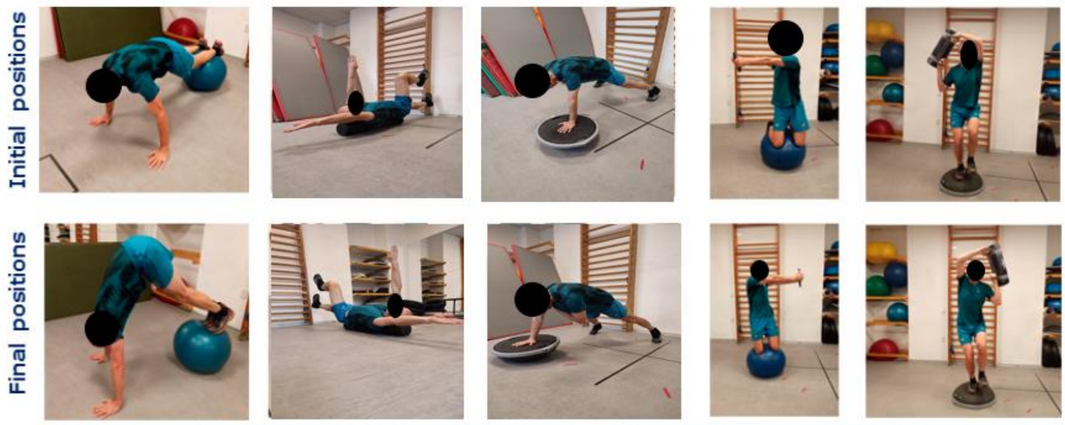
Three variations of strength-oriented exercises with the aim of activating the DSS muscles were designed for the Czech extra-league level futsal players. Each variant was practiced during 1-year training cycle in the preparatory period for 10 weeks with a frequency of 2–3 times a week. The training unit usually lasted between 35 and 45 minutes. A total amount of 25 interventions were completed per year, and 75 during all the research. The first variant (CE) focused on the conventional isolated exercises – lying sit-ups, crunches, and their modifications. The second variant (US) consisted of complex exercises of a new type on labile aids. The third variant (SS) was similar to variant US with the only difference being that it was performed entirely on stable mats.

All exercises in variant CE were performed at a tempo of 1-0-1-0, where the individual numbers successively represent the eccentric, the maximum eccentric, the concentric, and the maximum concentric phase of the main agonist muscle. Variant US on a labile pad and variant SS on a stable pad were performed at a tempo of 2-2-2-0. However, the TUT (Time Under Tension) was always the same for all variants, as more repetitions were included in variant CE. The total loading time for all exercises ranged from 20 to 40 s. Initial testing was performed each year before the start of the intervention, following by control measurement after 5 weeks and final measurement after 10 weeks.

Loading progression

Exercise tempo	Week	Repetitions	sets	Rest interval (s)	Time under tension (s)
1/0/1/0	1	15	2	60	2 x 30, 60
	2	18	3	50	3 x 36, 108
	3	18	4	40	4 x 36, 144
	4	15	2	60	2 x 30, 60
	5	18	4	50	4 x 36, 144
	6	20	4	40	4 x 40, 160
	7	20	4	30	4 x 40, 160
	8	15	2	30	2 x 30, 60
	9	20	4	30	4 x 40, 160
	10	20	4	30	4 x 40, 160

Figure 1. The conventional exercises program (control group – CE) performed at exercise tempo 1/0/1/0 with work-load progression. The main difference between the unstable surface exercises (US) and **stable** surface-oriented exercises (SS) groups was in the tempo, center of the gravity during exercises, or in the stability of the surface.



Loading progression

Exercise tempo	week	Repetitions	sets	Rest interval (s)	Time under tension (s)
2/2/2/0	1	5	2	60	2 x 30, 60
	2	6	3	50	3 x 36, 108
	3	8	3	40	3 x 48, 144
	4	5	2	60	2 x 30, 60
	5	8	3	50	3 x 48, 144
	6	9	3	40	3 x 54, 162
	7	10	3	30	3 x 60, 180
	8	5	2	30	2 x 30, 60
	9	10	3	30	3 x 60, 180
	10	10	3	30	3 x 60, 180

Figure 2. The unstable surface-oriented exercises program (experimental group – US) performed at exercise tempo 2/2/2/0 with work-load progression. The main difference between the conventional exercises was in the position of the center of gravity or the instability of the surface.

Loading progression

Exercise tempo	week	Repetitions	sets	Rest interval (s)	Time under tension (s)
2/2/2/0	1	5	2	60	2 x 30, 60
	2	6	3	50	3 x 36, 108
	3	8	3	40	3 x 48, 144
	4	5	2	60	2 x 30, 60
	5	8	3	50	3 x 48, 144
	6	9	3	40	3 x 54, 162
	7	10	3	30	3 x 60, 180
	8	5	2	30	2 x 30, 60
	9	10	3	30	3 x 60, 180
	10	10	3	30	3 x 60, 180

Figure 3. The stable surface-oriented exercises program (experimental group – SS) performed at exercise tempo 2/2/2/0 with work-load progression. The main difference between the unstable surface-oriented exercise program (experimental group – US) was in the position of the center of gravity or the stability of the surface.

2.3. *Additive training intervention*

During one season, participants performed in total 25 intervention sessions of chosen variant lasting for 30–40 min (including warm-up) in the period of 10 weeks. During the first season variant CE was performed and then respectively variant US and SS in the following seasons.

Variant CE involved conventional exercises consisting of sit-ups, side crunches, lateral arm, and rotations perpendicular to the floor contralateral, limb swings (Figure 1). If external resistance was applied, a similar external load was applied in both experimental groups. The conventional (control group) exercises were characterized by dominance of dynamic contractions, without putting focus on the control of movement (tempo 1-0-1-0).

The US variant group performed stability-oriented exercises, including reverse sit-ups on a gym ball (Powerball Premium ABS–45 cm, Togu GmbH, Prien-Bachham, Germany) and slide board (FLOWIN PRO, Vintrie, Sweden), one arm planks, lateral arm raises on a gym ball with bodyweight or a light external load (Eleiko, Halmstad, Sweden), and one leg squats (to 80–90° of knee flexion) on a Bosu ball (Bosu ELITE, Ashland, OH, USA) with an aqua bag (Jordan, Kings Lynn, Norfolk, England) side switch (Figure 2).

The SS variant group performed the same exercises as variant US, only on stable ground (Figure 3). The training for experimental groups US and SS was balanced for all 3 types of contraction (eccentric, isometric and concentric) with tempo of 2-2-2-0, with focus on the control of movement. The isometric phase was set up for 2 s at initial repetitions with an allowed decrease to 1 s during later repetitions to maintain the exercise technique.

2.4. *The evaluation of deep stabilization system (DSS)*

The DSS test were performed by aspection and palpation of one certified physiotherapist, who was blinded for the participants contribution in type of intervention. The physiotherapist evaluated the DSS function on a five-point scale, where 1 was sufficient activity of DSS, 2 – DSS activity with one lack in activity function, 3 – DSS activity with several lacks in activity function, 4 – insufficient position hold and 5 – insufficiency in the DSS function. The reliability of this method is the same as other similar physiotherapy methods [33]. The six following DSS tests were performed according to Kolar [34].

2.4.1. Diaphragm test (DT)

The subject is in a seated position in the upright posture, arms and legs relaxed. The chest is in a caudal or expiratory position. The examiner places fingers between and inferiorly to the patient's caudal ribs and instructs the individual to take a deep breath and create counter-resistance toward the examiner's fingers to activate the laterodorsal sections of the abdominal wall. The examiner evaluates visually and by palpation any lateral movement of the lower ribs, the amount and symmetry of activation of the laterodorsal sections of the abdominal wall [34, 35].

2.4.2.Trunk flexion test (TF)

The subject is set out in the supine position, with arms relaxed along the trunk. Examiner instructs the individual to slowly flex the neck, followed by the trunk until the lower scapular angles come off the table. The examiner visually assesses the action of the thorax muscles [34, 35].

2.4.3.Trunk back extension test (TE)

The subject is assessed in the prone position, with arms relaxed along the trunk. Examiner instructs the individual to lift the head and do slide spine extension above the table. The stabilization pattern is assessed visually from side and from side above (involved back and a lateral group of abdomen muscles) and by palpation of laterodorsal sections of the abdominal wall [34, 35].

2.4.4.Hip flexion test (HF)

The subject is assessed in the seated position in an upright posture at the edge of the table; arms and legs are relaxed and without contact with the ground. Examiner instructs the subject to slowly alternately flex the hip (approximately 10–20 cm) above the table. The movement of the spinal and pelvic section is assessed visually; the laterodorsal section of the abdominal wall is assessed by palpation of coordinated activity of the abdominal muscles [34, 35].

2.4.5.Intraabdominal pressure test (IAP)

The subject is assessed in the seated position in an upright posture; arms and legs are relaxed. The lower abdominal section above the groin (medially from the anterior superior iliac spine and the femoral heads of hip joints) is palpated by the examiner. Furthermore, the subject is instructed to activate the abdominal wall and create intra-abdominal pressure by pushing against the examiner´s fingers placed above the inguinal ligaments. The amount of the symmetry of activation is assessed, while visually observing the abdominal contour and any umbilicus movement at the same time [34, 35].

2.4.6.Side plank (bridge) test (SP)

The subject is assessed in a side plank position; the lower arm is supported on the forearm; the upper arm is placed relaxed on the homolateral hip. The action of the abdominal and thorax muscles is assessed with simultaneously coordinated action of shoulder gilder muscles [24]. Additionally, the quality of the segmental spine stability was evaluated with the supine test of corset action (supination test) and the prone test of action of m. transversus abdominis and m. obliquus internus abdominis (pronation test) using the stabiliser as tool to evaluate the pressure biofeedback unit [36].

2.4.7.Pronation test (PT)

To examine the stabilizing function of the m. transversus abdominis and m. obliquus internus abdominis while lying on the abdomen (the so-called PRONE test), the subject lies with the upper limbs along the body and the pressure biofeedback unit (PBU) is placed under the abdominal wall so that the distal edge of the pad is at the level of the junction of the right and left spina iliaca anterior superior and the umbilicus is in the middle. Then the PBU was inflated to 70 mmHg, with a break allowing the pressure to stabilize. The subject is instructed to relax the abdominal wall before the test. After that he inhales and exhales and then encircles the abdominal wall without breathing. The instruction given to the subject is: "Circumcise the abdominal wall without moving the back and pelvis." The pressure should drop by 6 to 10 mmHg. The most successful way to emphasize activation of m. transversus abdominis is to instruct the subject to concentrate on the lower abdominal wall [37].

2.4.8.Supination test (ST)

To test the stabilizing function of the m. transversus abdominis in the supine position (the SUPINE test), the subject is lying on his/her back on a lounger, with the upper limbs along the body and the lower limbs flexed. This position is advantageous, since it is easier to observe and palpate the abdominal wall, or possible to simultaneously monitor by ultrasound. This position is beneficial for the subject as well, since it is easier for him to activate m. transversus abdominis. PBU is placed under the lumbar spine and inflated to 40 mmHg. Instructions for breathing are the same as for the PT examination. The patient then abducts the abdominal wall without moving the back and pelvis, and the pressure value on the manometer should remain unchanged at 40 mmHg according to the original authors [37]. However, research was conducted in 2013 in which the authors tried to specify an appropriate target value for the pressure change during m. transversus abdominis in the SUPINE test. The results showed that a suitable target value was a 0 to 2 mmHg increase in pressure [37].

2.5. Statistical analysis

Although the gathered data consist of ordered categories of 1 to 5 and hence cannot be normally distributed, the shape of probability mass function still resembles the probability density function of normal distribution. This justifies our choice of the classical Linear Mixed-Effects Model (LMM – Laird & Ware, 1982) [40], where we rely on its asymptotical properties that still provide reasonable results for such data. Such a model eliminates the (random) effect of each participant across all 9 assessed measurements – under three different training regimes (variant – CE, US, SS) and at three different stages (stage – Enter, Control, Final) of the trainings. The fixed part of our regression model is primarily formed by the interaction term between training and stage to evaluate the effect of each of the combinations and their comparisons. Moreover, the predictor of the model could be extended by any other additional information about the individual. We included the BMI since in many cases it turned out to be a significant contributor to the model. By LMM of the same structure, the results of each of the 8 different tests were independently analyzed. Asymptotic properties of the estimated effects were used to construct 95% confidence intervals for any linear combination, appropriate choice of which leads to any desired comparison of combinations of interventions and stages. Corresponding p-values were used for statistical testing at significance level of $p < 0.05$. Statistical analysis was performed by free statistical software R (version 4.0.3) with the use of nlme package.

3. Results

A necessity to adjust effects on participants' level has been confirmed by likelihood ratio tests for significance of random-effects structure where p-values of all tests (with an exception of PT) lied below the 0.05 threshold. The greatest discrepancies among players were found in the Diaphragm Test (DT) and the Side Plank Test (SP). According to the present model, higher values of BMI probably resulted in worse scores in almost all tests (with the exception of DT and TE). For example, an additional unit of the BMI increased the expected score by approximately 0.13 (TF, HF, IAP, SP, PT tests, *p*-values: 0.003, 0.011, 0.005, 0.024, < 0.001). Figure 4 presents the estimated improvements in score (both point and interval estimators) between the evaluation at the beginning and at the end of follow-up period. The conventional variant CE did not lead to improvement in any of the considered tests with exception of the Side Plank Test (SP). On the other hand, with all *p*-values < 0.001, it can be claimed that both remaining variants of the training (US and SS) significantly improved the scores in all tests, while comparing the initial and final the test (Table 1, Table 2).

The improvement through the timeline in the PS and PT tests is higher by more than a half point for the training variant SS compared to the variant US in the early phase ($p = 0.002$ and $p < 0.001$, respectively). However, this significant improvement flattens in the follow-up period. On the other hand, the Side Plank Test (SP) appears to have significantly improved in the variant US, but only in the later phases ($p = 0.013$). In other circumstances, the two variants of the training seem to yield comparable score improvements.

Table 1. Mean and SD for pre and post measurements for diaphragm, trunk flexion and trunk extension tests.

	DT		TF		TE		HF	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
US	3.25 ± 0.79	2.08 ± 0.5*	2.83 ± 0.64	2.08 ± 0.5*	3.29 ± 0.62	2.13 ± 0.54*	2.88 ± 0.8	2.13 ± 0.61*
SS	2.88 ± 0.85	2.71 ± 0.55*	2.58 ± 0.72	1.88 ± 0.68*	3.17 ± 0.7	1.92 ± 0.58*	2.75 ± 0.79	1.71 ± 0.55*
CE	2.57 ± 0.66	2.63 ± 0.58	3.13 ± 0.76	2.92 ± 0.65	2.65 ± 0.57	2.67 ± 0.48	2.57 ± 0.66	2.83 ± 0.64

* significant improvement $p < 0.05$, DT = Diaphragm Test, TF = Trunk Flexion Test, TE = Trunk Extension Test, HF = Hip Flexion Test

Table 2. Mean and SD for pre and post measurements for intraabdominal pressure, supination, and pronation tests.

	IAP		SP		ST		PT	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post
US	2.83 ± 0.76	1.92 ± 0.41*	2.83 ± 0.76	2.25 ± 0.68*	3.46 ± 0.59	1.79 ± 0.51*	3.46 ± 0.59	1.79 ± 0.51*
SS	2.67 ± 0.76	7.71 ± 0.46*	2.42 ± 0.72	1.58 ± 0.58*	3.25 ± 0.68	2.17 ± 0.38*	3.21 ± 0.59	2.21 ± 0.41*
CE	2.61 ± 0.89	2.67 ± 0.56	2.74 ± 0.62	2.38 ± 0.65	3.04 ± 0.21	2.96 ± 0.36	3.09 ± 0.29	2.88 ± 0.45

* significant improvement $p < 0.05$, IAP = Intraabdominal Pressure Test, SP = Side Plank Test, ST = Supination Test, PT = Pronation Test

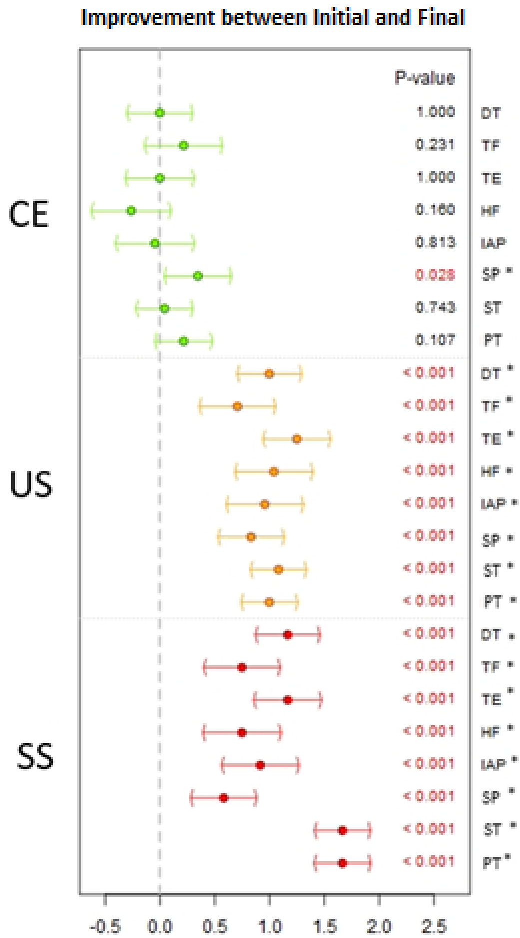


Figure 4. Estimated 95% confidence intervals and corresponding p-values for the overall improvement in scores separately for each test and for each training variant.
Red color and * marks significant results ($p < 0.05$). DT = Diaphragm Test, TF = Trunk Flexion Test, TE = Trunk Extension Test, HF = Hip Flexion Test, IAP = Intraabdominal Pressure Test, SP = Side Plank Test, PT = Pronation Test, ST = Supination Test

4. Discussion

The primary conclusion of our research reveals that slower, controlled movement exercises are significantly more effective in enhancing DSS than traditional dynamic exercises. Interestingly, our findings also demonstrate that the efficacy of these controlled exercises remains consistent, irrespective of whether they are performed on a stable or unstable surface. This contrasts with previous studies, such as the one conducted by Vera Garcia [40], which showed that unstable surfaces lead to increased trunk muscle activity and could thus offer superior neuromuscular adaptations. Interestingly, Yong-chan Do [42] and Susan A. Saliba [42] also observed higher transverse abdominis activation when exercises were performed on an unstable surface when compared to those performed on a stable one, respectively for the plank and the glute bridge. However, our data does not support the notion that exercising on an unstable surface provides any additional benefits when compared to a stable one, even though previously mentioned studies revealed higher trunk muscle activity when using unstable surfaces during the execution of DSS exercises, which suggested that the integration of unstable surfaces in DSS strength training could generate superior neuromuscular adaptations compared with training using stable surfaces [43]. Our results showed no greater benefit of exercise on an unstable surface of exercise when compared to a stable one.

Previous studies showed beneficial effects of incorporating the core training program to improve sport performance [44–46]. However, to the best of our knowledge, our study is the first one to directly examine the impact of the type of exercise surface on DSS using a pressure biofeedback unit. Previous research, such as the study by Prieske [47], focused on evaluating the effects of DSS strengthening programs on various types of surfaces by comparing metrics like maximal isometric force (MIF) of the trunk muscles, as well as athletic performance indicators like sprint speed, kick performance, countermovement jump (CMJ) height, and agility time. Prieske's findings indicated significant improvements in trunk muscle strength and sprint and kicking performance but did not show any discernible difference between exercising on stable versus unstable surfaces [47]. These results align with our own; we also observed measurable improvements in DSS when comparing pre- and post-exercise measurements, regardless of the stability of the surface. In a study conducted by Lago-Fuentes [28], the use of an unstable exercise surface showed limited benefits in the area of repeated sprint ability, when compared to a stable surface. However, no other significant differences between the two conditions were observed in the remaining test.

Additionally, we found that no improvement was observed when participants engaged in traditional dynamic exercises. Those observations are well explained by Mahdieh, and Lago-Fuentes [28, 48], where they indicate that the main difference between the dynamics and lower- tempo controlled motion is in motor control of the speed of contractions and contraction range of motion, which is responsible for the activation of DSS. Therefore, slower controlled tempo seems to be more appropriate when aiming to strengthen the DSS when compared to a dynamic exercise.

In his study, Snarr [49] observed significantly lower activity of m. rectus abdominis, m. externus obliquus abdominis, and m. erector spinae on a stable surface, while comparing with several types of instability modifications. Similar results were observed in another study [50], where the activity of selected DSS muscles was higher in unstable conditions, excluding the back bridge. Still another study [51] compared DSS activity in several plank positions performed on different surfaces (stable surface, Bosu ball, Swiss ball), resulting in different muscle activity. While prioritizing prone bridge on a Swiss ball for the highest EMG activity of measured muscles (m. rectus abdominis, m. external/internal oblique abdominis, m. transversus abdominis), this exercise provided the lowest activity of the external oblique and the internal oblique with the transversus abdominis when compared to m. rectus abdominis. This may result in shifts in the pattern of motor activity, enabling synergic muscles to generate the necessary forces required for functional tasks [37].

Our findings, in conjunction with previous studies, suggest that the choice between stable and unstable surfaces does not significantly impact the effectiveness of exercises aimed at strengthening DSS. However, we did observe a notable advantage in employing slower, controlled-tempo exercises for enhancing DSS as compared to traditional dynamic exercises. The research suggests that the choice of surface for training deep stability muscles may be interchangeable in the training process, with the exception being when the transverse muscle is specifically targeted.

Limitations of the study

Previous studies [7, 37, 50, 51] clearly indicate that performing exercises on unstable surfaces, compared to stable ones, does not just change muscle activity, but also shifts it. This might also be the reason why the PT and PS tests showed improvement in the group that performed the exercises on solid ground, compared to an unstable surface. Therefore, it seems beneficial, firstly, to compare EMG activity of the selected exercises on different surfaces prior to putting them into a testing battery. Furthermore, the choice of proper DSS testing must be considered, as each of the methods (functional tests, palpation, EMG activity, EMG ratio) has different advantages and limitations, which makes it difficult to compare them with each other. Although the DSS condition is an important aspect of dynamic stabilization during athletes' performance, thus decreasing the risk of injury [52], its effect on athletic performance remains questionable. Several studies [53–55] mentioned that the effectiveness of DSS training and its possible transfer to sport performance is not affected just by the athlete's fitness level, but also by the sport discipline. Therefore, future studies should consider adding sport-specific performance tests and detailed training load monitoring [56] to confirm or deny if the actual improvement in DSS has a real impact on current sports performance.

5. Conclusions

The research findings suggest that performing resistance exercises at a slower and more controlled pace is more effective in engaging the deep stability muscles compared to dynamic exercises. Moreover, there is no evident advantage in terms of enhancing the strength of deep stability muscles when these exercises are performed on an unstable surface. Consequently, various exercise surfaces can be used interchangeably.

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