Sport Sciences and Health Research

University of Tehran
Faculty of
Physical Education and Sport Science

The effect of neuromuscular training on kinetic variables in male athletes with trunk control defects

Behnam Moradi[1*], Amir Letafatkar[1], Malihe Hadadnezhad[1], Mehdi Hosseinzadeh[2], Mehdi Khalghi[1]

1. Department of Biomechanics and Sports Injuries, Faculty of Physical Education and Sport Sciences, University of Kharazmi, Tehran, Iran. (*Corresponding author: ✉ b_moradi91@yahoo.com, https://orcid.org/0000-0001-6803-2947)
2. Department of Sport Injuries and Corrective Exercises, Sport Sciences Research Institute, Tehran, Iran.

Article Info

Original Article

Article history:
Received: 19 August 2022
Revised: 29 December 2022
Accepted: 30 December 2022
Published online: 01 January 2023

Keywords:
Biomechanics,
neuromuscular training,
sport injuries.

Abstract

Background: Trunk control defect is one of the neuromuscular defects that can cause sports-related injuries in athletes.

Aim: This research investigated whether neuromuscular training affects several kinetic parameters in male athletes who had trouble controlling their trunks during a change-of-direction movement.

Materials and Methods: The present study used a pre-test-post-test design and was conducted semi-experimentally. Purposefully chosen male athletes (n= 29) with trunk control defects were randomly divided into two groups: control (n= 14) and experiment (n= 15). A Kistler force plate was used to quantify kinetic variables. The exercises were performed for 6 weeks, 3 sessions per week (30 min each session). To analyze the data, dependent t-test and analysis of covariance and SPSS software version 21 were used at the significance level of $P<0.05$.

Results: The findings indicated a significant decrease in the time to peak anterior-posterior force ($P=0.010$), time to peak mediolateral force ($P=0.001$), time to peak vertical force ($P=0.003$), and rate of loading ($P=0.001$) of the experimental group. The differences in all control group variables were insignificant, $P>0.05$.

Conclusion: Performing neuromuscular training is likely to improve the direction change mechanism and prevent injury in athletes with trunk control defects.

Cite this article: Moradi B, Letafatkar A, Hadadnezhad M, Hosseinzadeh M, Khalghi M. “The effect of neuromuscular training on kinetic variables in male athletes with trunk control defects”. *Sport Sciences and Health Research*. 2023, 15(1): 53-66. doi: https://doi.org/10.22059/SSHR.2024.363547.1102.

EISSN: 2717-2422 | Web site: https://sshr.ut.ac.ir/ | Email: sshr@ut.ac.ir
 Publisher: University of Tehran, Faculty of Sport Sciences and Health

1. Introduction

Neuromuscular control defects are defined as incorrect activation patterns, feeble muscle power, and strength in the trunk and lower extremities, which result in increased stresses on the anterior cruciate ligament and knee joint during athletic activity [1, 2]. Trunk dysfunction, which is characterized by insufficient control and coordination to combat trunk inertia during athletic movements, is one of these neuromuscular control flaws [3, 4].

In general, it should be noted that being able to regulate the trunk during athletic activities is crucial since it offers a sturdy platform for the lower body's motions [5, 6]. This region contains the trunk and hip muscles, whose actions occur before the major motions and are very important for avoiding sports injuries [7]. Before the major motions, the trunk muscles are contracted, increasing the spine's stiffness to provide sturdy support [8, 9].

Meanwhile, several studies have examined non-collision ACL injuries as a result of inadequate body control, which can place the knee joint of the athlete at risk [10]. This means that the presence of a defect in an area, particularly the trunk, which plays a crucial role in transferring energy and connecting the movements of the lower and upper extremities, can expose the athlete to severe sports injuries [8].

According to studies, athletes need enough strength in their hip and trunk muscles to achieve the required stability in various movement planes [11, 12], and a decline in the strength and control of these muscles results in a weak and unstable foundation for growth. and the lower leg receives force [13]. To put it another way, it can be said that a lack or reduction in trunk control is one of the risk factors for lower limb injuries because it is directly linked to their occurrence, particularly in sports that involve running, jumping, and other rapid movements [12, 13]. However, in sports like football, handball, and basketball, which place a premium on this talent, good direction-changing is seen as the key to success [14, 15]. Angle and speed might affect the biomechanical requirements for shifting directions. As a result, shifting directions will presumably cause athletes to apply strategies and kinetic parameters differently [16]. Movements that change direction are also thought to be a major contributor to the development of non-collision ACL injury [17, 18].

It is advised to adopt a variety of training regimens in this respect to lower the risk of anterior cruciate ligament injury. It has been shown that the probability of anterior cruciate ligament injury has lowered from 51 to 88%, particularly in training regimens intended to improve neuromuscular capacity. In rehabilitation settings, specialized exercises known as neuromuscular training are often utilized to improve muscle strength and stability in the hips and trunk [19]. Adult research demonstrates that these exercises may be utilized in this situation to improve trunk control, lessen valgus pressure, and guard against lower limb injuries. Proprioception and sensory inputs are enhanced by the practice of these activities to help adults avoid lower limb injuries [19].

In this regard, Read et al. (2021) reported that performing neuromuscular training led to a decrease in the tuck jump score and landing test error. In other words, regardless of the participants' maturity level, they demonstrated an improvement in the landing mechanism and a decrease in the risk of damage [20].

In this line, Mohammadi and Ghaeeni (2019) found that the incidence of trunk control abnormalities among the male athletes they were connected to non-collision injuries to the anterior cruciate ligament. Regarding the significance of lower limb injuries, particularly the stresses on the knee, 26% of respondents indicated that emphasis be paid to programs to address this deficit [21].

According to Mirjamali et al. (2019), who compared the effects of central stability exercises on stable and unstable levels on the static and dynamic balance of female athletes with trunk control defects, both types of exercises, which strengthen the trunk and hip muscles, help women with trunk control defects balance better. This exercise is suggested to the appropriate athletes owing to the established trunk control deficiency and the increased impact of workouts on an unstable level [22].

Hadadnezhad et al. (2015) examined the impact of stability exercises on the activity of the trunk muscles in women with defects in trunk control and found that after completing the exercises, the amount of activity in the muscles of the experimental group decreased, indicating an improvement in neuromuscular control [23].

Paying attention to the athlete's ability to control and properly absorb forces, during dynamic and functional activities, can be considered as a basic key in preventing injuries, especially lower limb injuries [14]. Uncontrolled forces are one of the causes of sensory information disruption, inappropriate muscle activation, and the formation of abnormal movement patterns that can cause various lower limb injuries [24]. On the other hand, trunk and thigh neuromuscular training can increase trunk and thigh control by improving proprioceptive information and increasing the integration of sensory inputs and muscle coordination, which ultimately reduces valgus pressure and prevents lower limb injuries [20].

Thus, regarding the report of trunk control deficiency in male athletes, and the significance of investigating the consequences and correcting it in the nervous-muscular-skeletal system, it is required to pay attention to the trunk and hip neuromuscular training program, which is more functional than the exercises applied in the literature, not finding a study to correct the trunk control deficiency in male athletes despite its suggestion and the lack of evidence to study the task of changing the direction of men who are prone to injury in sports fields that need successive changes of direction, so this study aims to survey neuromuscular training trunk and hip were done on a selection of kinetic variables of male athletes with a trunk control defect during the change of direction maneuver.

2. Materials and Methods

2. 1. Subjects

The method of the present study was semi-experimental and practical with a pre-test-post-test design along with a control group. The statistical population of this study involved all male athletes (handball, basketball and football with trunk control impairments) of Kharazmi University, with 32 qualified male athletes from the mentioned statistical population in two control and experimental groups (16 people in each group randomly) as statistical sample applying G power software with statistical power of 0.8, alpha 0.05, effect size 0.28 and regarding 10% drop, mean and standard deviation of the community and statistical sample of the studied variables due to similar studies [25].

The inclusion criteria included the following: Male student-athletes at

Kharazmi University, 18 to 25 years old, play football, basketball, and handball (with at least 5 years of playing experience) having issues with trunk control, as seen by the tuck jump test with ongoing athletic exercise (Beck questionnaire score of 13 to 15). They are classified as competitive athletes and belong to the second class under the McKinney criteria (according to which, the male athletes in the current study work out for at least two hours per session, three times per week, and are prepared to compete in formal competitions) [26, 27]. Its body mass index (kg/m^2) is within the normal range [28].

Exclusion criteria also include: Subjects in an injury prevention exercise program in the past 6 months, history of injury in the past year in the trunk and lower limbs, the presence of lower limb abnormalities (crossed knee, braced knee, backward knee, Flat soles) can be detected by visual assessment, the presence of pain at the time of research or a history of surgery in the trunk and lower limbs, the presence of a history of vestibular, inner ear and ligament damage in the lower limbs in the past year, the subjects' lack of satisfaction and unwillingness. To continue the research process, they were missing two consecutive sessions and three non-consecutive sessions in exercises and lack of compatibility with exercises [28].

Based on this, a call to action for subjects to submit to screening and participate in the research was issued between October and November 2022.

The pre- and post-tests for this study were conducted between December and March of 2022 in the Mofaqian laboratory of Sharif University of Technology (pre-test and post-test), as well as Pahlavanan Hall at Kharazmi University (6 weeks of neuromuscular training that were carried out on the experimental group in January and February). In the end, 1 and 2 subjects from the experimental and control groups, respectively, were eliminated from the research because they did not match the aforementioned requirements. The experimental group, which consisted of 15 individuals, took part in pre-and post-tests after 6 weeks of neuromuscular training. The 14 members of the control group went about their daily activities throughout this period.

Before the research began, all subjects completed an informed consent form after receiving information about the study's objectives, procedures, length of participation, advantages, dangers, or potential problems, the subject's nature of the study, and the confidentiality of the data. Moreover, this study attempted to comply with the ethical principles mentioned in the 2008 Helsinki Declaration of Ethics, and its generalities were approved and registered by the National Ethics Committee in Biomedical Studies under the number IR.SSRC.REC.1401.032 on 2022-05-21.

2. 2. Instrument

The Tuck Jump Test was developed to assess (before performing the pre-test, to screen and select the subjects) the lack of trunk control. Each patient was required to stand with their feet shoulder-width apart, begin leaping vertically, and elevate their knees as far as possible to identify the trunk control deficit. The hips are parallel to the ground at the height of the leap. The subjects must start the subsequent tuck jump after touching down. Ten seconds will pass during this test. To increase the precision of the examination, two video cameras (Two Sony FDR-AX53 video cameras, Made in Japan) were employed. The cameras were positioned parallel to the frontal and sagittal planes and adjusted for the subjects' height. After the test, Kinova software was applied to check the jumping sequences. A subject who is unable to land at the starting point of the jump, whose hips are not parallel to the ground at the peak of the jump, and whose jumps are done with a pause of 10 sec, was regarded as a subject with trunk control deficiency. To be sure about the existence of trunk defects in male athletes, before handling the study, an experimental plan or pilot of the Tuck jump test was carried out [27].

Figure 1. Tuck jump test

Next, kinetic parameters in the anterior-posterior, mediolateral, and vertical directions as well as the amount of incoming stress were assessed using a Swiss-made Kistler-9260AA6 force plate angle (Figure 2) and Cortex software.

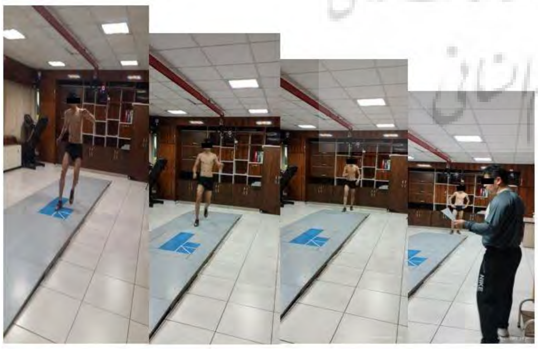

Figure 3. Performing a maneuver to change of direction on the force plate

The natural frequency for these components is 400 Hz. The greatest center of pressure inaccuracy was 2 mm, while the vertical frequency was 200 Hz. To measure the frequency, the power plate was set with a sampling rate of 1000 Hz (Data collection was done in the last 50% of the stance phase) [20]; Furthermore, data noise was decreased using Butter worthy digital low-pass filter of the fourth order and with a cut-off frequency of 50 [29].

The measured variables included the time to peak anterior-posterior force, time to peak mediolateral force, time to peak vertical force and rate of loading. Times to peak force were calculated using Winter's inverted pendulum formula [28].

The rate of loading as a normalized peak vertical force, divided by the time to first peak of the ground reaction force from the moment the heel contacting (The point is considered heel contact when the vertical ground reaction force exceeds 10 N) was calculated [28].

The formula for calculating the rata of loading is:

$$\text{loading rate} = \left[\frac{\text{peak } F_z \text{ (N)/body weight (N)}}{\text{time to peak } F_z}\right] = \frac{\text{BW}}{\text{ms}}$$

Finally, the subjects in this study were exposed to a risk of ACL injury by performing a change of direction task at a 45° angle (Figure 4). By sprinting from a distance of 10 m at their full speed, the subjects of the experimental and control groups in the pre-test and post-test then abruptly halt (with the dominant leg) at the location specified on the force plate and shift their direction at an angle of 45° [30].

2. 3. Neuromuscular training protocol

The training protocol, which was employed in 18 training sessions over 6 weeks, was adapted from research work by Myer et al. (2008) Steps, one's body weight, a medicine ball, a Swiss ball, and a bosu ball were used for these workouts [31]. Each training session lasted about 30 min, including the starting warm-up and the closing cool-down (10 min each). This training was created in 5 steps such that at the start of each phase, the training was done with a straightforward form, reduced volume, both legs, correct technique, and a reasonable degree of ease. The methods and actions then progressively became better and harder depending on the subjects' performance and ability. The subject moved on to the next stage when the trainer was confident in the athlete's effectiveness and competence in putting particular approaches into practice (Table 1). When required, the training should be conducted to execute the right technique, coupled with feedback, and the subject should complete the exercises at the set volume and intensity. During the training period, the control group did their daily activities [31].

Table 1. Variables of neuromuscular training

Variable	Control group Mean±SD	Intervention group Mean±SD
Age (year)	23.6 ±2.7	22.8±2.5
Height (cm)	177.3 ±6.3	178.1±8.2
Weight (kg)	74.5 ±2.7	73.5±3.2
BMI (kg/m^2)	22.4 ±1.0	21.9±2.1

2. 4. Statistic

Kinetic data was filtered with Butterworth 4th order with a cut of frequency of 30 hertz [29]. MATLAB software version 2021 was used to filter and process the force plate data, and ORIGIN software version 2021 made in the USA was used to present the output information [28]. The Shapiro-Wilk test was used to investigate the normality of the data. Dependent t-test was used to obtain intragroup changes. In order to compare the two groups with each other in the post-test, the analysis of covariance test was used to control the effect of the pre-test as a covariate variable. A $P< 0.05$ was considered statistically significant. The data were analyzed using SPSS (Version 21).

3. Results

In this study, 29 athletes with trunk control deficits, ages 18 to 25, were divided into two control (14) and experimental (15) groups (Table 2). Shapiro-Wilk test verified that the data had a normal distribution. In the following, to examine a selection of kinetic variables that include the time to peak anterior-posterior, time to peak mediolateral, and time to peak vertical force, and the rate of loading from the analysis of T test applied Intra-group changes in the time to peak anterior-posterior force of the control group from the pre-test (Mean=0.20, SD=0.11) to the post-test (Mean=0.20, SD=0.09) T=0.052, *P*=0.822, which shows no difference; the intra-group changes of the control group were significant, while the intra-group changes of the experimental group from the pre-test (Mean=0.22, SD=0.06) to the post-test (Mean=0.10, SD=0.07) T=2.534, *P*=0.037 were significant (Table 3). Furthermore, in the examination of inter-group changes in post-test, the time to peak anterior-posterior force F=25.691, *P*=0.010 has a significant difference (Table 4).

The control group's time to peak mediolateral force did not alter between the pre-test (Mean=0.38, SD=0.09), and post-test (Mean=0.37, SD=0.15), indicating no intra-group differences T=0.122, *P*=0.549. But the experimental group's intra-group changes from the pre-test (Mean=0.39, SD=0.10) to the post-test (Mean=0.25, SD=0.20) were significant T=3.411, *P*=0.007 (Table 3). Furthermore, in the examination of inter-group changes in post-test, the time to peak mediolateral force F=31.542, *P*=0.001 has a significant difference (Table 4).

Table 2. Basic demographics of the subjects

Type of exercise	Phase 1	Phase 2	Phase 3	Phase 4	Phase 5
Lateral jumping progression	Lateral jump and hold	Lateral jumps	Lateral hop and hold	Lateral hops	10- hops
Single-leg anterior progression	Step-hold	Jump- single-leg hop	Hop hold	Hop-hop- hold	Crossover hop-hop- hold
Prone trunk stability progression	BOSU (round) toe-touch swimmers	BOSU (round) swimmers with partner perturbations	Prone bridge (elbows and knees) hip extension opposed shoulder flexion	Prone bridge (elbows and toes) hip extension	Prone bridge (elbows and toes) hip extension opposite shoulder flexion
Kneeling trunk stability progression	BOSU (round) double-knee-hold	BOSU (round) single-knee-hold	Swiss ball bilateral kneel	Swiss ball bilateral kneel with partner perturbations	Swiss ball bilateral kneel with lateral ball catch
Single-leg lateral progression	Single-leg lateral Airex hop hold	Single-leg lateral BOSU (round) hop hold	Single-leg lateral BOSU (round) hop hold with ball catch	Single-leg four-way BOSU (round) hop hold	Single-leg four-way BOSU (round) hop hold with ball catch
Tuck jump progression	Single tuck jump soft landing	Double tuck jump	Repeated tuck jump	Side-to-side tuck jump	Side-to-side reaction barrier tuck jump
Lunge progression	Front lunges	Walking lunges	Walking lunges unilaterally weighted	Walking lunges with plate crossover	Walking lunges with unilateral shoulder press
Lunge jump progression	Lange jumps	Scissor jumps	Lange jumps unilaterally weighted	Scissor jumps unilaterally weighted	Scissor jumps with ball swivel
Hamstring-specific progression	BOSU (flat) pelvic bridge	BOSU (flat) single-leg pelvic bridge	BOSU (flat) single-leg pelvic bridge	Supine Swiss ball hamstring curl	Russian hamstring curl with lateral touch
Single-leg rotatory progression	Single leg 90 hop hold	Single leg 90 Airex hop hold	Single leg 90 hop-hold reaction ball catch	Single leg 180 Airex hop hold	Single leg 180 Airex hop-hold reaction ball catch
Lateral trunk progression	BOSU (round) lateral crunch	Box lateral crunch	BOSU (round) lateral crunch with ball catch	Swiss ball lateral crunch	Swiss ball lateral crunch with ball catch
Trunk flexion progression	Box double crunch	Box swivel double crunch	BOSU (round) swivel ball touches (feet up)	BOSU (round) double crunch	BOSU (round) swivel crunch
Trunk extension progression	Swiss ball back hyperextensions	Swiss ball back hyperextensions with ball reach	Swiss ball hyperextensions with back fly	Swiss ball hyperextensions with ball reach lateral	Swiss ball hyperextensions with lateral ball catch

Table 3. Intra-group changes of the dependent t-test of kinetic variables

Groups	Variable (ms)	Pre-test	Post-test	T	*P*
		Mean±SD			
Control	TPKAPF	0.20±0.11	0.20±0.09	0.052	0.822
experimental		0.22±0.06	0.10±0.07	2.534	0.037*
Control	TPKMLF	0.38±0.09	0.37±0.15	0.122	0.549
experimental		0.39±0.10	0.25±0.20	3.411	0.007*
Control	TPKVF	0.25±0.04	0.26±0.11	0.134	0.465
experimental		0.25±0.07	0.13±0.24	2.985	0.028*
Control	RL (N)	0.48±0.17	0.49±0.15	0.116	0.573
experimental		0.49±0.19	0.35±0.54	3.877	0.004*

* Significantly difference; TPKAPF: Time to Peak Anterior-Posterior Force; TPKMLF: Time to Peak Mediolateral Force; TPKVF: Time to Peak Vertical Force, RL: Rate of Loading (N)

Table 4. Intergroup changes of covariance analysis of kinetic parameters

Groups	Variable (ms)	Post-test Mean±SD	F	df	*P*
Control	TPKAPF	0.20 ±0.09	25.691	1	0.010*
experimental		0.10 ±0.07			
Control	TPKMLF	0.37 ±0.15	31.542	1	0.001*
experimental		0.25 ±0.20			
Control	TPKVF	0.26 ±0.11	27.198	1	0.003*
experimental		0.13 ±0.24			
Control	RL (N)	0.49 ±0.15	36.747	1	0.001*
experimental		0.35 ±0.54			

* Significantly difference; TPKAPF; Time to Peak Anterior-Posterior Force, TPKMLF; Time to Peak Mediolateral Force, TPKVF; Time to Peak Vertical Force, RL; Rate of Loading (N).

The intra-group changes in the time vertical force of control group from the pre-test (Mean=0.25, SD=0.04) to the post-test (Mean=0.26, SD=0.11) T=0.134, *P*=0.465 which shows no significant difference in the changes within the group, it was the control group, while the changes within the experimental group from the pre-test (Mean=0.25, SD=0.07) to the post-test (Mean=0.13, SD=0.24) T=2.985, *P*=0.028 are significant (Table 3). Furthermore, in the examination of inter-group changes in post-test, the time to peak vertical force F=27. 198, *P*=0.003 has a significant difference (Table 4).

Intra-group changes in the rate of the loading control group from the pre-test (Mean=0.48, SD=0.17) to the post-test (Mean=0.49, SD=0.15) T=0.116, *P*=0.573 was provided, which shows no significant difference in intra-group changes. In control group, the intra-group changes of the experimental group from the pre-test (Mean=0.49, SD=0.19) to the post-test (Mean=0.35, SD=0.54) T=3.877, *P*=0.004 are significant (Table 3). Furthermore, in the examination of inter-group changes in post-test, the rate of the loading F=36.747, *P*=0.001 has a significant difference (Table 4).

4. Discussion

This research was designed to study the effect of trunk and hip neuromuscular training on a selection of kinetic variables of male athletes with trunk control defects during the change of direction maneuver. The findings of this research indicated the significant effect of neuromuscular training on the time to peak anterior-posterior force, time to peak mediolateral force, time to peak vertical force and rate of loading in the comparison of pre-test to post-test of the experimental group. While the pre-test to post-test comparison of noted variables in the control group was not significant. Moreover, by the comparison among the groups, the differences were significant only in comparing the post-tests, which indicates the effect of these exercises in the experimental group and their significant improvement in the post-test.

Thus, the findings of this research are similar to the findings of researchers like Ghaderi et al. (2021) [25], Letafatkar et al. (2020) [32], Rostami et al. (2020) [33], Mohamadpour et al. (2019) [34], Hewett et al. (2017) [35] are consistent.

Male athletes who had ACL repair were the subjects of Ghaderi et al.'s (2021) investigation on the effects of neuromuscular training employing an external focus of attention. Twenty-four male athletes were divided into two experimental groups (12 each) and a placebo control group (12 each). Finally, the researchers of this study concluded that neuromuscular training with an external focus of attention enhances landing biomechanics in patients following ACL surgery. The experimental subjects showed a reduction in the vertical force of the ground response [25].

Letafatkar et al. (2020) also looked at how neuromuscular training with a focus on knee valgus control advice affected the biomechanics of men runners' lower limbs. The effects of neuromuscular training with a focus on knee valgus control tools were investigated in 60 male runners divided into three groups of 20 (neuromuscular training, neuromuscular training with a focus on valgus control instructions, and placebo group). Neuromuscular training groups with and without instructions reported a decrease in injuries of 65.52% and 31.58%, respectively. The damage increased by 13.46% in the placebo group. The authors concluded that trained male runners' kinetic forces may be decreased with neuromuscular training that includes valgus control instructions. Additionally, it may be useful in lessening the damage caused by these persons [32].

After strengthening muscle structures during neuromuscular training, proprioceptive ability can be increased via the stimulation of muscle spindle and Golgi tendon organ [36]. Muscle spindles receive stimuli from static and dynamic gamma afferent neurons, and these exercises may increase the activity of gamma afferents, which, consequently, increases joint position sense, and correct activation patterns and actions [37].

According to the theory of system performance, which views the capacity to control body position in space as a result of the intricate interaction of the nervous system and the skeletal-muscular system, the influence of kinetic variables in subjects with trunk control defects through neuromuscular training is likely possible in this regard [36]. This posture control system views maintaining equilibrium and subsequently producing movement as needing the interference of sensory input to identify the location of the body in space and the capacity of the muscular-skeletal system to apply force. This hypothesis states that the biomechanical relationships between various components, muscle properties, and joint range of motion are all important skeletal-muscular elements in controlling body control [37].

The mechanisms that allow for the conversion of sensory stimulation into a nerve signal, transmission of that signal through afferent pathways to the central nervous system, integration of that signal by various brain centers, and motor responses that result in activity are collectively referred to as the sensory-motor system [38]. Muscles used for joint stability and performing functional tasks are considered to be muscular. Information communicated by joint afferents has a significant impact on information received by muscle spindles, which are muscle sensory receptors. Nerve afferents are significant movement control components. In other words, a joint-tendon-muscle interaction is represented by an efferent reaction to afferent signals that result in joint dynamic control [39].

As a result, the effect of afferent-efferent pathways as well as muscle sensory receptors may contribute to the improvement of kinematic variables in subjects as a result of neuromuscular training. Another factor may be the improvement in posture stability and stability of movement in subjects as a result of sports training, which is influenced by sensory organs that can also influence movement and posture [38].

In other words, the development of the central nervous system's ability to activate the muscles of the trunk and lower limbs, followed by the correction of the movement angles of the joints, may be related to the success of the exercises performed in the current study. By itself, this problem may improve the body's capacity to withstand ground reaction forces, ensuring that such forces are evenly distributed throughout the lower limbs and don't result in painful motions [39].

The coordination and interaction between the feedforward and feedback activity of the lower limb muscles, which results in the creation of suitable muscle stiffness in the lower limb muscles, actually allows for the response and reaction to the ground reaction forces during the change of direction. According to reports, the knee muscles' feedback activity occurs primarily as a reflex following foot contact with the ground [40].

According to scientific research, in contrast to the feed-forward activity of the muscles, which is mostly carried out by the nervous system's pre-designed programs, the feedback activity is primarily carried out spontaneously and in reaction to the information received. In actuality, the perception of location is a second regulator that affects the activation of muscle feedback [41]. The movements utilized in the exercises used in the current study create higher involvement of sensory receptors and continually engage and activate the sensory-motor system since they are often done in a closed movement chain. The knee joint has full proprioceptive receptors, which communicate with the neurological system through afferent signals. As a result, the nervous system responds to the joints' requests for movement by sending more exact movement orders [41].

Meanwhile, the results of the future study do not agree with those of Camacho (2019). This researcher looked at the neuromuscular risk factors for anterior cruciate ligament injury in female college soccer players as part of his study. He used a novel technique of central stability exercises and looked at the ground response force and other biomechanical variables in three dimensions before, during, and after central stability workouts for lateral cutting. The findings of this investigation did not reveal a statistically significant difference in the factors mentioned [42].

This discrepancy may be caused by several factors, including the length and type of exercises used (in the present study, the exercises were performed for 6 weeks and were neuromuscular, whereas the exercise in Camacho et al.'s study was a new method of central stability that was performed for 8 weeks, the subjects examined (in the present study, male athletes with trunk control deficits were examined, whereas Camacho' study concentrated on female college football players and their performance) [42].

In total, the neuromuscular training of the present study, probably through improving the proprioceptive information, increasing the integrity of this information, and accuracy in calling and coordinating the trunk and thigh muscles, has been able to establish the correct control of these areas in athletes with trunk control deficiency [25]. As a result, by correcting the abnormal and uncontrolled movement pattern due to the implementation of the stated exercises, has led to correct control and proper absorption of forces in the post-test of the present study [39].

It must be mentioned that this study has limitations like the impossibility of comparison with other neuromuscular defects such as ligament dominance and considering female athletes in the research. As a research proposal derived from the present study, it can be mentioned to compare the effect of neuromuscular training between female and male athletes with different neuromuscular defects such as trunk control defects, ligament dominance, etc.

5. Conclusions

The findings of the current study demonstrated that, in male athletes with trunk control deficits, 6 weeks of trunk and hip neuromuscular training can improve the kinetic variables in the task of changing direction, allowing for use in the rehabilitation and avoidance of potential injuries to these athletes' lower limbs.

Highlights

- Neuromuscular training of the trunk and hips in male athletes with trunk control defects can decrease the time to peak anterior-posterior ($F=9.691$, $P=0.004$), time to peak mediolateral ($F=11.342$, $P=0.008$) and time to peak vertical force ($F=8.798$, $P=0.033$).
- Neuromuscular training of the trunk and hips in male athletes with trunk control defects can decrease the rate of loading ($F=6.777$, $P=0.021$).

Plain Language Summary

One of the major neuromuscular deficits that may result in inconsistent muscle activation, appropriate movement patterns, energy transfer, establishing communication between the upper and lower limbs, and eventually injury to the lower limbs is a deficiency of trunk control. In this research, 29 male athletes with trunk control deficiencies were randomly split into two control groups (14 people) and an experimental group (15 people) using the functional jump rope test.

For 6 weeks, the experimental group engaged in 3 sessions of weekly hip and trunk neuromuscular training. Selected ground response force parameters that were measured using a force plate during the change of direction maneuver were examined in the pre-test and post-test. In male athletes with deficiencies in trunk control, neuromuscular training of the hips and trunk significantly improved and decreased the aforementioned variables in the experimental group. As a result, doing neuromuscular training might be thought of as helpful for protecting against and treating potential injuries in these athletes.

Conflict of interest

The authors declared no conflicts of interest.

Authors' contributions

All authors contributed to the original idea, study design.

Ethical considerations

The authors have completely considered ethical issues, including informed consent, plagiarism, data fabrication, misconduct, and/or falsification, double publication and/or redundancy, submission, etc. The participants were informed about the purpose of the research and its implementation stages; they were also assured of the confidentiality of their information. Moreover, they were allowed to leave the study whenever they wanted, and if desired, the results of the research would be available to them.

Data availability

The dataset generated and analyzed during the current study is available from the corresponding author on reasonable request.

Funding

This research did not receive any grant from funding agencies in the public, commercial, or non-profit sectors.

Acknowledgment

This article reports the results of Behnam Moradi's doctoral dissertation in the field of sports pathology and corrective exercise of the Faculty of Physical Education, Kharazmi University, Tehran. The authors would like to thank all the participants who contributed to the study.

References

[1] Prodromos C, Joyce B, Shi K. “A meta-analysis of stability of autografts compared to allografts after anterior cruciate ligament reconstruction”. *Knee Surgery, Sports Traumatology, Arthroscopy*. 2007; 15: 851-6. doi: https://doi.org/ 10.1007/s00167-007-0328-6.

[2] Ardern CL, Webster KE, Taylor NF, Feller JA. “Return to sport following anterior cruciate ligament reconstruction surgery: a systematic review and meta-analysis of the state of play”. *British Journal of Sports Medicine*. 2011; 45(7): 596-606. doi: https://doi.org/10.1136/bjsm.2010.076364.

[3] Kiapour AM, Murray MM. “The basic science of anterior cruciate ligament injury and repair”. *Bone & Joint Research*. 2014; 3(2): 20-31. doi: https://doi.org/10.1302/2046 3758.32.2000241.

[4] Kessler MA, Behrend H, Henz S, Stutz G, Rukavina A, Kuster MS. “Function, osteoarthritis and activity after ACL-rupture: 11 years follow-up results of conservative versus reconstructive treatment”. *Knee Surgery, Sports Traumatology, Arthroscopy*. 2008; 16: 442-8. doi: https://doi.org/10.1007/s00167-008-0498-x.

[5] Joseph AM, Collins CL, Henke NM, Yard EE, Fields SK, Comstock RD. “A multisport epidemiologic comparison of anterior cruciate ligament injuries in high school athletics”. *Journal of Athletic Training*. 2013; 48(6): 810-7. doi: https://doi.org/10.4085/1062-6050-48.6.03.

[6] Boden BP, Sheehan FT, Torg JS, Hewett TE. “Non-contact ACL injuries: Mechanisms and risk factors”. *The Journal of the American Academy of Orthopaedic Surgeons*. 2010; 18(9): 520. doi: https://doi.org/10.5435/00124635-201009000-00003.

[7] Kubo T, Hoshikawa Y, Muramatsu M, Iida T, Komori S, Shibukawa K, Kanehisa H. “Contribution of trunk muscularity on sprint run”. *International Journal of Sports Medicine*. 2010: 223-8. doi: https://doi.org/10.1055/s-0030-1268502.

[8] Pollard CD, Sigward SM, Ota S, Langford K, Powers CM. “The influence of in-season injury prevention training on lower-extremity

kinematics during landing in female soccer players". *Clinical Journal of Sports Medicine*. 2006; 16(3): 223-7.
[9] Hewett TE, Ford KR, Hoogenboom BJ, Myer GD. "Understanding and preventing ACL injuries: current biomechanical and epidemiologic considerations-update 2010". *North American Journal of Sports Physical Therapy: NAJSPT*. 2010; 5(4): 234. doi: https://doi.org/PMID: 21655382; PMCID: PMC3096145.
[10] Madhavan S, Shields RK. "Movement accuracy changes muscle-activation strategies in female subjects during a novel single-leg weight-bearing task". *PM&R*. 2009; 1(4): 319-28. doi: https://doi.org/10.1016/j.pmrj.2009.01.002.
[11] Chappell JD, Limpisvasti O. "Effect of a neuromuscular training program on the kinetics and kinematics of jumping tasks". *The American Journal of Sports Medicine*. 2008; 36(6): 1081-6. doi: https://doi.org/10.1177/0363546508314425.
[12] Robinson RL, Nee RJ. "Analysis of hip strength in females seeking physical therapy treatment for unilateral patellofemoral pain syndrome". *Journal of Orthopedic & Sports Physical Therapy*. 2007; 37(5): 232-8. doi: https://www.jospt.org/doi/10.2519/jospt.2007.2439.
[13] Brumitt J, Dale RB. "Functional rehabilitation exercise prescription for golfers". *International Journal of Athletic Therapy and Training*. 2008; 13(2): 37-41. doi: https://doi.org/10.1123/att.13.2.37.
[14] Young WB, Dawson B, Henry GJ. "Agility and change-of-direction speed are independent skills: Implications for training for agility in invasion sports". *International Journal of Sports Science & Coaching*. 2015; 10(1): 159-69. doi: https://doi.org/10.1260/1747-9541.10.1.159.
[15] Karcher C, Buchheit M. "On-court demands of elite handball, with special reference to playing positions". *Sports Medicine*. 2014; 44: 797-814. doi: https://doi.org/10.1007/s40279-014-0164-z .
[16] Nimphius S, Callaghan SJ, Bezodis NE, Lockie RG. "Change of direction and agility tests: Challenging our current measures of performance". *Strength & Conditioning Journal*. 2018; 40(1): 26-38. doi: https://doi.org/10.1519/SSC.0000000000000309.
[17] Brophy RH, Stepan JG, Silvers HJ, Mandelbaum BR. "Defending puts the anterior cruciate ligament at risk during soccer: a gender-based analysis". *Sports Health*. 2015; 7(3): 244-9. doi: https://doi.org/10.1177/1941738114535184.
[18] Montgomery C, Blackburn J, Withers D, Tierney G, Moran C, Simms C. "Mechanisms of ACL injury in professional rugby union: a systematic video analysis of 36 cases". *British Journal of Sports Medicine*. 2018; 52(15): 994-1001. doi: http://dx.doi. org/10.1136/bjsports-2016-096425.
[19] Ambegaonkar JP, Cortes N, Caswell SV, Ambegaonkar GP, Wyon M. "Lower extremity hypermobility, but not core muscle endurance influences balance in female collegiate dancers". *International Journal of Sports Physical Therapy*. 2016; 11(2): 220. doi: http://dx.doi. org/PMID: 27104055; PMCID: PMC4827365.
[20] Read PJ, Oliver JL, Dobbs IJ, Wong MA, Kumar NT, Lloyd RS. "The effects of a four-week neuromuscular training program on landing kinematics in pre-and post-peak height velocity male athletes". *Journal of Science in Sport and Exercise*. 2021; 3: 37-46. doi: https://doi.org/10.1007/s42978-020-00097-8.
[21] Mohammadi H, Ghaeeni S. "Prevalence of neuromuscular deficiencies associated with non-contact anterior cruciate ligament injury in healthy collegiate student-athletes". *Physical Treatments*. 2019; 9(4): 193-202. http://dx.doi. org/10.32598/ptj.9.4.193.
[22] Mirjamali E, Minoonejad H, Seidi F, Samadi H. "Comparison of the effects of core stability training on stable and unstable levels on the static and dynamic balance of female athletes with trunk dysfunction". *The Scientific Journal of Rehabilitation Medicine*. 2019; 8(1): 61-70. doi: https://doi.org/10.22037/jrm.2018.111331.1920.
[23] Hadadnezhad M, Rajabi R, Jamshidi AA, Shirzad E. "Effect of stabilization training on trunk muscle activation of females with trunk control deficit". *Studies in Sport Medicine*. 2015; 7(17): 68-51. doi: https://doi.org/20.1001.1.23221658.1394.7.17.3.7.
[24] Welinski ML, Lee LN, McBroom B, Mufarreh B, Gidley AD. "Ground reaction forces and temporal characteristics define cutting performance". *International Journal of Exercise Science*. 2021; 14(1): 211. doi: https://doi.org/PMID: 34055139; PMCID: PMC8136564.
[25] Ghaderi M, Letafatkar A, Thomas AC, Keyhani S. "Effects of a neuromuscular training program using external focus attention cues in male athletes with anterior cruciate ligament

reconstruction: A randomized clinical trial". *BMC Sports Science, Medicine, and Rehabilitation*. 2021; 13(1): 1. doi: https://doi.org/10.1186/s13102-021-00275-3.

[26] McKinney J, Velghe J, Fee J, Isserow S, Drezner JA. "Defining athletes and exercisers". *The American Journal of Cardiology*. 2019; 123(3): 532-5. doi: https://doi.org/10.1016/j.amjcard.2018.11.001.

[27] Myer GD, Ford KR, Khoury J, Succop P, Hewett TE. "Development and validation of a clinic-based prediction tool to identify female athletes at high risk for anterior cruciate ligament injury". *The American Journal of Sports Medicine*. 2010; 38(10): 2025-33. doi: https://doi.org/10.1177/0363546510370933.

[28] Naserpour H, Khaleghi Tazji M, Letafatkar A. "Immediate effect of cryotherapy on the kinetic factors associated with injury during the side-cutting maneuver in healthy male athletes: Pilot study". *The Scientific Journal of Rehabilitation Medicine*. 2020; 9(2): 1-8. doi: https://doi.org/10.22037/jrm.2020.113786.2436.

[29] Ishida, T., Yamanaka, M., Takeda, N., Homan, K., Koshino, Y., Kobayashi, T., ... Aoki, Y. "The effect of changing the direction on knee kinematics during drop vertical jump: a possible risk factor for anterior cruciate ligament injury". *Knee Surgery, Sports Traumatology, Arthroscopy*. 2015; 23(4): 1004-1009. doi: https://doi.org/10.1007/s00167-013-2815-2.

[30] Hader K, Palazzi D, Buchheit M. "Change of direction speed in soccer: how much braking is enough?"s *Kinesiology*. 2015; 47(1): 67-74. doi: https://hrcak.srce.hr/140253.

[31] Myer GD, Ford KR, Hewett TE. "Tuck jump assessment for reducing anterior cruciate ligament injury risk". *International Journal of Athletic Therapy and Training*. 2008; 13(5): 39-44. doi: https://doi.org/10.1123/att.13.5.39.

[32] Letafatkar A, Rabiei P, Afshari M. "Effect of neuromuscular training augmented with knee valgus control instructions on lower limb biomechanics of male runners". Physical *Therapy in Sport*. 2020; 43: 89-99. doi: https://doi.org/10.1016/j.ptsp.2020.02.009.

[33] Rostami A, Letafatkar A, Gokeler A, Tazji MK. "The effects of instruction exercises on performance and kinetic factors associated with lower-extremity injury in landing after volleyball blocks". *Journal of Sport Rehabilitation*. 2020; 29(1): 51-64. doi: https://doi.org/10.1123/jsr.2018-0163.

[34] Mohamadpour F, Letafatkar A, Eftekhari F. "The effect of neuromuscular training on postural stability and performance of lower extremity in females with ligament dominance. *Sport Medicine Studies*. 2019; 10(24): 29-42. doi: https://doi.org/10.22089/smj.2018.4666.1268. [in Persian]

[35] Hewett TE, Ford KR, Xu YY, Khoury J, Myer GD. "Effectiveness of neuromuscular training based on the neuromuscular risk profile". *The American Journal of Sports Medicine*. 2017; 45(9): 2142-7. doi: https://doi.org/10.1177/0363546517700128.

[36] Kaminski TW, Buckley BD, Powers ME, Hubbard TJ, Ortiz C. "Effect of strength and proprioception training on eversion to inversion strength ratios in subjects with unilateral functional ankle instability". *British Journal of Sports Medicine*. 2003; 37(5): 410-5. doi: https://doi.org/10.1136/bjsm.37.5.410.

[37] Sekir U, Yildiz Y, Hazneci B, Ors F, Aydin T. "Effect of isokinetic training on strength, functionality and proprioception in athletes with functional ankle instability". *Knee Surgery, Sports Traumatology, Arthroscopy*. 2007; 15: 654-64. doi: https://doi.org/10.1007/s00167-006-0108-8.

[38] Mettler A, Chinn L, Saliba SA, McKeon PO, Hertel J. "Balance training and center-of-pressure location in participants with chronic ankle instability". *Journal of Athletic Training*. 2015; 50(4): 343-9. doi: https://doi.org/10.4085/1062-6050-49.3.94.

[39] Webster KA, Gribble PA. "Time to stabilization of anterior cruciate ligament–reconstructed versus healthy knees in National Collegiate Athletic Association Division I female athletes". *Journal of Athletic Training*. 2010; 45(6): 580-5. doi: https://doi.org/10.4085/1062-6050-45.6.580.

[40] Webster KA, Gribble PA. "Functional rehabilitation interventions for chronic ankle instability: a systematic review". *Journal of Sport Rehabilitation*. 2010; 19(1): 98-114. doi: https://doi.org/10.1123/jsr.19.1.98.

[41] Lederman E. Neuromuscular Rehabilitation in Manual and Physical Therapy: Principles to Practice. Elsevier Churchill Livingstone. 2016.

[42] Camacho A. The Effects of a Novel Core Stability Training Program on Neuromuscular Anterior Cruciate Ligament Risk Factors in Female Collegiate Soccer Players. California State University, Long Beach. 2019. doi: https://doi.org/1088323677, 9781088323670.