Asian J Sports Med. 2019 June; 10(2):e82011. doi: 10.5812/asjsm.82011.

Published online 2019 June 2. Research Article

The Effect of Ankle TheraBand Training on Dynamic Balance Index Among Elite Male Basketball Players

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Received 2018 July 11; **Revised** 2019 March 28; **Accepted** 2019 April 12.

Abstract

Objectives: The purpose of this study is to determine the effect of ankle TheraBand resistance training on dynamic balance index among elite male basketball players.

Methods: This was a randomized trial performed on 24 male professional basketball players without lower extremity injury. The participants were selected using purposeful sampling and were randomly assigned into 3 groups of 8, including: (1) high-intensity resistance training using TheraBand (80% - 95% 1RM), (N = 8); (2) moderate-intensity resistance training using TheraBand (65% - 80% 1RM), (N = 8); and (3) control group with regular basketball training (N = 8). The groups were trained in three sessions for 8 weeks. Trial and error table for TheraBand resistance from American Physical Therapy Organization (APTA) 2012 was used to measure maximum 1RM in each participant. In addition, the dynamic balance index in the APSI (anterior - posterior stability index), MLSI (medial-lateral stability index) and OSI (overall stability index) were measured using Biodex stability system. Covariance analysis was used to analyze the data ($P < 0.05$).

Results: Results showed that the high-intensity resistance training and moderate-intensity resistance training significantly improved dynamic stability index in the anterior - posterior axis, medial - lateral axis and overall axis ($P = 0.0001$). No significant changes were observed in the anterior - posterior and medial - lateral axes after a detraining period (4 weeks), "durability rate". However, the overall axis values of the dynamic balance index in the moderate intensity training group indicated a higher durability rate than the high intensity resistance training group after detraining ($P = 0.02$).

Conclusions: It can be concluded that the high and moderate intensity resistance training improved dynamic balance index, and even moderate intensity resistance training was effective after a period of detraining, so it can be recommended for basketball players.

Keywords: Strength Training, Dynamic Balance, Neuromuscular Coordination, Elite Basketball Players

1. Background

Maintaining balance is a necessity in the activities of daily life and athletic performance enhancement and is an inseparable part of the daily activities and an important index in the evaluation of athletes' performance improvement (1).

Professional basketball players, whose performance was better in shooting, demonstrated a better control over their posture (Barbieri et al. 2017).

However, maintaining enough balance during activity to generate enough force applied to the muscles and body levers require a complex interaction involving the musculoskeletal and nervous systems (2). According to the general classification, balance is divided into static, semi-dynamic and dynamic categories (3). Dynamic balance can be defined as the individual's ability to maintain the body's center of gravity within the surface mobile reliance (3, 4). The ankle joint plays a significant role in restoring and maintaining a person's body balance as a major portion of proprioceptive function (5). While exposed to its disruptive factors, poor balance can lead to injuries, including pain, sprains in ankle and knee as well as joint stiffness (6). A weaker control over the posture in university basketball players has been considered a hazardous factor for ankle sprain (Verhoeven et al., 2016).

Therefore, a number of studies have been conducted to examine the effect of designing resistance exercise programs to improve balance, body movements control, improved record and sports injury prevention (7). Although neuromuscular adaptations including activation of agonist muscles (muscle favoring motion) and inhibition of antagonist muscle (muscle opposing movement) play an important role in the increased muscle strength in a wide variety of sports including basketball (8, 9); there have been a number of studies focusing on the impact of resistance training on balance levels using free weights or different devices, and the effect of elastic resistance training on the dynamic balance index has received less attention from the researchers. Thus, we hypothesize that TheraBand resistance training (elastic training) is a suitable method for improvement of muscle strength in four directions of ankle movement rather than free weight or different machines training.

2. Objectives

The aim of the present study was to investigate the effect of ankle resistance training among elite basketball player using TheraBand, in two high and moderate intensity groups and its durability rate, on the dynamic balance index.

3. Methods

The present randomized trial study with a pretest and posttest design was performed on 24 basketball players of an Iran Premier league club who were selected using a purposeful sampling method. They were randomly (randomization was done independently by drawing lots) assigned into three groups including: (1) high-intensity resistance training using TheraBand (80% - 95% 1RM); (N = 8); (2) moderate-intensity resistance training using TheraBand (65% - 80% 1RM); (N = 8); and (3) control group with regular basketball training (N = 8). After selecting the participants, the testing process, measurement steps and objectives of the study were completely explained to the participants and the written consent form was signed by each participant. The inclusion criteria were: competition in the professional league, no injury to the ankle and surgery in the lower extremities during the past year, and lack of neurological disturbances (without visual and vestibular disorders). The exclusion criteria included: lack of cooperation in the process of data collection and injury occurrence. The general characteristics of the participants under the study are presented in Table 1.

3.1. Dynamic Balance Assessment

First, the participants of each of the three groups referred by the Iran Sports Medicine Federation were managed on scheduled times and were coordinated by the conditioning trainer and club team manager in order to participate in the pre-test. This included a dynamic balance test on the dominant foot (the primary foot used to kick the ball) using the Biodex stability system over the course of one week. The dynamic balance was measured by Biodex stability system ("945-302 BSS"). It should be noted that the Biodex stability system (BSS) measures the stability index in two anterior-posterior, medial - lateral axes and overall axis, respectively. In addition, since BSS focuses on the proprioceptive neuromuscular mechanism, it can affect the unilateral, bilateral, and dynamic postural control of the joint and assess the individual's neuromuscular control. It has eight difficulty levels (rigidness with level 8 as the lowest intensity rate and level 1 the most intensive rate). The BSS with difficulty level 2 was applied. First as a warm-up exercise, the participants ran on the treadmill for 10 minutes at a speed of 8 - 8.5 km/h to prepare and generate the appropriate neuromuscular coordination needed for the administration of the dynamic balance assessment. To get familiarized with the training program, the participants were asked to stand on the apparatus with their dominant leg three times for 20 seconds. After a rest period of 3 minutes, the participants performed a dynamic balance test by standing on their dominant leg on the BSS for 20 seconds and tried to maintain their balance during this period. If each athlete was not able to maintain his balance in 20 seconds on one foot, use the other foot for stability or lost their balance, there was only one chance for the participant to repeat the test. The number registered on the device was taken as the evaluation criterion and recorded as data. The dynamic balance index including anterior- posterior axis, medial-lateral axis, and overall stability axis were measured and recorded applying the Biodex stability system for each of the three groups.

3.2. Training Program

The first and second groups participated in a resistance training program with TheraBand to strengthen the ankle muscles at the gym and had been instructed on how to perform the training program phases through a supervised club conditioning trainer. A trial and error method was used to determine the one-repetition maximum (1RM) for each athlete (Shariatet al.2015). A set of TheraBands with different colors, elasticity and resistance levels were used and the color of TheraBand and its elasticity for the athlete was chosen in such a way that the participant was not able to perform more than one repetition of each movement

Table 1. Descriptive Statistics of Participants' Characteristics in Terms of Central Tendency and Dispersion Indicators[a]

	Age (y)	Height (cm)	Weight (kg)	BMI
Moderate intensity training	26 ± 3	193 ± 2.5	95 ± 3	24.16 ± 2
High intensity training	27 ± 2.5	194 ± 3	93 ± 2.5	24.71 ± 3
Control	26.5 ± 3	196 ± 1.8	95 ± 3	24.73 ± 2.5

[a]Values are expressed as mean ± SD.

from each muscular group (7 colors: yellow, red, green, blue, black, silver, and gold, with a resistance rate of 0.5, 0.7, 0.9, 1.3, 1.6, 2.3, and 3.6 kg, respectively). With an increased rate in the elastic length (25, 50, 75, 100, 125, 150, 175, 200, 225, and 250%), the resistance of the TheraBand was also increased. The maximum resistance (1RM) (kg) for each athlete (depending on the color and percentage of elasticity) was determined using the TheraBand resistance table from the American Physical Therapy Association (APTA 2012). The percentage of training load was designed based on the training tables for both the first and second groups (Table 2).

It should be noted that the training program was administered for all intervention groups for three sessions a week (in the morning on Saturdays, Mondays, and Wednesdays). The high intensity exercise with TheraBand was performed with the first group in the following order. The first two weeks, consist of 3 sets of 10 repetitions at 80% of the 1RM, the second two weeks, consist of 3 sets of 10 repetitions at 85% of the 1RM, the third two weeks, consist of 3 sets of 10 repetitions at 90% of the 1RM, the fourth two weeks, consist of 3 sets of 10 repetitions at 95% of the 1RM. The rest period between each set was designated as 1 minute. The training program in the second group (moderate intensity training) was performed as follows:

The first two weeks, consist of 3 sets of 20 repetitions at 65% of the 1RM, the second two weeks, consist of 3 sets of 20 repetitions at 70% of the 1RM, the third two weeks, consist of 3 sets of 20 repetitions at 75% of the 1RM, the fourth two weeks, consist of 3 sets of 20 repetitions at 80% of the 1RM and the rest period between each set was designated as 1 minute.

In order to perform plantar flexion, dorsiflexion, inversion, and eversion movements, the participant first sat on the ground with both legs straight out, fastened one side of the resistance TheraBand to a stationary object and the other side fastened around the foot. The participant moved their foot in a forward, backward, inward, and outward twisted based on the amount of load and elasticity. This was performed with repetitive sets and resting periods according to the training program. After 8 weeks of the training program, the dynamic balance of the participants was immediately measured during a 3-day period in order to record the post-test values by BSS. The process replicated the same procedures as the pretest phase.

3.3. Durability Rate of Dynamic Balance Index in the Participants

To determine the durability rate (after 4 weeks of the detraining period), dynamic balance of the participants in each of the 3 groups was measured for the third time according to the pattern in the pre and posttests. It should be noted that the participants did not receive any training intervention during this period and performed their regular basketball exercise.

3.4. Statistical Analysis

All data collected was reported in the text, figures and tables using mean and standard deviation. Covariance analysis was used to determine the effect of the training program. Bonferroni post hoc test was used for the analysis of significant difference. The statistical significance level was considered ($P \leq 0.05$) at all stages. Data was analyzed using SPSS software version 20.

4. Results

According to the results, training had a significant effect on the dynamic balance index in the anterior - posterior axis ($F\,2, 30 = 23.433$, 0.0101, $P = 0.0001$, $\eta = 0.701$), so that a significant reduction was observed in the numerical values of the stability index (dynamic balance improvement) in the anterior-posterior axis. In addition, the Bonferroni test indicated that training with high ($P = 0.0001$) and moderate intensities ($P = 0.0001$) resulted in the improvement of the dynamic balance index in anterior-posterior axis. However, no difference was found between the two intensities of training (Figure 1). The intensity of training did not have a significant effect on the stability index in the anterior - posterior axis of the participants. Both high and medium intensity exercises resulted in the reduction of numerical values of the stability index (dynamic balance improvement) in the anterior - posterior directions.

It should be noted that in the dynamic balance test, the lower of numerical values of the balance index, the better the balance is (the more favorable balance index).

No significant difference was observed between the stability index in both interventional groups with high

Table 2. APTA TheraBand Resistance Table Based on Color and Resistance Scale (Resistance in kg)

Elasticity Percentage	Gold	Silver	Black	Blue	Green	Red	Yellow
25	3.6	2.3	1.6	1.3	0.9	0.7	0.5
50	6.3	3.9	2.9	2.1	1.5	1.2	0.8
75	8.2	5.0	3.7	2.7	1.9	1.5	1.1
100	9.8	6.0	4.4	3.2	2.3	1.8	1.3
125	11.2	6.9	5.0	3.7	2.6	2.0	1.5
150	12.5	7.8	5.6	4.1	3.0	2.2	1.8
175	13.8	8.6	6.1	4.6	3.3	2.5	2.0
200	15.2	9.5	6.7	5.0	3.6	2.7	2.2
225	16.6	10.5	7.4	5.5	4.0	2.9	2.4
250	18.2	11.5	8.0	6.0	4.4	3.2	4.6

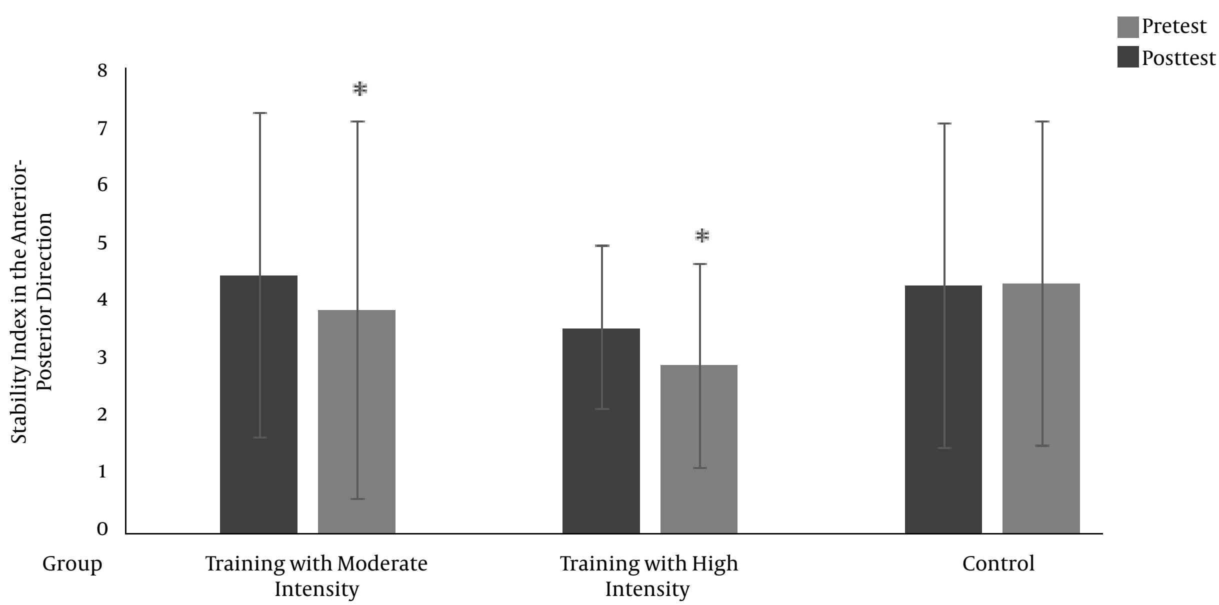

Figure 1. Effect of resistance training intensity on the stability index in the anterior-posterior direction. * indicates a significant decrease compared to the control group. Data are reported based on average and standard deviation.

and moderate intensities after 4 weeks at the end of the training (durability rate) in the anterior - posterior axis (F 2, 20 = 1.296, P = 0.296, η = 0.115) (Table 3).

The intensity of training in the medial - lateral axis had the same effect on the dynamic balance index in the anterior-posterior axis, that the training significantly improved the dynamic balance index in the medial-lateral axis (F 2, 20 = 61.549, P = 0.0001, η = 0.860).

The stability index in the medial - lateral axis in the groups with high (P = 0.0001) and moderate intensity trainings (P = 0.0001) indicated a significant difference compared to the control group. The intensity of training did not have a significant impact on the stability index in the medial-lateral axis. That is both high and medium intensity trainings reduced the numerical values of the medial - lateral axis (dynamic balance improvement).

No significant difference was observed between the stability index in both interventional groups with high and moderate intensities after 4 weeks at the end of the training (durability rate) in the medial - lateral axis (F 2, 20 = 1.477, P = 0.252, η = 0.129) (Table 4).

Training resulted in a significant reduction in numerical values (dynamic balance improvement) of the dynamic balance index in the overall axis (F 2, 20 = 27.231, P = 0.0001, η = 0.732). However, training with high (P = 0.0001) and moderate (P = 0.0001) intensities had an equal effect.

The intensity of training had a significant effect on the dynamic balance index (F 2, 20 = 5.008, P = 0.017, η = 0.334), so that the durability rate in the overall axis in the group with moderate intensity was significantly higher than the group with high intensity (Table 5).

Table 3. Effect of Resistance Training Intensity on the Stability Index in the Anterior - Posterior Axis[a]

	Pretest	Posttest	After 4 Weeks
Moderate intensity training	4.42 ± 3.22	3.82 ± 2.78[b]	4.35 ± 3.04
High intensity training	3.52 ± 1.74	2.88 ± 1.39[b]	2.98 ± 1.41
Control	4.25 ± 2.77	4.27 ± 2.78	4.71 ± 2.05

[a]Values are expressed as mean SD.
[b]Indicates a significant decrease compared to the control group.

Table 4. Effect of Resistance Training Intensity on the Stability Index in the Medial - Lateral Axis[a]

	Pretest	Posttest	After 4 Weeks
Moderate intensity training	3.01 ± 1.34	2.38 ± 1.07[b]	2.85 ± 1.06
High intensity training	2.68 ± 1.14	2.05 ± 0.82[b]	2.17 ± 0.79
Control	2.72 ± 1.04	2.76 ± 0.99	2.85 ± 0.5

[a]Values are expressed as mean SD.
[b]Indicates a significant decrease compared to the control group.

Table 5. Effect of Resistance Training Intensity on the Stability Index in the Overall Axes[a]

	Pretest	Posttest	After 4 Weeks
Moderate intensity training	5.23 ± 3.33	4.32 ± 2.76[b]	4.92 ± 2.89[b]
High intensity training	4.26 ± 1.97	3.38 ± 1.52[b]	3.57 ± 1.59
Control	4.97 ± 3.08	4.97 ± 3.07	4.86 ± 2.28

[a]Values are expressed as mean SD.
[b]Indicates a significant decrease compared to the control group.

5. Discussion

Sensory-motor system responses have a different impact on the improvement of the dynamic balance index according to the type and intensity of exercise (10). A number of studies have shown that resistance and proprioception training positively influence the individual's ability to maintain dynamic equilibrium (11). According to the findings of the present study, resistance training using Thera-Band led to an improvement of stability index in the anterior - posterior, medial - lateral axes and overall axes. Furthermore, no significant difference was found considering the durability rate of the stability index in both training groups with high and moderate intensity in the anterior - posterior and medial - lateral axes. Moderate resistance training resulted in a higher durability rate in the overall dynamic balance axis, which was not found in the training group with high intensity. Several studies have demonstrated that the development and maintenance of balance in relation to the exercise task reveals its effect on the function of sensory - motor receptors and nerve and muscle adaptations (12, 13). According to the results of our study, different levels of equilibrium can be attributed to the effective and improved contribution of moderate - intensity resistance training on the enhanced response of the balance axes among the elite basketball players. In fact, it was obvious that the improvement in balance may be effective for a reduction of acute ankle sprain in elite basketball players. Dynamic equilibrium resulting from resistance training, along with the optimum development of various components of the sensory - motor system and the central processor followed by the integration of information derived from various senses, might be associated with various motor functions, flexible and adjustable behaviors after the exercise (14, 15). Numerous studies have found that mechanical, functional instability or a combination of both predispose participants to frequent ankle injuries due to weak muscles and joints (16, 17). Many studies have suggested that proprioceptive exercises improve the functioning of the athlete's ankle in basketball and soccer players, which may enhance stability of the anterior-posterior and medial - lateral axes resulting in less injuries (18-20). Proprioceptive information from the ankle joint has a significant contribution in maintaining overall body balance and stability of the local areas, including the range of joint function and motion (15, 21). In addition, according to the results of the study by Akuthota (1997), resistance training may lead to the improved function of the nervous mechanisms exerted from the spinal cord to co-activate agonist muscles compared to the antagonist muscles. Facilitation in the integrated responses to the large fast-twitch motor units (22), stimulation of muscle spindles, self-inhibition of golgi tendon organ and increased gamma efferent nerve activity have been regarded as the reasons for improved balance after resistance training and consequently improvement of joint function (23). However, some researchers believe that resistance training does not have any impact on the equilibrium levels due to the different type, severity, duration of training, and characteristics of the participants (24). Other researchers have acknowledged the positive impact of resistance training on the improvement of static equilibrium (25). Regarding the training type, the results of some studies have shown the impact of plyometric strength training on improving neuromuscular changes and dynamic balance among the female athlete (26). In addition, some studies have shown that hopping strength training leads to enhanced competitive performance of athletes (27). Because of the initial explosive tensions with hopping exercises in the muscle, joint stability, balance, and proprioceptive sense can play an effective role in promoting neural efficacy so increasing the ability of an individual to control the muscle's contraction and lead to improved power as well as providing an appropriate feedback (28). More powerful concentric muscle contractions can lead to better performance, reflected in the type of resistance training (29). Some studies have shown the effect of combined balance exercises along with plyometric exercises in different directions in decreasing ankle instability and increasing athlete's posture control (27). Other studies have also suggested the positive effects of resistance exercises on the increased balance through strengthening the ligaments, stability of the joints and the stimulation of the proprioceptive sense can be effective in preventing sports injuries and the rehabilitation of athletes (30, 31). It is worth mentioning that many studies have focused on the assessment of the effect of resistance training on the improvement of static equilibrium. Their results indicated that the effect of resistance training on the improvement of dynamic balance which different impacts based on the training type (4). As described above, the type of exercise will lead to the development of different neuromuscular adaptation responses in athletes. According to the results of our study, moderate - intensity resistance training was effective in the durability rate of stability index including the overall dynamic balance axes that can be attributed to the intensity of training. Some inconsistent results have been mentioned regarding the effectiveness of dynamic balance using resistance trainings based on the exercise types. However, basketball players often perform fundamental skills with high acceleration and maximum speed, including passes, shots and dribbles with their upper extremities and jumping - landing maneuvers using high speed and power with a need to a rapidly change of direction. This can lead to alterations in the capacity and structure of the cells and adaptation in their neuromuscular structure which can influence their reflective and volitions activities (32, 33). Based on the results of this study, moderate resistance training using TheraBand can be effective in preventing sports injuries in maintaining the proprioceptive sense of the ankle receptors, and improving nerve and muscle responses in basketball players, and these results are heavily dependent on the intensity of training.

4.1. Conclusions

The results of this study indicated that resistance training can lead to the improvement of balance in intervention groups but there was no significant difference in the dynamic balance index between resistance training with high and moderate intensity using TheraBand. In addition, the overall durability rate of the stability index was found to be higher in the training with moderate intensity. Therefore, it is recommended that basketball players use moderate intensity training to gain further favorable outcomes in the competition and improve and maintain the balance.

Acknowledgments

This article was extracted from a part of the Ph.D. thesis on sport injuries and corrective exercises at Isfahan University. The authors wish to express their sincere gratitude to the participants and staff of the Sports Medicine Federation of Islamic Republic of Iran for their contribution to this study.

Footnotes

Authors' Contribution: All authors contributed in the study designing, data collections, and writing the manuscript.

Conflicts of Interests: The authors have no conflict of interests to declare.

Ethical Considerations: It is not declared by the authors.

Funding/Support: There was no funding/support for this study.

References

1. Akuthota V, Nadler SF. Core strengthening. *Arch Phys Med Rehabil*. 2004;**85**:86–92. doi: 10.1053/j.apmr.2003.12.005.
2. Gribble PA, Hertel J, Denegar CR. Chronic ankle instability and fatigue create proximal joint alterations during performance of the Star Excursion Balance Test. *Int J Sports Med*. 2007;**28**(3):236–42. [PubMed: 17447273].
3. Punakallio A. Trial-to-trial reproducibility and test-retest stability of two dynamic balance tests among male firefighters. *Int J Sports Med*. 2004;**25**(3):163–9. doi: 10.1055/s-2003-45251. [PubMed: 15088238].

4. Mahieu NN, Witvrouw E, Van de Voorde D, Michilsens D, Arbyn V, Van den Broecke W. Improving strength and postural control in young skiers: Whole-body vibration versus equivalent resistance training. *J Athl Train*. 2006;**41**(3):286–93. [PubMed: 17043697]. [PubMed Central: PMC1569559].
5. Testerman C, Vander Griend R. Evaluation of ankle instability using the Biodex Stability System. *Foot Ankle Int*. 1999;**20**(5):317–21. doi: 10.1177/107110079902000510. [PubMed: 10353771].
6. Kisner C, Colby LA. *Therapeutic exercise: Foundations and techniques*. F.A. Davis Company; 2012.
7. Rozzi SL, Lephart SM, Sterner R, Kuligowski L. Balance training for persons with functionally unstable ankles. *J Orthop Sports Phys Ther*. 1999;**29**(8):478–86. doi: 10.2519/jospt.1999.29.8.478. [PubMed: 10444738].
8. Komi PV. Physiological and biomechanical correlates of muscle function: Effects of muscle structure and stretch-shortening cycle on force and speed. *Exerc Sport Sci Rev*. 1984;**12**:81–121. [PubMed: 6376140].
9. Spurrs RW, Murphy AJ, Watsford ML. The effect of plyometric training on distance running performance. *Eur J Appl Physiol*. 2003;**89**(1):1–7. doi: 10.1007/s00421-002-0741-y. [PubMed: 12627298].
10. Rosendahl E, Littbrand H, Lindelof N, Lundin-Olsson L, Yngve G, Nyberg L. A high-intensity functional exercise program is applicable for older people with cognitive impairment. *Research and practice in Alzheimer's disease*. Paris: Serdi Publisher; 2007. p. 212–5.
11. Mattacola CG, Lloyd JW. Effects of a 6-week strength and proprioception training program on measures of dynamic balance: A single-case design. *J Athl Train*. 1997;**32**(2):127–35. [PubMed: 16558442]. [PubMed Central: PMC1319815].
12. McKay GD, Goldie PA, Payne WR, Oakes BW. Ankle injuries in basketball: Injury rate and risk factors. *Br J Sports Med*. 2001;**35**(2):103–8. doi: 10.1136/bjsm.35.2.103. [PubMed: 11273971]. [PubMed Central: PMC1724316].
13. Rougier E, Munjiza A, John NWM. Numerical comparison of some explicit time integration schemes used in DEM, FEM/DEM and molecular dynamics. *Int J Numer Meth Eng*. 2004;**61**(6):856–79. doi: 10.1002/nme.1092.
14. Hertel J, Gay MR, Denegar CR. Differences in postural control during single-leg stance among healthy individuals with different foot types. *J Athl Train*. 2002;**37**(2):129–32. [PubMed: 12937424]. [PubMed Central: PMC164334].
15. Rozzi SL, Lephart SM, Fu FH. Effects of muscular fatigue on knee joint laxity and neuromuscular characteristics of male and female athletes. *J Athl Train*. 1999;**34**(2):106–14. [PubMed: 16558552]. [PubMed Central: PMC1322898].
16. Luebbers PE, Potteiger JA, Hulver MW, Thyfault JP, Carper MJ, Lockwood RH. Effects of plyometric training and recovery on vertical jump performance and anaerobic power. *J Strength Cond Res*. 2003;**17**(4):704–9. [PubMed: 14636088].
17. Coppieters MW, Kurz K, Mortensen TE, Richards NL, Skaret IA, McLaughlin LM, et al. The impact of neurodynamic testing on the perception of experimentally induced muscle pain. *Man Ther*. 2005;**10**(1):52–60. doi: 10.1016/j.math.2004.07.007. [PubMed: 15681269].
18. Hewett TE, Myer GD, Ford KR, Paterno MV, Quatman CE. Mechanisms, prediction, and prevention of ACL injuries: Cut risk with three sharpened and validated tools. *J Orthop Res*. 2016;**34**(11):1843–55. doi: 10.1002/jor.23414. [PubMed: 27612195]. [PubMed Central: PMC5505503].
19. O'Driscoll J, Kerin F, Delahunt E. Effect of a 6-week dynamic neuromuscular training programme on ankle joint function: A case report. *Sports Med Arthrosc Rehabil Ther Technol*. 2011;**3**:13. doi: 10.1186/1758-2555-3-13. [PubMed: 21658224]. [PubMed Central: PMC3141569].
20. Paterno MV, Myer GD, Ford KR, Hewett TE. Neuromuscular training improves single-limb stability in young female athletes. *J Orthop Sports Phys Ther*. 2004;**34**(6):305–16. doi: 10.2519/jospt.2004.34.6.305. [PubMed: 15233392].
21. Hertler SC. The continuum of conscientiousness: The antagonistic interests among obsessive and antisocial personalities. *Pol Psychol Bull*. 2014;**45**(1):52–63. doi: 10.2478/ppb-2014-0008.
22. Herrick C, Steger-May K, Sinacore DR, Brown M, Schechtman KB, Binder EF. Persistent pain in frail older adults after hip fracture repair. *J Am Geriatr Soc*. 2004;**52**(12):2062–8. doi: 10.1111/j.1532-5415.2004.52566.x. [PubMed: 15571543].
23. Docherty CL, Moore JH, Arnold BL. Effects of strength training on strength development and joint position sense in functionally unstable ankles. *J Athl Train*. 1998;**33**(4):310–4. [PubMed: 16558526]. [PubMed Central: PMC1320579].
24. Schiltz M, Lehance C, Maquet D, Bury T, Crielaard JM, Croisier JL. Explosive strength imbalances in professional basketball players. *J Athl Train*. 2009;**44**(1):39–47. doi: 10.4085/1062-6050-44.1.39. [PubMed: 19180217]. [PubMed Central: PMC2629038].
25. Blackburn T, Guskiewicz KM, Petschauer MA, Prentice WE. Balance and joint stability: The relative contributions of proprioception and muscular strength. *J Sport Rehabil*. 2000;**9**(4):315–28. doi: 10.1123/jsr.9.4.315.
26. Wilkerson GB, Colston MA, Short NI, Neal KL, Hoewischer PE, Pixley JJ. Neuromuscular changes in female collegiate athletes resulting from a plyometric jump-training program. *J Athl Train*. 2004;**39**(1):17–23. [PubMed: 15085207]. [PubMed Central: PMC385257].
27. Huang PY, Lin CF, editors. Effects of balance training combined with plyometric exercise in postural control: Application in individuals with functional ankle instability. *6th World Congress of Biomechanics (WCB 2010)*. Singapore. Springer, Berlin, Heidelberg; 2010. p. 232–5.
28. Holm I, Tveter AT, Fredriksen PM, Vollestad N. A normative sample of gait and hopping on one leg parameters in children 7-12 years of age. *Gait Posture*. 2009;**29**(2):317–21. doi: 10.1016/j.gaitpost.2008.09.016. [PubMed: 19019681].
29. Duda M. Plyometrics: A legitimate form of power training? *Phys Sportsmed*. 1988;**16**(3):212–8. doi: 10.1080/00913847.1988.11709466. [PubMed: 27404840].
30. Bahr R. No injuries, but plenty of pain? On the methodology for recording overuse symptoms in sports. *Br J Sports Med*. 2009;**43**(13):966–72. doi: 10.1136/bjsm.2009.066936. [PubMed: 19945978].
31. Stane ML, Powers ME. The effects of plyometric training on selected measures of leg strength and power when compared to weight training and combination weight and plyometric training. *J Athl Train*. 2005;**42**(3):186–92.
32. Kyrolainen H, Komi PV. Neuromuscular performance of lower limbs during voluntary and reflex activity in power- and endurance-trained athletes. *Eur J Appl Physiol Occup Physiol*. 1994;**69**(3):233–9. [PubMed: 8001535].
33. Paasuke M, Saapar L, Ereline J, Gapeyeva H, Requena B, Oopik V. Postactivation potentiation of knee extensor muscles in power- and endurance-trained, and untrained women. *Eur J Appl Physiol*. 2007;**101**(5):577–85. doi: 10.1007/s00421-007-0532-6. [PubMed: 17674025].