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Comparison of different methods of core muscle fatigue on lower extremity function tests among female athletes

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Despite the importance of core muscles in kinetic chains, the importance of each muscle compared to others has rarely been investigated. The purpose of this study was to compare the effect of each core muscle fatigue on lower extremity function tests. This quasi-experimental study with a pretest-posttest design was performed on 30 physical educations, female students with the mean age of 23.46±2.54 years, mean height of 1.63 ± 0.05 cm, and mean weight of 55.61 ± 7.67 kg. The participants performed lower extremity function tests at the first session in normal conditions (without fatigue), and at the next sessions (second, third and fourth) after performing a fatigue protocol of selected core muscles and the results were compared. In order to analyze the data paired samples t-test and repeated measures ANOVA were performed in SPSS. Core muscle fatigue (flexor's fatigue, trunk extensor fatigue and hip abductor fatigue), significantly reduced lower extremity function test scores ($P<0.05$). Overally, a decrease in test scores after three jumps, single-leg hip abductor muscle fatigue with the large effect size (0.82) trunk extensor and flexor muscles to fatigue was observed. Function of core muscles affects lower extremity function tests because core muscle fatigue causes a reduction in the reaching distance in anterior direction and increases the number of errors in all the components of Y balance test. Exercises that can provide an improvement in core muscles endurance and their ability to cope with fatigue are recommended and can be used by coaches to prevent injuries.

Keywords: Core body muscles, fatigue, functional tests

Introduction

Due to the clear relationship between core muscle activity and lower limb movements, core stability provides several benefits to the musculoskeletal system from back health maintenance to prevention of lower extremity injuries. Strengthening the core stability muscles to improve exercise performance is a controversial issue [1].

In fact, the role of core stability in the prevention and treatment of a number of sports injuries has been somewhat proved [2], but its mechanism and extent on exercise performance has not been clearly ascertained [3-5]. In this regard, researchers have suggested that in order to assess the role of core stability in athletes' performance, it is better to use sport specific tests and functional performance tests requiring complex exercise movements [4,6,7].

Functional performance tests are a group of physical and skill tests that are part of everyday activities of an individual, whether it is an athlete, student, patient, industrial worker, or housewife. The common point among these people is that they need components of the performance to perform their tasks and skills [8]. Over the past few years, the literature on the relationship between core stability and sport performance has significantly increased. However, this relationship has not yet been defined precisely, and relatively few studies have attempted to determine the correlation between these two variables [9].

In this regard, in a study by Sharrock et al. (2011) on university athletes, a significant (but not strong) correlation between the double leg

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lowering test (as the core stability test) and the medicine ball throw as a performance test was found [8]. Although Okada et al. (2011) found a significant correlation between McGill's trunk muscular endurance test and agility T-test and single squat in a non-athletic group, due to the weakness or moderateness of observed associations, they suggested core stability cannot be a strong predictor of athletic performance [6].

Sharrock et al. (2011) reported on their findings that there seems to be a correlation between core stability tests and exercise performance tests. However, they suggested that more research is required to provide a definitive answer to the nature of this relationship. Ideally, specific functional tests can be better able to define the relationships between core stability [8].

Nasser et al. (2008) also observed only a weak or moderate relationship between a number of McGill's torso muscular endurance endpoints and some functional performance tests in American football athletes, and thus stated that increased core stability cannot significantly improve the performance of athletes [4].

Evidence suggests that studying the effect of core muscle fatigue on lower limb function can provide valuable information about how core stability affects lower limb function because fatigue is one of the factors that can reduce muscle coordination and decline muscle performance [6] and given that core muscles are necessary to maintain center of gravity for suitable movements, the fatigue of these muscles may affect the function of individuals, especially athletes [10].

In this regard, Nasser has suggested that the relationship between core stability and exercise performance during fatigue should be studied in order to obtain more information about the nature of the relationship [4]. It has been shown that abilities, weaknesses, and overall, muscle function are better identified at the time of fatigue [11]. Functional tests are more capable of evaluating muscle function during fatigue compared to normal conditions, and it is therefore suggested that these tests be used in both conditions without fatigue and with fatigue [11,12].

Abt et al. (2007) examined the effect of a core muscle fatigue protocol on pedaling mechanics in 15 professional cyclists and found that core muscle fatigue caused changes in pedal mechanics and lower extremities of cyclists [13]. In addition, the reduction of balance and postural control following fatigue of the core muscles has also been observed in a number of studies [14,15].

McMullen et al. (2011) showed that fatigue of the gluteus medius muscles (as one of the core muscles of the body) reduces static and dynamic balance and quality of movement in non-athletic men and women [16]. Vuillerme et al. (2007) also found that trunk extensor muscle fatigue led to decreased postural control in young healthy people [17].

Sheikh Hassani (2013) in his study on the effect of core fatigue on performance scores of lower extremities in athletes showed that core muscle fatigue caused a significant reduction with a large effect size in the scores of all functional tests of lower extremities and concluded that the function of core muscles affects the function of the lower extremities [7], because of the negative effect of core muscle fatigue on the functional performance scores of lower extremities.

Regarding the championship sports and the huge costs of sports injuries and the contradictory results in relation to the relationship between core stability and sport performance and limited number of studies on the performance of athletic women, especially in the Iranian community, we aimed to investigate the effect of different methods of core fatigue on functional performance of lower extremities (figure-eight hop test and triple hop test) in athletic women. It seems that the study of fatigue of core muscles and determining the effect of each of these muscles on exercise performance can provide valuable information to coaches and athletes, which will eventually help coaches in designing an optimal training program to increase athletic performance and reduce the risk of injuries and athletes in achieving better records in sports competitions.

Materials and Methods

This semi-experimental study with a pretest-posttest design was performed on 30 female physical education students with a mean age of 23.46 ± 2.54 years, mean height of 1.63 ± 0.05 cm, and mean weight of 7.67 55.15 kg. The controlled constraints in the randomized selection of subjects include the absence of specific diseases (e.g., asthma or heart problems), the absence of severe spinal abnormalities (e.g., scoliosis and kyphosis) and poor bodily alignment of the lower extremities (e.g., Genuvarum, genuvalgum, and flatfoot), lack of surgery in the trunk or lower extremities (e.g., Minsk or knee ligament ruptures), and the subjects were in the follicular phase of their menstrual cycle.

The functional performance test scores of the subjects were evaluated before and after the three selected core muscle fatigue protocols separately and by the tests (figure-eight hop test and triple hop test). Four test sessions were held (at a minimum interval of 48 hours and a maximum of one week) in a similar location and time. At the beginning of the first session, the height and leg length of the subjects were measured by the tape measure and their weight was measured by a digital scale.

After 10 minutes of warm-up (5 minutes of in-situ warming, 5 minutes of static stretching, with an emphasis on the ankle, knee and thigh joints), the subjects were first shown how the tests are performed and they then carried them out several times to learn the test.

After 2 minutes of active rest, to eliminate fatigue in the learning phase, the subjects performed the tests in normal conditions without fatigue and the results were recorded by the examiner. In the next sessions, each of which was held at a 48-hour interval, the subjects were asked not to do intense physical activity during this period. The subjects participated in the fatigue protocol after 10 minutes of warming up and performed the test at an interval of less than 10 seconds.

The protocol of core muscle fatigue and its implementation:

Trunk flexor fatigue method: The subject sat on the bed, and leaned her trunk against the heal panel at a 40-degree angle. The thighs and knees of the subjects had a 90-degree angle, her hands were crossed over the chest and her feet were firmly tied with the help of the examiner.

When the subject was in a good position, the head panel was pulled back about 10-centimeter and the subject was asked to keep her trunk at a 40-degree angle for a long time, as long as possible, and the time until the trunk touch the head panel was measured. Fatigue occurred when the participants could not maintain their trunk at this angle and lower their back and reached the panel again. People were given less than 10 seconds to go from the fatigue to the place where they collected the post-test data [18] (Fig. 1).

Chen et al. (2003) showed that the use of a back angle of 45 degrees makes the test results more reliable, and due to the difficulty of the test at this angle, it requires less time [19].

Trunk extensor fatigue protocol: The subject was placed on the bed with her hip on the edge of the bed and trunk outside the bed. Another person fixed her legs firmly to the bed. The subjects' hands were placed on a chair placed in front of the bed.

Figure 1: Trunk flexor fatigue

To begin the protocol, the examiner asked her to keep her arms crossed on her shoulders by keeping her trunk in the horizon. The time since the moment the athlete picked up her hands from the chair and held her trunk with the extensor muscles along her body until the upper part of the subject was lower than the horizontal plane of the bed and her hands touched the chair again was measured [20,21]. The results of the research by Reiman et al. (2010, 2012) showed that the results of the test would be more reliable if instead of using a strip another person was used to stabilize the subject's feet [19] (Fig. 2).

Figure 2: Trunk extensor fatigue

Hip abductor fatigue method: The subject lied on the lateral position such that the entire body was in a straight line, then placed her hand over her chest, and the upper leg was above the other leg a towel was placed between the two legs. The examiner first recorded the maximal contraction (100%) with a manual dynamometer, such that the head of the dynamometer was fixed on the distal edge of the thigh.

The examiner then asked the subject to perform abduction with maximum power, this was repeated twice at a 10-second interval, and the average power was recorded for the individual. Then, the person was asked to perform the abduction of the thigh with 50% of maximum contraction. The time was measured from the point at which the subject started the movement until the subject was not able to maintain this position [22] (Fig. 3)

Figure 3: Hip abductor fatigue

Statistical analysis

Finally, after collecting the data, data on the characteristics of the subjects such as age, height, weight and research variables were analyzed using descriptive (Table 1) and inferential statistics (Table 2) in SPSS, version 19. After assuring that the data were normally distributed using the Kolmogorov–Smirnov test, to test the effect of core muscle fatigue on lower limb function tests paired t-test was used. To measure the effect size of fatigue Cohen's d method was employed and the effect size of 0.25 to 0.5 was considered small, the effect size of 0.5 to 0.8 moderate, and the effect size of 0.8 and above was considered large [19]. Repeated measures analysis of variance (ANOVA) and Bonferroni correction were used to compare each of the functional tests using the three fatigue methods.

Table 1. Descriptive statistics

Variable	Number	Mean±SD	KS value	P-value
Age (year)	30	23.46 ± 2.54	0.764	0.604
Height (cm)	30	1.63 ±0.05	0.489	0.079
Weight (kg)	30	55.61 ±7.67	0.821	0.051
Body mass index (kg/m^2)	30	20.77 ±2.64	0.565	0.809
Eight test	30	15.41 ±2.08	0.677	0.947
Triple hop test	30	3.95 ±0.51	0.250	0.880

Results

Based on the results of paired t-test, the fatigue protocol of the selected core muscle group (trunk flexor and extensor and hip abductor) with moderate to large effect size resulted in a significant reduction in the functional performance score of the lower extremities (figure-eight hop test and triple hop test) at the level of $P \leq 0.05$. The results of repeated measures ANOVA in relation to the functional performance test scores (figure-eight hop test and triple hop test) showed a significant difference between the three types of fatigue protocols (p=0.001).

Also, based on the results of Bonferroni test the difference in fatigue of the trunk flexor and hip abductor muscles and fatigue between the trunk extensor and hip abductor muscles in the triple hop test was significant (p=0.017, p=0.002, respectively). Overall, the score of the triple hop test following the fatigue of the hip abductor muscle group with a large effect (0.82) was significantly lower than the flexor and extensor muscles fatigue.

Discussion

Among the athletes' population, the most disabling injuries are the lower limb and spinal cord injuries in the lumbar region. Most of these injuries are attributed to muscle impairment, such as poor muscle strength; therefore, it has been suggested that loss of trunk and thighs strength may expose athlete to back and lower limb injury [23].

Table 2. Results of the statistical tests

		T-test	Effect size			Analysis of variance	Bonferroni			
			Flexor	Extensor	Abductor		Pre- and post-fatigue	Between flexor and extensor fatigue	Between flexor and abductor fatigue	Between extensor and abductor fatigue
Eight hop	1	0.001*	70.0	65.0	70.0					
	2	0.001*				*0.001	*0.001	-	-	-
	3	0.001*								
Triple hop testپا	1	0.001*								
	2	0.001*	74.0	51.0	82.0	*0.001	*0.001	-	*0.017	*0.002
	3	0.001*								

*P<0.05 was set as the significance level.

Because core is the center of kinetic chain is most motor activities, especially sports. Also, control of core power, balance and movement increases the kinetic chain of the upper and lower limbs [24].

The posterior kinetic chain muscle group that plays a role in muscular control of the lower extremities, including large and small gluteal muscles, hamstrings, gastrocnemius and soleus, which should be appropriately recruited to capture ground reaction forces. Some researchers have reported that athletes with stronger abductors and hip lateral rotator muscles compared to less strong athletes experience lower ground response forces

In all activities, ground reaction force is exerted to the center of the body (actually in the trunk area), so trunk and its motion control are critical to controlling the response force to the body [25]. Neuromuscular fatigue, which can be defined as a decrease in muscle fibers' capacity in energy absorption and power generation, may be considered as an effective factor in musculoskeletal injuries during long-term activity. The results showed that fatigue causes complete changes in the lower limb kinematics in practice of jumping and landing. They reported that men and women use a rigorous landing strategy after fatigue with maximum knee valgus and knee flexion in the initial contact in landing and jumping. There is evidence that neuromuscular fatigue leads to changes in landing and subsequent compensatory strategies [26]. In a study by Adlerton et al. (2003), it was concluded that fatigue in trunk and lower extremity muscles cause postural instability [27].

Sarnock et al. (2008) also found that trunk muscle fatigue had a negative effect on static and dynamic balance [5]. Since the functional performance tests of the present study are part of balance tests, considering the above-mentioned issues regarding the effects of fatigue, the reduction in the score of functional tests in the present study is logical. The kinematic trunk flexion changes the sagittal plane during landing.

Researchers found that trunk and hip flexion are two important motor patterns of the sagittal plane, and the low amount of flexion of the trunk and hip increases the ground reaction force [25]. Findings of Jashua et al. (2015) showed that trunk extensor fatigue resulted in lower height and reduced muscle activation in the lower limbs. Trunk stability plays an important role in transmission of forces and angular movements. In multi-articular movements, activation patterns usually occur following a proximal to distal sequence, especially in kinetic and jumping movements. Research on jumping mechanics has shown that all forces should be transmitted to the vertical plane to maximize jump height. When postural muscles are tired, there is a tendency to increase postural fluctuations and lose postural control [28].

Sarnock et al. (2008) using an isokinetic machine created trunk fatigue to test lactate accumulation and dynamic balance test, and they found a significant positive relationship between lactate accumulation and reduced dynamic balance, which is consistent with the findings that the posterior chain fatigue affects the person's ability to correct the position and maintain balance and adversely affects the jumping height [5].

There are a number of possible mechanisms that can provide insight into the irregular muscle activity following the extensor muscle fatigue, first, the modified Biering-Sorensen test, which was used in the fatigue protocol was designed to cause fatigue in extensor muscles of the back. These limb contractions can potentially reduce the activation of both gastrocnemius and tibialis anterior muscles in the course of the fatigue protocol.

Quadriceps muscle activity also decrease due to fatigue of the trunk extensor muscles [29]. However, the strength of the quadriceps muscles plays a significant role in the implementation of the triple hop test [25]. Considering these points, the reasons for reducing the jump height in the triple hop test may be partly the reduction of activity in quadriceps muscles, gastrocnemius muscle, and tibialis anterior due to trunk extensor muscle fatigue.

The results of an electromyographic study showed that the gluteus maximus and gluteus medius muscles are active during the single-hop forward movement, and the trunk extensors cause fatigue in hip extensor muscles [30]; therefore, the fatigue and loss of function of gluteus maximus and gluteus medius muscles in the Sorensen's fatigue protocol may be another reason for reduced triple hop test score [31].

Fatigue and power loss have been proven to reduce the performance of vertical jumps during maximal vertical jumps or successive jumps. Also, some of the fatigue effects were observed during a 30-second successive maximal vertical jump test, including a drop in jump height, power output, flight time, and increased contact with the ground during the test. Jenny et al. (2010) reported that fatigue reduced muscle activity, power generation and neuromuscular balance and jump technique in a study that evaluated the effect of fatigue on kinetic and kinematic variables over 60 seconds of successive vertical jump testing on male and female athletes [32]. The functional performance tests of the present study require sequential jumps, eight hop test requires performing rotational and shear movements. Their successful performance requires high neuromuscular coordination [31].

The results of electromyographic studies have shown that shear movements require synchronous and contractile activity of the hamstrings, quadruples, and gluteus maximus and medius. Reducing neuromuscular coordination, as well as increasing the response time in the muscles (especially in gluteus maximus and medius muscles) due to the fatigue protocol can possibly increase the record of subjects in eight hop test and lateral jump after fatigue [33].

These two tests also require a sudden change of direction, and proper function of the central muscles (especially the lumbar area) is necessary to stabilize the trunk and to withstand the pressure forces exerted to the spinal column when performing such movements that require a change of direction. Reduced ability of the core muscles due to fatigue in coping with the pressure forces exerted to the spinal column during direction shift maneuvers in eight hop test and lateral jump may have a negative effect on the performance of athletes in these two tests, and athletic women had significantly lower lumbar muscle endurance compared to men [6].

Conclusion

Regarding the negative effect of fatigue on lower limb functional tests by reducing the distance and increasing the time of the test and increasing the number of errors and decreasing the quality of the tests, core muscles play an important role in balance and athletic performance. As a result, improving core muscles and increasing their ability to cope with fatigue can be considered by educators and rehabilitation specialists as a way to prevent injury, because the muscles that can withstand long contractions are more resistant to fatigue and can support the trunk in the long term which can maintain exercise performance in long-term activities.

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Conflicts of interest
None declared

Clinical Trial Registration
IRCT201104251457N8

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