Asian J Sports Med. In Press(In Press):e62843. doi: 10.5812/asjsm.62843.
Published online 2019 February 2. Research Article

Relationship of Core Power and Endurance with Performance in Random Intermittent Dynamic Type Sports

Anis I Shaikh[1], Shibili Nuhmani[2,*], Shaji Kachanathu[3] and Qassim I Muaidi[2]

[1]Department of Rehabilitation Sciences, Jamia Hamdard, New Delhi, India
[2]College of Applied Medical Sciences, Imam Abdulrahman Bin Faisal University, Dammam, Saudi Arabia
[3]College of Applied Medical Sciences, King Saud University, Riyadh, Saudi Arabia

[*]*Corresponding author*: College of Applied Medical Sciences, Imam Abdulrahman Bin Faisal University, P.O. Box 2435, Dammam 31451, Saudi Arabia. Tel: +966-554270531, Email: snuhmani@iau.edu.sa

Received 2017 October 14; **Revised** 2018 December 30; **Accepted** 2019 January 04.

Abstract

Objectives: To investigate the relationship of the core power and endurance with variables of athletic performance such as T test, medicine ball throw test, vertical jump test and 40 yard dash test in random intermittent dynamic type sports (RIDS).
Methods: 58 male collegiate athletes involved in RIDS with mean age of 19.41 $\pm$ 1.19 years, height of 172 $\pm$ 6.62 cm, weight of 67.41 $\pm$ 8.80 kg and BMI of 22.56 $\pm$ 2.00 participated in this correlation study. The subjects were tested for core power, core endurance and performance variables. The core endurance was measured by McGill protocol and double leg lowering test (DLL) and the core power was measured by 60 seconds maximal sit-up test.
Results: McGill protocol was positively correlated with medicine ball throw test (r = 0.688) and vertical jump test (r = 0.463). A strong negative correlation of McGill was identified with 40 yard dash test (r = -0.525) and T test (r = -0.687). At the same time DLL was positively correlated with 40 yard dash test (r = 0.374) and T test (r = 0.524). Only medicine ball throw test related significantly with the tests of core power.
Conclusions: McGill test and DLL more significantly correlates with the performance variables such as medicine ball throw test, vertical jump test, 40 yard dash test and T test when compared with the core power measures of 60 seconds maximal sit-up test. The current study results also show that core muscle endurance is necessary for optimal performance and should not be neglected.

Keywords: Core Power, Core Endurance, Physical Fitness, Athletic Performance

1. Background

The term "core" refers to the muscles around pelvis, hip and low back region. The major function of these core muscles is to maintain the pelvis in neutral position while protecting the lumbar spine (1). It plays an integral role in transferring the forces between the trunk and extremities (2). Core training has become an integral part of all sports training and is widely used by sports trainers and coaches with an assumption that this may lead to enhancement in sports performance and reduction in the risk of injuries (3, 4). Weak core muscles paired with strong extremity muscles may lead to insufficient force generation and altered transfer of forces causing musculoskeletal injuries and deteriorated performance (5, 6).

Sports which involve a pattern of dynamic intermittent activities such as soccer, hockey, basketball, tennis etc. are referred to as random intermittent dynamic type sports (RIDS) (7). The pattern of skilled movement activities in these sports are randomized and are performed in various intensities throughout the game. Highly complex physical fitness abilities such as agility, speed, power etc. are essential components in these types of sports. As athletes are constantly transferring their forces between extremities, core muscle strength and endurance are assumed as some of the most desirable qualities required in these sports for successful performance (8).

Even though several studies have been conducted to establish the role of core muscles in performance among various sports populations, the (2, 5, 6, 9-12) relationship between core strength or power and sports performance is still a controversial issue. A strong relationship between core and athletic performance has been reported among soccer players, surfing athletes and climbers (13-15). Nesser et al. (5) investigated the relationship between core endurance training and athletic performance among collegiate football players. The authors reported a weak to moderate correlation with inconstant results. It was also noted by the authors that the test used for the measurement of core function was more focused on endurance than core strength and the latter was more crucial in performance. Although a short-term core stability training by a Swiss ball had a positive impact on stability, it did not have much influence on physical performance in high school athletes (9). The improvement in core stability measurement doesn't transfer into an improvement in performance. It has also been observed that core training does not cause much improvement in functional performance in swimmers and rowers respectively (2, 16). Tse et al. (2) reported that an 8-week core endurance training does not have any influence on performance tests such as vertical jump, broad jump, shuttle run and sprint tests. These findings made the researchers to state that core strength and power may be more influential than core endurance in athletic performance. In most of the studies conducted to establish the relationship between core muscles and performance, the major focus was given to core endurance rather than core strength or power which is also crucial in athletic performance (17). No studies have been found in the literature regarding the correlation of core endurance and core power with athletic performance in RIDS and a field test for measuring core power and core endurance that correlates most to the components of sports performance is yet to be established in the literature. Thus, the objective of this study is to investigate the relationship of the core strength and endurance with the variables of performance such as T test, medicine ball throw test, vertical jump test and 40 yard dash test in RIDS and to find out appropriate core stability test which correlates the most with variables of performance.

2. Methods

Fifty eight male collegiate athletes involved in RIDS with mean age of 19.41 ± 1.19 years, height of 172 ± 6.62 cm, weight of 67.41 ± 8.80 kg and BMI of 22.56 ± 2.00 participated in the study. All the subjects were recruited from Jamia Hamdard University, New Delhi. Among all participants, n = 20, n = 20 and n = 18 were from soccer, hockey and basketball sports, respectively. All the participants were free from injuries at the time of testing. The participants were explained to about the aim and expectation of the study and a written informed consent was taken. Institutional Ethical Committee of Jamia Hamdard, New Delhi approved the study.

2.1. Procedure

A multivariate correlation design was used in this study. The data collection was done in three sessions in three consecutive days with a 24-hour gap between each session. The core power was measured by using 60 seconds maximal sit-up test in the first session. The core endurance was measured in the second session by using McGill protocol (18) and double leg lowering test (DLL) (19). The order of tests of McGill protocol for each subject was randomly assigned. In order to ensure recovery between the four measurements, a five-minute rest was given between tests. In addition to the individually scored test, all four test times were combined to create a total core score.

Measurement of performance by using T test (20) medicine ball throw test (17) vertical jump test (17, 21) and 40 yard dash test (17, 22) were done on the third session. The sequence of performance tests was randomly assigned. No encouragement or feedback was given to the participants during the testing except regarding the correct procedure of the testing. A four-minute rest period was given to each subjects between each performance test for adequate recovery. All tests were performed three times and an average was taken for analysis. None of the participants missed any of the testing sessions.

2.1.1. Sixty Seconds Maximal Sit-Up Test

The sixty second maximal sit-up test, with a built in 30 second test was performed by the participants. The subjects was lying supine on the field turf with 45° of hip flexion and 90° of knees flexion. The fingers were interlocked behind the neck and the feet secured down by another participant. Time started on the word "go" and athletes flexed the trunk up far enough to have their elbows touch their thighs. Athletes had to lower their trunk towards the turf until the scapula came in contact with turf. The athletes were not permitted to touch their head or hands against the field turf during the 60 seconds. Each up-down cycle was considered as a successful repetition of the sit-up. The investigator recorded the number of repetitions at 30 and 60 seconds (23).

2.1.2. McGill Protocol

The McGill protocol consisted of the: (a) Trunk flexion test; (b) a modified Biering-Sorensen trunk extension test (Biering-Sorensen, 1984); (c) right flexion test; and (d) left flexion test (18). The tests were scored as individual held isometric postures for time.

Trunk flexion test: The test begins with the athlete in sit up position with hips and knees 900 flexed, arms across the chest and back rested on a wooden plank. The athlete holds the position isometrically and then the plank was pulled 10 centimeters backward and the athlete was asked to hold this unsupported position. Timer begins from the moment the plank was pulled back till any part of the athlete's body touched the plank (5, 6, 18).

Biering-Sorenson trunk extension test: The test started in the "Biering-Sorensen position" (24) with subjects lying prone with anterior superior iliac spine (ASIS) aligned with the edge of the couch and the upper body was planked out.

Before the test began, the upper half of the body was allowed to rest on a chair. At the beginning of the test, the subjects were instructed to maintain the horizontal position of the body and clear from the chair. The arms were folded across the chest and hands were rested on the shoulders. An inclinometer was placed in the interscapular area to make sure that the subject is maintaining the position. The investigator measured the time the subject was able to maintain the position by using a stop watch. The test was terminated when the subject was unable maintain the position (25).

Right and left flexion tests: The lateral musculature tests started with the subjects in side-bridge position. The legs were fully extended and the subjects had to place their top foot in front of the lower foot to increase their base of support. The subjects had to support themselves on the involved elbow while the uninvolved arm was placed on the opposite shoulder. Subjects were instructed to lift their hips off of the turf, creating a straight line with their body. Time started once subjects were in this position. The test was terminated when the subject was unable to maintain the straight line position and the hips lowered toward the turf.

2.1.3. Double Leg Lowering Test

The subject was in supine position on a plinth, the axis of hip joint co-insides with the goniometric grid placed on the wall adjacent to the plinth. Various practice trials were given to the subject to teach him the posterior pelvic tilt position. A standard pressure biofeedback device was kept under the lumbar spine inflated to 40 mmHg to monitor posterior pelvic tilt. The subject can see the dial of the pressure biofeedback device during the testing procedure. To begin with the test, the subject's hips are passively flexed to 90 degrees and the knees are actively kept in full extension and pelvis is in posterior tilted position. Then, slowly the researcher takes of his support and the subject is asked to maintain posterior pelvic tilt and knees in extension and simultaneously lower both legs on the plinth. At this moment the researcher kept a watch over the grid as well as the pressure biofeedback dial. The level of hip flexion at which the pressure in the dial drops down by 10 mmHg was recorded. The drop of 10 mmHg pressure in the pressure biofeedback device's dial objectively determines the loss of posterior pelvic tilt (19).

2.2. Statistical Analysis

Data analysis was performed using SPSS V. 21 (IBM Corp., Chicago, IL, USA) window software. Descriptive analysis was done for all the data. The relationship between multiple test variables of core stability and performance was determined by using multiple bivariate correlation represented by Karl Pearson correlation coefficient and 0.05 level of significance was used for all comparisons.

3. Results

The descriptive values for all the core and performance are shown in Table 1. The correlation between the core and performance test are shown in Table 2. The McGill protocol was positively correlated with medicine ball throw test (r = 0.688) and vertical jump test (r = 0.463). A strong negative correlation of McGill was identified with 40 yard dash test (r = -0.525) and T test (r = -0.687). At the same time DLL was positively correlated with 40 yard dash test (r = 0.374) and T test (r = 0.524). Only medicine ball throw test related significantly with the tests of core power.

Table 1. Descriptive Statistics for the Sit-Up Test, McGill Protocol, DLL, Vertical Jump Test, Medicine Ball Throw Test, 40 Yard Dash Test and T Test

Tests	Results[a]
30 sec max. sit-up test	24.96 ± 4.11
60 sec max. sit-up test	47.89 ± 7.65
Trunk flexion test	237.59 ± 89.13
Biering-Sorenson trunk extension test	135.59 ± 39.99
Right flexion tests	94.20 ± 23.90
left flexion tests	105.24 ± 26.06
Total McGill Score	572.62 ± 143.93
DLL	60.60 ± 4.32
Vertical jump test	17.09 ± 4.32
Medicine ball throw test	190.98 ± 17.91
40 yard dash test	5.46 ± 0.44
T test	10.57 ± 0.53

Abbreviation: DLL, double leg lowering test.
[a]Values are expressed as mean ± SD.

4. Discussion

Random intermittent dynamic type sports (RIDS) requires highly complex hybrid of physical fitness characteristics such as muscular strength, endurance, speed, agility and quickness (7). These athletes are continuously transferring forces between the extremities and are in need of support from the core muscles to keep the kinetic chain intact. Researchers have failed to show that training the core is effective for enhancing athletic performance in sports (2, 26, 27). Furthermore, only a few researchers appear to have even attempted to find out the inherent relationship between core stability and athletic performance (5, 6, 17). Core power was assessed by using repeated contractions of abdominal muscles in timed sit-ups test. We assessed core endurance by tests that elicited isometric contraction of core muscles i.e. McGill endurance test and also by the double leg lowering test. Athletic performance was assessed on the basis of the requirement of various performance parameters in RIDS.

Table 2. Pearson's Correlation Between Core Power (30 sec Max. Sit Up and 60 sec Max. Sit Up) and Endurance Tests (McGill Protocol & DLL) and Performance Tests (Vertical Jump Test, Medicine Ball Throw Test, 40 Yard Dash Test and T Test)[a]

	30 Sec Max. Sit-Up Test	60 Sec Max. Sit-Up Test	McGill Score	DLL
Vertical jump test				
r	0.238	0.340	0.463	-0.260
P value	0.72	0.009[b]	0.000[b]	0.049
Medicine ball throw test				
r	0.621	0.665	0.688	-0.649
P value	0.000[b]	0.000[b]	0.000[b]	0.000[b]
40 yard dash test				
r	-0.225	-0.399	-0.525	0.374
P value	0.089	0.002[b]	0.000[b]	0.004[b]
T test				
r	-0.102	-0.268	-0.687	0.524
P value	0.448	0.042	0.000*	0.000[b]

Abbreviation: DLL, double leg lowering test.
[a]Pearson's correlation coefficient.
[b]Significant difference ($P < 0.05$).

The result of our study showed several significant positive (McGill vs. medicine ball throw and vertical jump, DLL vs. 40 yard dash and T test) and negative (McGill vs. 40 yard dash and T test, DLL vs. medicine ball throw) in relationship of core endurance and performance variables.

Total McGill score was the combined score of all the 4 test i.e. flexors, extensors, and lateral flexors of both sides. The total McGill score had significant positive correlation with medicine ball throw test and vertical jump test. In our study, the position selected to perform the medicine ball throw was a tall-kneeling position and the participants instructed not to fall forward once throw is completed, which required isometric control of the core muscles. By performing the test in this manner participants were required to stabilize their trunks while performing the explosive upper extremity countermovement. This means that the core muscles were isometrically active throughout the ball throw and throughout the jump. According to McGill (18), the trunk flexors, extensors, and lateral muscles of the trunk provide spinal stability during nearly every dynamic movement, and there is an obvious need to have balanced muscular capacities among them. Performing the lateral trunk endurance tests in the test requires the activation of "local" muscles, mainly the quadratus lumborum and abdominal wall (28). The flexor endurance portion of the McGill test targets the major trunk flexor, the rectus abdominis, which is a "global" muscle (18). The back extensor test, which was modified from the classic Biering-Sorensen test, activates the major extensors of the spine, the longissimus and multifidi, which are part of the "local" stabilizing system (18, 29). As the McGill test targeted the core muscle endurance isometrically, thus these similarities in muscle contraction and activation type may have lead to significant relationship.

Similar results were obtained in the study of Nesser et al. (5) in male football players, where the results showed moderately strong positive correlation of total McGill score and the counter movement jump (r = 0.591), and moderate positive correlation with bench press/body weight (r = 0.369) as this test is similar to the medicine ball throw test because it also measures upper extremity power and strength, and their result suggested that core stability is moderately related to strength and performance in division I male football players. While the results of our study are not consistent with the study of Nesser and Lee (6) whose results showed that there is no significant correlation of total core score and counter movement jump, this may be because of the small sample size (N = 16) and as there were female subjects in their study. According to Leetun et al. (29) the superiority in core muscle strength in males than females may be due to postural differences in the pelvis and bone structure.

The total McGill score showed moderately strong negative correlation with the 40 yard dash and T test. This means that the more is the muscular endurance of the core muscles less time is required to clear a 40 yard sprint and finish T test i.e. the more the core endurance, the faster the athlete. The quadratus lumborum stabilizes the frontal flexion and extension and resists shearing of spine through activation in extension, flexion and lateral bending. A good performance in T test requires better ability to change the directions. Thus both T test and side flexors test of McGill could demand quadratus lumborum activity during the test. 40 yard dash is a test of speed and power of lower extremity, our results support the work of Nesser et al. (5) which showed a moderate negative correlation of total McGill score with 20 yard sprint (r = -0.485) and 40 yard sprint (r = -0.479) and concluded that core stability is moderately related with strength and performance.

Another measure of core endurance was double leg lowering test and the results of our study showed significant positive (DLL vs. 40 yard dash, T test) and negative (DLL vs. vertical jump, medicine ball throw) correlation with the variables of performance.

The EMG activity of rectus abdominis, external and internal oblique muscles were studied by Shields and Heiss (30) in DLL and isometric knee curl exercises. They found that if the muscle length and the type of contraction are controlled, the muscle activation level is greater in DLL test than the knee curl. DLL demands a narrow base of support of upper body and trunk and a longer lever arm of leg segment; therefore a higher need for trunk stabilization results. Thus DLL shows better relevance to core muscle activation than compared to other tests.

The results of our study showed a moderately strong negative correlation between DLL and medicine ball throw test. The core muscles were isometrically active throughout the throw as the subjects were prohibited from falling forward. Similar results were found in a pilot study by Sharrock et al. (17) who correlated DLL with different performance tests and concluded that medicine ball throw best correlates to the DLL compared to other tests.

The results of this study showed moderate positive correlation of DLL with 40 yard dash and T test. Our finding slightly differs from the results of Sharrock et al. (14) where there was a weak positive correlation of DLL with 40 yard dash and T test. This may be due to a small sample size in the study of Sharrock et al. (N = 35) and also lower number of male subjects in the study (N = 18). Our study showed better correlation of DLL with tests of speed and agility i.e. 40 yard dash and T test compared to the study of Sharrock et al. (17), but the results of both the studies does not suggest that there is strong correlation of DLL with speed and agility tests.

We also found correlation between core power and performance test and the results of our study showed 60 sec maximum sit-up test with an inbuilt 30 sec test does not relate significantly to most of the measures of performance. Medicine ball throw test relates significantly with both the tests of core power i.e. 30 sec and 60 sec maximum sit-ups test. Our results showed moderately strong positive correlation of 30 sec and 60 sec maximum sit-ups test with the medicine ball throw test. As previously discussed the subjects were stabilizing their trunk during the throw which made the core muscles isometrically active throughout the ball throw. Sit-ups activate mainly the "global" system muscles (i.e. rectus abdominis, internal and external oblique) and also require minimal activation of the transversus abdominis to ensure sufficient spinal stiffness (18). Researchers have reported greater trunk muscle coactivation between the abdominals, which act as the primary movers of the trunk, and the erector spinae, which are considered to be the antagonists, when the speed of sit-ups increase. So this suggests that during the medicine ball throw and during the timed sit-ups muscle activation is similar and hence it shows a significant correlation.

Nesser et al. (5) studied the relationships between core stability and various athletic performance measurements among Division I football players (n = 29). The athletic performance variables were the vertical jump, 20-yard shuttle run, 20- and 40-yard sprint, one-repetition maximum (1-RM) squat lift, 1-RM power clean, and 1-RM bench press. A relative-to-bodyweight score for the 1-RM squat lift, power clean, and bench press were also obtained. McGill protocol was used to assess the muscular endurance of the core stabilizers, and like in the previous study of this research group, the individual timed endurance scores of the four tests were combined to make a "total core" score. Only weak-to-moderate correlations were found between all performance measures and the "total core" scores. Moderate correlations were observed in the vertical jump and power clean relative to body weight score. Authors state that results are due to the McGill protocol, not being a specific enough measure to relate to athletic performance. Alternatively, core strength may only play a minimal role in athletic performance. Our study supports the work of Nesser et al. (5), but McGill test is having the better correlation to performance when compared with other tests. And from the results of our study it also seems that core strength may only play a minimal role in athletic performance. The study by Tse et al. (2) examined the effectiveness of a core endurance training program on various performance measures in college-age rowers. Subjects were separated into either the control group (n = 14) or the core training group (n = 20). The McGill protocol was used to assess core musculature endurance against various common field tests of athletic performance, such as the vertical jump and the 2000-m rowing ergometer test. After 8-weeks of core training, the core group, who performed trunk stability exercises that progressed from static to more dynamic, showed significant improvements in both right and left lateral endurance tests. No significant differences were observed in the core training group in terms of the performance measures; the researchers suggested that the 8-week training program was too short to elicit an effect on muscular endurance.

The results of our study suggest that core endurance measures i.e. McGill test and DLL correlate more with the performance variables when compared with the core power measures of timed sit-ups test. McGill test is the best on-field test that correlates with athletic performance. Medicine ball throw test is the best performance test that correlates with all core stability test of our study. From our study it seems that performance of an athlete does not depend strongly to the core stability. It relates moderately to the performance measures and thus as suggested by Tse et al. (2) a long term program should be incorporated in athletes for core stability training, to achieve improvement in the performance measures.

The limitations of this study are absence of height and weight in correlating with other variables, it could be possible that a relationship exists between these variables and core stability. Another limitation of this study was core power was only defined by timed sit-ups test rather than other tests. In DLL test the subjects were positioned in full knee extension. In case of tightness of hamstring muscles, it may affect the positioning of the pelvis, and the activity of the abdominals in controlling the pelvic tilt may have been masked.

Future research may include height, weight and BMI and other anthropometric measures of the subject and correlate it with performance test as well as with core stability. More specific tests that define core power should be established. In DLL test the future author must allow slight knee flexion to overcome hamstring bias.

4.1. Conclusion

Our study suggest that core endurance measures i.e. McGill test and DLL correlates more significantly with the performance variables when compared with the core power measures of timed sit-ups test. McGill test is the most significant on-field test that correlates to performance while medicine ball throw test is the most significant performance test that correlates with all core stability test of our study. From the results of our study it can be concluded that core muscle endurance is necessary for optimal performance and should not be neglected.

Acknowledgments

We would like to thank all the athletes who participated in the study. We also acknowledge the support received from faculties of physical therapy, Hamdard University during the study process.

Footnotes

Authors' Contribution: Study conception and design: Anis I Shaikh, Shibili Nuhmani, and Qassim I Muaidi; acquisition of data: Anis I Shaikh; analysis and interpretation of data: Anis I Shaikh, and Shaji Kachanathu; drafting of manuscript: Shibili Nuhmani, Shaji Kachanathu, and Qassim I Muaidi; critical revision: Qassim I Muaidi.

Conflict of Interests: The authors have no conflict of interests relevant to this article.

Ethical Considerations: The participants were explained to about the aim and expectations of the study and a written informed consent was taken. Institutional Ethical Committee of Jamia Hamdard, New Delhi approved the study.

Funding/Support: This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

1. Malanga GA, Aydin SM, Holder EK, Petrin Z. Functional therapeutic and core strengthening. *The hip and pelvis in sports medicine and primary care*. Springer; 2017. p. 185–214. doi: 10.1007/978-3-319-42788-1_10.
2. Tse MA, McManus AM, Masters RS. Development and validation of a core endurance intervention program: Implications for performance in college-age rowers. *J Strength Cond Res*. 2005;**19**(3):547–52. doi: 10.1519/15424.1. [PubMed: 16095402].
3. Clover J. *Sports medicine essentials: Core concepts in athletic training & fitness instruction*. Cengage Learning; 2015.
4. Huxel Bliven KC, Anderson BE. Core stability training for injury prevention. *Sports Health*. 2013;**5**(6):514–22. doi: 10.1177/1941738113481200. [PubMed: 24427426]. [PubMed Central: PMC3806175].
5. Nesser TW, Huxel KC, Tincher JL, Okada T. The relationship between core stability and performance in division I football players. *J Strength Cond Res*. 2008;**22**(6):1750–4. doi: 10.1519/JSC.0b013e3181874564. [PubMed: 18978631].
6. Nesser TW, Lee WL. The relationship between core strength and performance in division I female soccer players. *J Exerc Physiol Online*. 2009;**12**(2):21–8.
7. Bloomfield J, Polman R, O'Donoghue P, McNaughton L. Effective speed and agility conditioning methodology for random intermittent dynamic type sports. *J Strength Cond Res*. 2007;**21**(4):1093–100. doi: 10.1519/R-20015.1. [PubMed: 18076227].
8. Willardson JM. Core stability training: Applications to sports conditioning programs. *J Strength Cond Res*. 2007;**21**(3):979–85. doi: 10.1519/R-20255.1. [PubMed: 17685697].
9. Stanton R, Reaburn PR, Humphries B. The effect of short-term Swiss ball training on core stability and running economy. *J Strength Cond Res*. 2004;**18**(3):522–8. doi: 10.1519/1533-4287(2004)18<522:TEOSSB>2.0.CO;2. [PubMed: 15320664].
10. Watson T, Graning J, McPherson S, Carter E, Edwards J, Melcher I, et al. Dance, balance and core muscle performance measures are improved following a 9-week core stabilization training program among competitive collegiate dancers. *Int J Sports Phys Ther*. 2017;**12**(1):25–41. [PubMed: 28217414]. [PubMed Central: PMC5294944].
11. Hibbs AE, Thompson KG, French D, Wrigley A, Spears I. Optimizing performance by improving core stability and core strength. *Sports Med*. 2008;**38**(12):995–1008. doi: 10.2165/00007256-200838120-00004. [PubMed: 19026017].

12. Imai A, Kaneoka K, Okubo Y, Shiraki H. Effects of two types of trunk exercises on balance and athletic performance in youth soccer players. *Int J Sports Phys Ther*. 2014;**9**(1):47–57. [PubMed: 24567855]. [PubMed Central: PMC3924608].
13. Prieske O, Muehlbauer T, Borde R, Gube M, Bruhn S, Behm DG, et al. Neuromuscular and athletic performance following core strength training in elite youth soccer: Role of instability. *Scand J Med Sci Sports*. 2016;**26**(1):48–56. doi: 10.1111/sms.12403. [PubMed: 25559249].
14. Saeterbakken AH, Loken E, Scott S, Hermans E, Vereide VA, Andersen V. Effects of ten weeks dynamic or isometric core training on climbing performance among highly trained climbers. *PLoS One*. 2018;**13**(10). e0203766. doi: 10.1371/journal.pone.0203766. [PubMed: 30303973]. [PubMed Central: PMC6179192].
15. Silfies SP, Ebaugh D, Pontillo M, Butowicz CM. Critical review of the impact of core stability on upper extremity athletic injury and performance. *Braz J Phys Ther*. 2015;**19**(5):360–8. doi: 10.1590/bjpt-rbf.2014.0108. [PubMed: 26537806]. [PubMed Central: PMC4647147].
16. Scibek JS. *The effect of core stabilization training on function performance in swimming [dissertation]*. Microform Publications, University of Oregon; 1999.
17. Sharrock C, Cropper J, Mostad J, Johnson M, Malone T. A pilot study of core stability and athletic performance: Is there a relationship? *Int J Sports Phys Ther*. 2011;**6**(2):63–74. [PubMed: 21713228]. [PubMed Central: PMC3109894].
18. McGill SM. *Low back disorders*. 3rd ed. Human Kinetics; 2015.
19. Lanning CL, Uhl TL, Ingram CL, Mattacola CG, English T, Newsom S. Baseline values of trunk endurance and hip strength in collegiate athletes. *J Athl Train*. 2006;**41**(4):427–34. [PubMed: 17273469]. [PubMed Central: PMC1748413].
20. McFarland IT, Dawes JJ, Elder CL, Lockie RG. Relationship of two vertical jumping tests to sprint and change of direction speed among male and female collegiate soccer players. *Sports (Basel)*. 2016;**4**(1). doi: 10.3390/sports4010011. [PubMed: 29910258]. [PubMed Central: PMC5968930].
21. Cheah PY, Cheong JPG, Razman R, Zainal Abidin NE, editors. Comparison of vertical jump height using the force platform and the vertec. *Proceedings of the International Conference on Movement, Health and Exercise*. 2016. p. 155–8.
22. Crawley AA, Sherman RA, Crawley WR, Cosio-Lima LM. Physical fitness of police academy cadets: Baseline characteristics and changes during a 16-week academy. *J Strength Cond Res*. 2016;**30**(5):1416–24. doi: 10.1519/JSC.0000000000001229. [PubMed: 26466133]. [PubMed Central: PMC4854178].
23. National Strength & Conditioning Association (US). *Essentials of strength training and conditioning*. 3rd ed. Champaign, IL: Human Kinetics; 2008.
24. Conway R, Behennah J, Fisher J, Osborne N, Steele J. Associations between trunk extension endurance and isolated lumbar extension strength in both asymptomatic participants and those with chronic low back pain. *Healthcare (Basel)*. 2016;**4**(3). doi: 10.3390/healthcare4030070. [PubMed: 27657149]. [PubMed Central: PMC5041071].
25. Latimer J, Maher CG, Refshauge K, Colaco I. The reliability and validity of the Biering-Sorensen test in asymptomatic subjects and subjects reporting current or previous nonspecific low back pain. *Spine (Phila Pa 1976)*. 1999;**24**(20):2085–9. discussion 2090. [PubMed: 10543003].
26. Sato K, Mokha M. Does core strength training influence running kinetics, lower-extremity stability, and 5000-M performance in runners? *J Strength Cond Res*. 2009;**23**(1):133–40. doi: 10.1519/JSC.0b013e31818eb0c5. [PubMed: 19077735].
27. Durall CJ, Udermann BE, Johansen DR, Gibson B, Reineke DM, Reuteman P. The effects of preseason trunk muscle training on low-back pain occurrence in women collegiate gymnasts. *J Strength Cond Res*. 2009;**23**(1):86–92. doi: 10.1519/JSC.0b013e31818b93ac. [PubMed: 19057402].
28. McGill S, Juker D, Kropf P. Quantitative intramuscular myoelectric activity of quadratus lumborum during a wide variety of tasks. *Clin Biomech (Bristol, Avon)*. 1996;**11**(3):170–2. [PubMed: 11415616].
29. Leetun DT, Ireland ML, Willson JD, Ballantyne BT, Davis IM. Core stability measures as risk factors for lower extremity injury in athletes. *Med Sci Sports Exerc*. 2004;**36**(6):926–34. [PubMed: 15179160].
30. Shields RK, Heiss DG. An electromyographic comparison of abdominal muscle synergies during curl and double straight leg lowering exercises with control of the pelvic position. *Spine (Phila Pa 1976)*. 1997;**22**(16):1873–9. [PubMed: 9280023].