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Research Article

Muscle Activity, and the Association between Core Strength, Core Endurance and Core Stability

Abstract

Introduction: Core training is often divided into the training approaches core endurance-, core stability- and core strength training. The aim of the study was to compare the association between core strength, core endurance and core stability testing 52 healthy males and females.

Methods: The core strength and endurance tests were tested isometric in hip flexion, extension and lateral flexion. The time maintaining the positions in the core endurance tests, maximal force output in the core strength tests and total displacement in the core stability tests were examined with electromyography measurement of the core muscles in randomized order.

Results: There were no significant correlations between the variables core strength, core stability or core endurance ($p = 0.102 – 0.965$, $r = 0.01 – 0.23$), except for the endurance lateral flexion which correlated significantly with the core strength (extension and lateral flexion) and the core stability using the left leg ($p = 0.001 – 0.048$, $r = 0.29 – 0.44$). Generally, the muscle activity of the core muscle decreased from strength < endurance < stability tests, respectively.

Conclusion: There were no systematic correlations between core endurance, core strength or core stability indicating that these capacities are largely independent from each other. Coaches, training instructors or physical therapists needs to address the core endurance, core strength and core stability as separate capacities and train them accordingly based on the aim of the training.

Abbreviations

ANOVA: Analysis of Variance; EMG: Electromyographic; ICC: Intra-Class Correlations; MVC: Maximal Voluntary Contraction; RMS: Root-Mean Square

Introduction

The core has been referred to as the lumbopelvic-hip complex [1] and core training has highlighted benefits for athletes [2], general health [3,4] and patients with low back pain [5]. In the literature core training is often divided into the training approaches core endurance-, core stability- and core strength training [6-10]. Core endurance is defined as the ability to maintain a position or perform multiple repetitions [8]. Core stability has been defined as "the capacity of the stabilizing system to maintain the intervertebral neutral zones within physiological limitations" [10]. Further, core strength referrer to the ability as the ability of the musculature to produce force through contractile force and intra-abdominal pressure [9]. To our knowledge, no previous study has compared the neuromuscular effects of the different approaches.

The different core training approaches have been recommended [6,11,14,15] and examined separately [13,16,17]. To improve core endurance training, low loads with long duration (30-45 seconds) and often isometric exercises have been proposed [9,11]. Core endurance has been used in preventing and in rehabilitation settings for low back pain patients [12,20]. Core stability training typically includes low threshold recruitment of the core muscles [12] with demanding instability exercises stressing the proprioceptive pathways [10]. Core stability training has been proposed to be beneficial in preventing low back pain, enhancing general fitness and improving performance [6,14,19]. In contrast, core strength training includes high-threshold recruitment (high load and few repetitions) and a large stress of the core muscles [2,13]. Several studies have promoted core strength to improve sports-related performance measures [2,18], but also to promote general health [6,14].

Several papers described their training protocol as core stability training, core strength training or core endurance training, but according to the definitions presented above, trained a different training approach [2,3,13,21]. Therefore, it seems to be a confusion of the terms used to describe the different training approaches. Importantly, core training exercises that facilitate core stability, strength or endurance have been examined separately [2,3,13,17,22,23], but to our knowledge, no previous studies have compared the association between core training approaches. To improve training practices, it is therefore necessary and important to examine the associations between these capacities. If these capacities are highly related, it could be expected that training one capacity also should improve another. Conversely, if they are unrelated this would imply that each capacity should be trained separately, depending on the needs of the individual (e.g. athletic enhancement, rehabilitation or daily-life activities). Furthermore, it is also of interest to assess relative muscle activations in stability and endurance tasks. Therefore, the aim of the study was to examine the core muscle activity and the

associations between core stability, core endurance and core strength in a healthy population. We hypothesized a small association between core stability, core endurance and core strength.

Materials and Methods

Participants

26 males (age 22.6 ±2.5years, body mass 77.9 ±7.3kg, and stature 1.81 ±0.06m) and 26 females (age 21.6 ±2.1years, body mass 63.7 ±7.6kg, stature 1.68 ±0.06m) participated in the present study. None of the participants were competitive power lifters, but had 2.7 (±3.2) years of strength-training experience. All participants were healthy, had no injuries that might reduce maximal effort and with no history of low back pain in the last 6 months. The participants were instructed to refrain from any additional resistance training exercises 48 hours before testing. Prior to the study, the participants were informed of the testing procedures and possible risks, and a written consent was obtained. Ethics approval was obtained from the local research ethics committee and conformed to the latest revision of the declaration of Helsinki.

Procedure

A within-participant cross-over design was used to examine core endurance, core strength and core stability. All tests were conducted in one session. No familiarization was conducted previous to the experimental test with exception of the core stability tests. 1-5 days before experimental test, each participant executed 5 series of 5 repetitions for each leg, where each repetition lasted 10 seconds to become familiarized with the testing procedures. The core endurance and core strength were tested in flexion (abdominal muscles), extension (back muscles) and lateral flexion (oblique muscles) in one session with EMG measurements of the core muscles. The stability test was performed standing on a knee with arms held across the chest. The orders of the endurance, strength and stability tests were randomized. All tests were executed after a 10 minutes general warm-up (cycle ergometer or treadmill jogging). Prior to the core strength test, 3-5 sub-maximal warm-up trials were executed. To assess the test-retest reliability, 13 males and 13 females performed the complete test battery separated by 7-10 days.

Core endurance measurements

As described by Tse and colleagues [24], core endurance was assessed using an isometric back extensor test (Figure 1a), abdominal test (Figure 1b) and lateral flexion test (Figure 1c). One warning was given if the correct position was not upheld and the test was terminated if the correct position was not maintained a second time. The Bering-Sorensen test was used to examine the low back core endurance (Figure 1a). The participant lay supine on a table and maintained a horizontal position as long as possible [8,24]. The tip of the iliac crest rested on the edge of the table and the arms were folded across the chest. The torso was extended in a straight line from the edge and once the participants assumed the horizontal position, a stopwatch started. The feet were attached by the ankles and the maximum time holding the position was recorded in one trial. The test was terminated when the participants fell below the horizontal position [8,24].

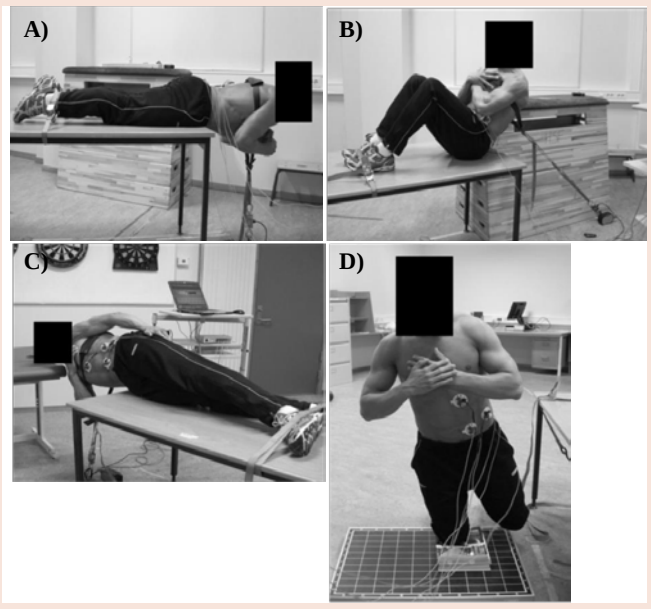

Figure 1: The test set-up for the core strength, endurance and stability. Identical positions were used in the core strength and core endurance tests examining flexion (a), extension (b) and lateral flexion (c). Core stability was performed on one knee examining the postural sway (d).

The abdominal endurance test was assessed [24] with the angle of 45° between the table and trunk and 90° in the knees and hip (Figure 1b). The natural sway in the spine was maintained and arms held across the chest. The feet were strapped to the table by the ankles. The test was terminated when the upper body could no longer maintain the hip angle [24].

During the lateral flexion test, the participants lay in a horizontal position, with their lower extremities and hip resting on a table. The participants had no support of the upper body on their elbow (Figure 1c). The feet were secured to the table by a band across the ankles. The test was only executed on the dominant side i.e. the performed throwing arm faced upwards and along the side. The other arm was held across the chest (Figure 1c). The test was terminated when the participants fell below the horizontal position. The time and muscle activity maintaining the position in the abdominal, back and lateral flexion tests were used in further analyses.

Core strength measurements

To assess the core strength, identical tests and positions as the core endurance tests were used but with maximal effort. A force cell (Model 333A, Ergo test Technology AS, Langesund, Norway) was attached to floor and the trunk underneath the arms (Figure 1a-1c). The force was gradually increased to maximum volunteered contraction (MVC) and maintained in 3 seconds. Each test was repeated 3 times with a 60-90 seconds pause between each trial and 3-4 minutes between each muscle group. The greatest mean force output over 3 seconds for each test (flexion, extension and lateral flexion) was used in further analyses, along with associated muscle activity. The maximal force was analyzed by commercial software V8.13 (Ergo test Technology AS, Langesund, Norway).

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Core stability measurements

Typically, postural sway is measured on a force platform to quantify the core stability [17,22,23,25-27]. The core stability tests were executed on a force platform (Ergo test Technology AS, Langesund, Norway) on the left and right leg separately (Figure 1d). 5 trials of 10 seconds were executed for both legs. The core stability tests were executed on the knee to eliminate the contribution from the ankle and knee. The tested foot was placed on a pocket-book. The arms were held across the chest with a neutral spine position while the participant looked straight forward (Figure 1d). The force platform consisted of 4 force sensors measuring the displacements (mm) in the forward/backward and right/left directions. The total displacements were the mean displacement forward/backward and right/left directions during the 10 seconds. The total displacement was analyzed by commercial software V8.13 (Ergo test Technology AS, Langesund, Norway). The lowest total displacement and mean muscle activity for each foot were used in further analyses.

EMG measurements

Electrodes (contact diameter = 11mm, center-to-center distance = 20mm) were placed parallel to muscle fiber orientation on the contralateral side of the preferred foot [28]. The surface EMG electrodes were positioned at the lower rectus abdomens (3 cm lateral to the umbilicus), upper rectus abdomens (3cm lateral to the umbilicus and approximately half the distance between lower sternum and umbilicus), the external abdominal oblique (approximately 15cm from the umbilicus), and the erector spinet at T9, L3 and L5 (located 5, 3 and 1cm lateral to the each spinouts process) [29-31]. Prior to the placement of gel-coated self-adhesive electrodes (Dri-Stick Silver Circular sEMG Electrodes AE-131, Neuro Dyne Medical, USA), the skin was shaved, washed with alcohol and abraded. A commercial EMG recording system was used to measure the EMG activation and synchronized with the force cells and force platform (Muscle Lab 4020e, Ergo test Technology AS, Langesund, Norway). To minimize the noise induced from external sources through the signal cables, the EMG raw signal was amplified and band pass filtered (fourth-order Butterworth filter) with cut-off frequencies of 8Hz and 600Hz. The preamplifier had a common mode rejection ratio of 100dB. The band passed EMG signals were converted to RMS signals using a hardware circuit network (frequency response = 0 – 600 kHz, averaging constant = 100ms, total error; ±0.5%). Finally, the RMS-converted signal was re-sampled at 100Hz using a 16-bit A/D converter (AD637). A commercial software (Muscle Lab V8.13, Ergo test Technology AS, Langesund, Norway) was used to analyze the stored EMG data.

The core strength tests (MVC) were used to normalize the muscle activity in the core endurance and core stability tests [32]. The mean associated muscle activity over the three seconds time interval performing the strength tests (flexion, extension and lateral flexion) was set to 100%. The muscle activities performing the stability or endurance tests were expressed as percentage of the MVC. The muscle activities performing similar exercises were compared e.g. the abdominal strength test and abdominal endurance test. For the core stability tests, the mean muscle activity performing the tests on the left – and right foot was compared to the primary muscle tested in the three core strength tests. Further, in the stability tests, the muscle activities were calculated as the average of the time the test lasted. In the core endurance tests, the time maintaining the isometric positions were divided into 0-25%, 26-50%, and 51-75% and 76-100% of time to exhaustion and the average muscle activity for each time interval were calculated.

Statistical analyses

All data were controlled for normally distribution using Shapiro-Wilk test. The time maintaining the positions in the core endurance tests (seconds), maximal force output in the core strength tests (Newton) and total displacement for each foot in the core stability (mm) tests were used to examine the correlation between the identical test parameter (i.e. strength in abdominal, back and lateral flexion) and between the different tests (i.e. core strength, endurance and stability).

To assess the differences in muscle activity during time to exhaustion for the core endurance tests and between core strength, core endurance and core stability tests, a repeated measurement one way analysis of variance (ANOVA) with Bonferroni post hoc corrections was used. Pearson`s product-moment correlation coefficient was used to evaluate the correlations between core strength, core endurance and core stability. Associations were reported by their correlation coefficient r and their level of significance; r values = 0.50 indicate large effects, r values = 0.30 medium and r values = 0.10 small [33]. The significance level was set at $\alpha = 0.05$. All analyses were performed using the statistical package for Social Sciences (SPSS) version 20.0. The results are presented as mean ± standard deviation.

Results

Correlations

There were no significant correlations between the test variables core strength, core endurance or core stability ($p = 0.102 – 0.965$, $r = 0.01 – 0.23$; Table 1) except for a correlation between core endurance in lateral flexion and core strength (lateral flexion; $r = 0.31$; $p = 0.029$ and back extension; $r = 0.44$; $p = 0.001$) and core stability using left leg ($r = 0.29$; $p = 0.049$). The effects were medium.

Significant correlations were observed between the three core strength tests (flexion, extension and lateral flexion, $p \leq 0.001$) with large effects ($r = 0.51– 0.72$, Table 1). Comparing the core endurance tests (flexion, extension and lateral flexion), revealed no significant correlation between the tests ($p = 0.611 – 0.966$, $r = 0.01 – 0.07$, Table 1) except for a large effect and a significant correlation between extension and lateral flexion ($p \leq 0.001$, $r = 0.55$, Table 1). Between the core stability tests (left and right leg), a significant correlation ($p \leq 0.001$) with large effect was observed ($r = 0.61$, Table 1).

The mean results in maximal force output in the strength tests (N), time to exhaustion in the endurance tests (sec) and total displacement (forward/backward and left/right) (cm) are also presented in Table 1.

EMG activity between the variables

All of core muscle activities during the core stability tests on the left and right leg were between 8.8 – 28.8% (± 4.5 – 11.8) and 7.6 – 21.2 % (± 4.3 – 8.1) of the muscle activities in the core strength tests. The muscle activity was significantly lower than all the core strength

Table 1: The maximal force output in the strength tests (N), time to exhaustion in the endurance tests (sec) and total displacement in x-and y direction (cm) with the correlation between core strength, endurance and stability tests.

		Core strength tests			Core endurance tests			Core stability tests	
	Tests	Flexion	Extension	Lateral flexion	Flexion	Extension	Lateral flexion	Right leg	Left leg
Core Strength tests	Flexion	371 ± 110N	0.51*	0.69*	0.02	-0.07	0.15	0.07	0.06
	Extension	0.51*	411 ± 150N	0.72*	0.04	-0.12	0.31*	-0.04	0.20
	Lateral flexion	0.69*	0.72*	309 ± 127N	-0.06	-0.03	0.44*	-0.01	0.22
Core endurance tests	Flexion	0.02	0.04	-0.06	214 ± 122 sec	0.07	0.01	0.08	0.03
	Extension	-0.07	-0.12	-0.03	0.07	175 ± 75 sec	0.55*	0.16	0.02
	Lateral flexion	0.15	0.31*	0.44*	0.01	0.55*	100 ± 38 sec	0.23	0.29*
Core stability tests	Right leg	0.07	-0.04	-0.01	0.08	0.16	0.23	4.3 ± 1.2 cm	0.61*
	Left leg	0.06	0.20	0.22	0.03	0.02	0.29*	0.61*	4.3 ± 1.3 cm

* Indicates a significant correlation between these two parameters on a $p \leq 0.05$ level.

tests ($p \leq 0.001$) and the core endurance tests for all time intervals to exhaustion ($p \leq 0.001$, 33.6 – 93.8% of MVC ± 13.4 – 52.0, Figures 2,3). Furthermore, the muscle activity in the core strength tests were significantly greater than in all time intervals of the core endurance tests ($p \leq 0.001$ – 0.027) except for the muscle activation between the 76 – 100% of the time to exhaustion in the lateral flexion (oblique external; $p = 0.418$) and flexion (upper rectus abdomens; $p = 0.081$; Figure 3).

Comparing the core stability tests, significantly greater muscle activity was observed using right leg in erector spinae (T9 and L5) and oblique external ($p \leq 0.001$) compared to left leg (17.7 – 28.8 % of MVC ± 9.4 – 10.0 vs. 10.2 – 14.1 % of MVC ± 5.3 – 9.0). No significant difference in muscle activity between the legs was observed in erector spinet (L3) and upper/lower rectus abdomens ($p = 0.132$ – 0.826).

In the back extension endurance test (Figure 2), the muscle activity in erector spinae (T9) increased significantly in the 76-100% of time to exhaustion compared to 0-25% and 26-50% of the time to exhaustion ($p = 0.013$ – 0.050). Between the other time intervals and erector spinet at T9, L5 and L3, no significant changed muscle activities were observed ($p = 0.202$ – 1.000).

In the lateral flexion and flexion endurance test (Figure 3), all three muscles: lower and upper rectus abdominal and external oblique were significantly greater in the time interval 76-100% of time to exhaustion compared to 0-25% and 26-50% of the time to exhaustion ($p \leq 0.001$ – 0.008). In addition, the muscle activities of the upper rectus abdominal and external oblique were significantly greater in the time interval 51-75% of time to exhaustion than the 0-25% interval ($p \leq 0.007$), while for the lower rectus abdominal muscle the muscle activity at the 0-25% interval was significantly lower than all other time intervals ($p \leq 0.046$; Figure 3).

The intra-class correlations (ICC) between the test and retest were for the core strength tests 0.79, 0.75 and 0.71 for the flexion, extension and lateral flexion. For the core endurance tests, the ICCs were 0.73, 0.82 and 0.91 for the flexion, extension and lateral flexion. For the core stability test, the ICCs for the left and right leg were 0.74 and 0.76.

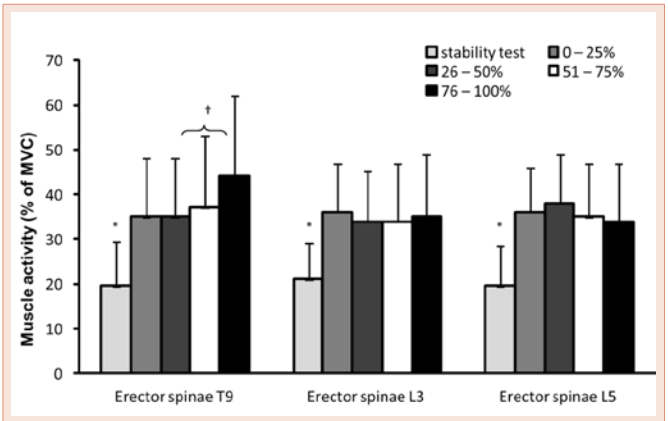

Figure 2: Muscle activity (% of maximal extension strength test) of the spinal erector muscles performing the core stability (light grey) and back endurance test. The muscle activity performing the endurance test was divided in four similar time periods (0-25, 26-50, 51-75 and 76-100% of time from start to exhaustion).

* indicates significant lower muscle activity between the core stability and core endurance test on a $p < 0.05$ level.

† indicates significant difference between these two time periods on a $p \leq 0.05$ level.

Discussion

There were no significant correlations between the variables core strength, core stability or core endurance, except for the endurance lateral flexion which correlated significantly with the core strength (extension and lateral flexion) and the core stability using the left leg. Generally, the muscle activity of the core muscle decreased from strength < endurance < stability tests.

To our knowledge, this is the first study that examines both EMG activity and the association between core endurance, strength and stability. In the core stability tests, which typically include low threshold recruitment of the core muscles [12], lower muscle activity than the core strength and endurance tests were observed. The total displacements in the core in the stability tests were small, and

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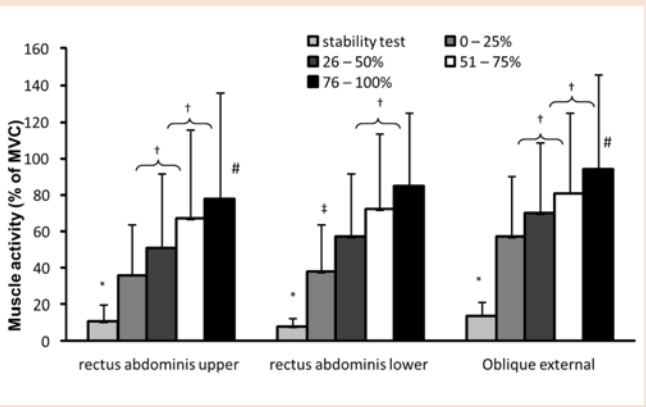

Figure 3: Muscle activity ((% of maximal flexion- and lateral flexion strength tests) of the abdominal muscles performing the core stability (light grey) and flexion- and lateral flexion core endurance tests. The muscle activity performing the endurance test as divided in four similar time periods (0-25, 26-50, 51-75 and 76-100% of time from start to exhaustion).

* indicates significant lower muscle activity between the core stability and core endurance test on a $p < 0.05$ level.

† indicates significant difference between these two time periods on a $p \leq 0.05$ level.

‡ indicates significant difference with all other time periods on a $p \leq 0.05$ level.

# indicates no significant difference with muscle activity with muscle activity at core strength test on a $p \leq 0.05$ level.

forceful movements were not necessary to maintain position. The results were therefore not surprisingly since the aim of the stability training approach is to improve the proprioception of the afferent signal and improve the synchronization of the muscles to stabilize the core. The present study demonstrated muscle activity in the core stability tests between ~10-20% of MVC. In contrast, previous studies have demonstrated core muscle activities between ~20-60% of MVC during isolated specific core stability exercises [34,35]. However, these exercises were executed in horizontal position on an unstable Swiss ball and the different methodological approaches are most likely the cause of the differences in core muscle activities.

For the core endurance tests, the muscle activity during the flexion and lateral flexion increased gradually during the time intervals to exhaustion (Figure 3). For the core endurance extension test, no change in muscle activity was observed in erector spinae between time intervals, with exception for the erector spinet at T9. The ability to include the glutei and hamstring muscles in the tests, are most likely the reason for similar and low muscle activity (% of MVC) compared to the other two core endurance tests. In contrast, the flexion and lateral flexion endurance tests reached the strength training activity level to gain strength (>60% of MVC) [36] and increased the muscle activity during the tests.

These comparable activity levels between the core endurance at exhaustion and the core strength test for the abdominal muscle could result in a significantly positive correlation comparing core strength and core endurance. However, this was only found for the lateral flexion in the core strength and core endurance test (Table 1). Furthermore, a significant, but small correlation was found between the lateral flexion endurance test and the left leg stability test. The associations between the core strength, core endurance and core stability in the lateral flexion, may be due to multiple tasks involving the oblique muscles and in contrast to the abdominal and back muscles. For example are the oblique muscles involved in rotation movement as throwing/kicking (strength) [2], lifting or carrying unilateral loads (endurance) [28] and for avoiding postural sway in the coronal plane (stability) [28].

Overall, there were significant correlations between the different core strength tests. This was not unsurprising since the primary purpose of the global core muscles is not only to generate force, but also to contribute to spinal stability during heavy lifting or large stability requirements [9,10,14,34,35]. This implicates that core muscles contribute to both stability and generating force in several movement planes (median and coronal). The core strength tests examined the force output in the median and coronal plane which reflects the daily living tasks like squats, carrying a back pack or one shopping bag. Due to the number of movement directions in the core, there is no surprise that the core muscle strengths correlated with each other.

In contrast to the correlation between the different core strength tests, there were no significant correlations between the abdominal endurance tests and the others and only a significant correlation between the lateral flexion and the back extension tests. It could be speculated that the correlation between these two tests was due to several large muscles groups (i.e. glutei and hamstring) involved in the tests in addition to the core muscles. In the abdominal test, the core muscles and the hip flexors were involved. The muscle mass of the hip flexors is small and not involved in daily living activities to the same extent as the glutei or hamstring. Furthermore, the abdominal test was tested in a 90˚ angle in the hip in contrast to the horizontal position in the back extension and lateral flexion test. Different positions might have influenced the endurance results.

Between the core stability test of the left and right leg, a significant correlation was observed. The results were not surprising as the joints contributing to stability were limited to the core and identical muscle groups were involved for both legs. In contrast to previous studies examining the core stability in standing position [22,23,25], the stability tests were executed on one knee with armed held across the chest. The test procedures isolated the core muscles in contrast to a standing position where it is impossible to separate the ankle and knee as contributors to maintain stability.

To our knowledge, this is the first study examine the association between core strength, endurance and stability. The present study was limited by using healthy participants and the results may not be representative for other populations. Furthermore, there is always an inherently risk of cross talk from other muscles. However, a short center-to center distance was used. The inter class correlation between the test-retest ranged from 0.71 – 0.91. We cannot exclude learning effects from the tests which may have influenced the results. Multiple correlations were performed and the risk for a chance finding is possible which must be taken into consideration.

Conclusion

There were no systematic correlations between core endurance, core strength and core stability indicating that these capacities are largely independent from each other. Furthermore, muscle activity executing the flexion and lateral flexion endurance tests surpassed the threshold suggested to increase strength. Coaches, training instructors or physical therapists needs to address the core endurance, core strength and core stability as separate capacities and train them accordingly based on the aim of the training. If high intensity exercises are contra-indicated, core endurance exercises should also increase strength if they are performed (close) to muscular fatigue, but this is not the case with stability exercises.

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