DOI: 10.48305/jrrs.2026.45378.1113 Published by Vesnu Publications

The Effects of Functional Training on Lower Extremity Biomechanics during Hopping in Adolescent Professional Basketball Players: AQuasi-experimental Study

Mostafa Awad[1], Morteza Sadeghi[2], Gholam Ali Ghasemi[3], Shahram Lenjannejadian[4]

Original Article

Abstract

Introduction: Knee kinetics and kinematics are important in anterior cruciate ligament (ACL) loading in elite basketball players who repeatedly practice jumping maneuvers such as hopping. The aim of this study was to evaluate the effect of 8 weeks of functional training on the knee flexion, reaction force, and load rate during hopping in professional basketball players.

Materials and Methods: In this quasi-experimental study, 30 professional basketball players were randomly assigned into experimental and control groups (n = 15 per group). The experimental group attended the functional training program three times a week, each 40 to 50 minutes, for eight weeks. Lower extremity kinetics and kinematics were collected in the pre-test and post-test stages during the hopping movement using a force plate and motion analysis system. The data were analyzed by repeated measures analysis of variance (ANOVA) at the significance level of $\alpha = 0.05$.

Results: The peak vertical ground reaction forces and peak loading rate significantly decreased following eight weeks of functional training ($P < 0.001$ and $P = 0.030$, respectively). The knee flexion angle in the experimental group significantly increased after 8 weeks of training ($P = 0.030$).

Conclusion: Based on the present findings, functional training improved the muscle recruitment strategy during the hopping movement probably through increasing the functional stability of the body. Therefore, it can be concluded that functional training may help to manage the risk factors for ACL injury, such as some biomechanical factors, during dynamic movements.

Keywords: Functional training; Kinetics; Kinematics; Anterior cruciate ligament; Basketball

Citation: Awad M, Sadeghi M, Ghasemi GA, Lenjannejadian S. **The Effects of Functional Training on Lower Extremity Biomechanics during Hopping in Adolescent Professional Basketball Players: AQuasi-experimental Study.** J Res Rehabil Sci 2024; 20.

Received date: 31.12.2023 Accept date: 04.02.2024 Published: 03.04.2024

Introduction

Basketball is one of the most common team games. From amateur to professional levels, injury prevention is essential. In this regard, identifying appropriate and effective training methods to prevent performance-determining factors is necessary. One of the common injuries in basketball is an anterior cruciate ligament (ACL) injury (1).

ACL injury, one of the most common ligamentous knee injuries, has drawn much attention not only among athletes but also among active nonprofessional individuals (2). ACL injury causes long-term disability

1- PhD Candidate, Department of Sport Injuries and Corrective Exercises, School of Sports Sciences, University of Isfahan, Isfahan, Iran
2- Assistant Professor, Department of Sport Injuries and Corrective Exercises, School of Sports Sciences, University of Isfahan, Isfahan, Iran
3- Professor, Department of Sport Injuries and Corrective Exercises, School of Sports Sciences, University of Isfahan, Isfahan, Iran
4- Associate Professor, Department of Sport Injuries and Corrective Exercises, School of Sports Sciences, University of Isfahan, Isfahan, Iran
Corresponding Author: Morteza Sadeghi; Assistant Professor, Department of Sport Injuries and Corrective Exercises, School of Sports Sciences, University of Isfahan, Isfahan, Iran; Email: m.sadeghi@spr.ui.ac.ir

and high costs (3) and is also of great importance in children and adolescents (4). Athletes participating in jumping, cutting, and pivoting team sports such as soccer, basketball, and volleyball are often 4-6 times more likely to sustain an ACL injury (5). Lower limb posture during high-risk activities such as running, cutting maneuvers, rotation, and landing is a predisposing factor for ACL rupture (6, 7).

It is believed that lower limb posture directly affects the load placed on the ACL and plays a major role in increasing ACL injury risk. For example, body posture during landing increases the individual's risk of injury (8). Increased knee valgus angle (9), decreased knee flexion angle (10), and decreased hip flexion angle (7, 11) during landing are associated with more severe ACL injury. Quadriceps contraction at 0–30 degrees of knee flexion causes an anterior shear force on the proximal tibia, which increases ACL strain (12, 13). Also, knee valgus and tibial rotation increase ACL strain, though this strain is less than that caused by shear force. The main loading mechanism on the ACL is anterior shear forces at the knee joint (14). Proper control and absorption of these forces during dynamic activities can reduce injury risk. Therefore, understanding the factors that affect the body's ability to absorb these forces may help prevent lower extremity injuries and improve ACL biomechanical function (15). The effect of foot mechanics on superior structures has been well studied, but the effect of proximal stability on lower-limb structures and pathology remains unclear (16).

Inefficiency or functional weakness of the body during normal daily activities (functional activities) may cause disturbances in lower-limb posture, thereby increasing torque and strain on the ACL. Inadequate neuromuscular control of the trunk may affect the dynamic stability of the lower limb, increase strain on the knee ligaments, and lead to injury (17). It seems that proximal muscle function affects forces on the knee joint (11), and functional training can reduce the risk of non-contact ACL injury (18). In a recently published pilot study, functional resistance training was shown to alter gait kinematics in individuals with ACL reconstruction (19).

Functional exercises are a rehabilitation approach designed to improve strength and function simultaneously. In this approach, ordinary daily activities are performed against resistance. For example, applying resistance while walking can engage leg muscles in a specific way and improve walking performance. In this context, functional walking training in research includes braces that resist knee motion during walking or devices that pull the ankle with elastic resistance. These devices have been studied in healthy individuals and those with neurological injuries. However, very few studies have examined functional training in individuals after ACL injury and reconstruction (19). Past research has shown that these devices can increase quadriceps activation during walking and affect kinematic and spatiotemporal parameters after acute training. These findings provide evidence for the clinical potential of this approach. However, it remains unclear how these devices can be used to alter gait kinetics through training. Altering gait kinetics following training is a goal of rehabilitative interventions in ACL injuries, because increasing joint loading in these individuals may improve cartilage health and reduce the progression of post-traumatic osteoarthritis (20).

Based on evidence, functional training appears to reduce forces on the knee during hopping, which could help reduce ACL loading (20). However, the specific effect of trunk interventions, especially functional training, on ACL loading has not been determined. While previous studies have examined forces on the body, it has been suggested that functional training may affect movement technique (20). Accordingly, this study was designed to determine whether eight weeks of functional training can affect knee flexion angle, ground reaction force, and loading rate during hopping in basketball players.

Materials and Methods

The present study used a quasi-experimental pretest–posttest design. Thirty professional basketball players participated. Exclusion criteria included history of trunk or lower limb surgery, history of neuromuscular-musculoskeletal disorders, severe spinal deformities (scoliosis, kyphosis, etc.), knee ligament rupture and meniscal lesions, vestibular deficits, persistent lower limb injury (e.g., degenerative knee joint changes, unstable ankle, etc.), history of ankle sprain in the past year, and visible lower limb malalignment. Inclusion criteria were age between 16 and 18 years and at least 4 years of regular basketball experience. Inclusion and exclusion criteria were checked based on self-report, medical records, and clinical examinations by a physician blinded to the study design when necessary. Sample size was calculated using G*Power statistical software (Version 3.1.9.7, Released March 17, 2020, University of Düsseldorf, Düsseldorf, Germany). From the target population and based on inclusion/exclusion criteria, 30 eligible individuals were purposefully selected (based on inclusion criteria) as study subjects and randomly divided into control (n=15) and experimental (functional training) groups (n=15). Initially, necessary information about the purpose and procedure was given to the subjects. All subjects read and signed an informed consent form and then became familiar with the testing procedure.

Demographic information was collected for each subject, and a health questionnaire was used to assess lower-limb injury status. After initial familiarization, subjects were invited to a pre-intervention assessment (week 1), including knee flexion, ground reaction force, loading rate, and measurements of height and body mass. The same procedure was repeated eight weeks after the intervention.

Instruments

A three-axis force plate (Portable Kistler Force plate, 9260AA6, Kistler Instruments, Switzerland) was used to record and measure ground reaction forces on the lower limb and to detect initial foot contact. Initial foot contact was defined as the moment when vertical ground reaction force exceeded 30 N (21). The force plate recorded ground reaction force data at 200 Hz (22).

Three-dimensional trajectory data were recorded using a Qualisys Track Manager Motion analysis system (Qualisys motion analysis, 41113, Packhusgatan 6, Qualisys AB, Gothenburg, Sweden), comprising 6 infrared cameras. An L-shaped frame with 4 markers and a T-shaped wand with 2 markers were used to calibrate the cameras. In this study, calibration was performed with an error accuracy of less than 0.6 mm (23). Data were sampled at 200 Hz and recorded digitally.

Testing Procedure

Reflective markers were placed on anatomical landmarks according to the Helen Hayes marker set. Markers were attached to the C7 vertebra, left and right acromion, sternum, left and right anterior superior iliac spines, left and right posterior superior iliac spines, sacrum, left and right iliac crests, left and right medial and lateral knee epicondyles, left and right medial and lateral malleoli, and first and fifth metatarsal heads and heels of both feet. Additionally, 4 clusters, each containing 3 markers attached to diamond-shaped plates, were fixed to the anterior surfaces of the shank and thigh using Velcro straps. To improve camera visibility, clusters were placed at equal distances from the anterior and lateral surfaces of the subjects' shanks. This marker placement method is common in many kinetic and kinematic studies (23).

After marker placement and complete familiarization with the testing procedure, the subjects performed the test. Prior to recording hopping data, subjects performed a 1-minute static test on the force plate to align with the laboratory coordinate system. Each subject's local joint coordinates were aligned with their standing position to control intra-subject anatomical variation during the static condition. Initial marker coordinates were recorded by Qualisys Track

Manager Software in quiet standing.

After a standard warm-up, subjects performed three hopping tests, with one minute of rest between each to limit neuromuscular fatigue. Three successful attempts were recorded for each subject. Before the test, subjects practiced the hopping test three times (24).

Ground reaction force data from the force plate and motion data from cameras were simultaneously recorded by QTM software.

Data Analysis

The tests taken from participants were converted from the motion analysis system (Qualysis motion capture) into 3D files and then, using Mokka software (3D Motion kinematic and kinetic analyzer, version 0.6.2), into a new Trc file. Another output, in the form of an ASCII file, was generated by Mokka software to determine ground reaction forces. Finally, the Trc file was modeled in the OpenSim software (model 2.0.3, Stanford University, California), and spatiotemporal parameters and kinematic variables were determined. Kinetic and kinematic data were filtered using a low-pass Butterworth filter with a cutoff frequency of 6 Hz (25).

Peak vertical ground reaction forces (Fz) were calculated using the ground reaction force data. The maximum force output from the software was used to calculate the loading rate and the mean loading rate.

To control for the confounding effect of body weight, ground reaction forces were divided by each subject's body weight and treated as a reference variable. The laboratory coordinate system was such that the X, Y, and Z axes were anterior-posterior, medial-lateral, and vertical, respectively. Relative peak landing force was calculated by dividing the peak vertical ground reaction force (N) by the subject's net body weight (NBW).

Loading rate was obtained as the normalized peak vertical force divided by the time from initial foot contact to peak force (Equation 1) (26).

Equation 1. Loading rate

$$Loading\ rate = \left[\frac{peakF_z(N) / body\ weight\ (N)}{Time\ to\ peak\ F_z}\right] = \frac{BW}{ms}$$

Training Program

Subjects in the control group continued their normal basketball training without any specific additional exercises and without knowing the conditions of the other subjects. Subjects in the experimental group, in addition to their regular basketball training, participated in a functional training program for 8 weeks (3 sessions per week, each lasting 40–50 minutes, progressive) under the direct supervision of the tester.

Table 1. An additional training program in the experimental group, beyond regular training

Exercise	Weeks 1 and 2	Weeks 3 and 4	Weeks 5 and 6	Weeks 7 and 8
Runner's reach	3 × 30 sec	3 × 35 sec	3 × 40 sec	3 × 45 sec
Step-up	3 × 20 reps	3 × 30 reps	3 × 40 reps	3 × 45 reps
Rotational single-leg squat	3 × 20 reps	3 × 30 reps	3 × 40 reps	3 × 45 reps
Medicine ball slam	3 × 20 reps	3 × 30 reps	3 × 40 reps	3 × 45 reps
Wall run at a 45° angle	3 × 20 reps	3 × 30 reps	3 × 40 reps	3 × 45 reps
Vertical jump	3 × 20 reps	3 × 30 reps	3 × 40 reps	3 × 45 reps
Scissor jump	3 × 20 reps	3 × 30 reps	3 × 40 reps	3 × 45 reps
Kettlebell squat	3 × 20 reps	3 × 30 reps	3 × 40 reps	3 × 45 reps

The training program of Santana et al. (27) was used in this study. Both experimental and control groups were allowed to perform their normal daily activities. The researcher supervised all training sessions for both groups. The training program for the experimental group is shown in Table 1.

Statistical Analysis: All data were analyzed using SPSS version 26 (IBM Corp. Released 2018. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY, USA). The Shapiro-Wilk test was used to assess data distribution in both groups, and a repeated-measures ANOVA was used to analyze knee flexion angle, ground reaction force, and loading rate. Hypothesis testing was performed at a significance level of 95% with alpha ≤ 0.05.

Results

Demographic characteristics of the 30 basketball players are presented in Table 2. Mean and standard deviation of knee flexion angle, ground reaction force, and loading rate during hopping in both groups in pre-test and post-test are listed in Table 2.

According to Table 3, the results of the repeated-measures ANOVA showed a significant difference between the pretest and posttest for peak vertical ground reaction force ($F=17.61$, $P\leq0.001$). Furthermore, the results showed no significant difference between the two groups ($F=19.1$, $P\leq0.001$). The time × group interaction (pre vs. post intervention) was significant ($F = 40.7$, $P \leq 0.001$). For the loading rate, there was a significant difference between pretest and posttest ($F=24.7$, $P=0.03$). The results also showed that the time × group interaction was significant (F = 15.61, P = 0.04). In addition, no significant difference was found between the two groups (F=4.5, P=0.3). Repeated-measures ANOVA showed a significant difference between pretest and posttest for knee flexion (F=17.7, P=0.03). Moreover, there was a significant difference between the two groups (F=14.01, P=0.039), and the time × group interaction was significant (F=33.7, P=0.01).

Discussion

In this quasi-experimental study, young basketball players were randomly assigned to two groups, and the experimental group received an 8-week functional training program in addition to their regular training. Functional training reduced ground reaction force and loading rate and increased knee flexion angle during hopping. These findings indicate that this training improves knee muscle activation in participating athletes.

The results of the present study showed that after eight weeks of functional training, peak ground reaction force, loading rate, and knee flexion angle during hopping changed significantly in the experimental group. In contrast, these measures did not change significantly in the control group. Increased impact forces during movements such as hopping and their repetition predispose the surrounding soft tissues to structural injury (28). Peak vertical ground reaction force depends on eccentric muscle activation and contraction (29). During weight-bearing activities (e.g., hopping), the lower limb is largely responsible for absorbing shock at foot contact and reducing the forces acting on the body (30). Also, to reduce ground reaction forces, the body must predict the landing and prepare itself, which is achieved through muscle contraction (31, 32).

Table 2. Demographic information of subjects in the studied groups

Variable	Group	Mean ± SD	t value	P value
Age (years)	Experimental	19.2 ± 3.1	0.95	0.39
	Control	20.1 ± 2.8		
Height (cm)	Experimental	184.11 ± 5.44	1.98	0.31
	Control	185.13 ± 4.3		
Weight (kg)	Experimental	70.5 ± 5.2	2.5	0.17
	Control	72.3 ± 6.4		

Table 3. Descriptive information and repeated measures ANOVA for study variables

Variable	Test session	Experimental group	Control group	Within-group changes	Between-group changes	Interaction
Peak vertical ground reaction force (N/NBW)	Pre-test	2.23 ± 1.7	2.12 ± 2.7	F=17.61	F=19.1	F=40.7
	Post-test	1.62 ± 1.31	2.07 ± 3.9	P≤0.001*	P≤0.001*	P≤0.001*
Loading rate (1/s)	Pre-test	9.4 ± 1.9	9.1 ± 1.1	F=24.7	F=4.5	F=15.6
	Post-test	7.5 ± 1.3	8.9 ± 0.9	P=0.03*	P=0.3*	P=0.04*
Knee flexion (deg)	Pre-test	8.8 ± 2.1	10.5 ± 2.1	F=17.7	F=14.01	F=33.7
	Post-test	9.3 ± 1.3	9.4 ± 0.7	P=0.03*	P=0.039*	P=0.01*

*P < 0.05

Pre-landing muscle activation and the associated contact forces during landing may be interdependent. The body's inability to produce eccentric and anticipatory muscle contractions significantly increases ground reaction forces (33). In other words, reducing loading rate and forces on body joints requires a strong muscular system to control them (34, 35). Studies have shown that various functional landing conditions alternately participate in energy absorption and reduction of forces on the body (23, 35, 36). Reduced proximal muscle activity likely alters knee load-bearing capacity and may result in greater knee forces per unit body mass (34, 37). A 2-week landing training program led to a significant 19% reduction in peak landing force per kilogram of body weight during the first landing phase, compared with a 1.4% reduction in the control group (38). The mechanism by which functional training interventions reduce peak vertical ground reaction force during drop jumps remains unclear; however, previous studies have shown that poor trunk neuromuscular control is associated with increased valgus, torque, and knee abduction motion (6) and a higher prevalence of lower limb injury (39). These kinematic changes are accompanied by increased peak vertical ground reaction force (40). Conversely, neuromuscular training, including trunk exercises, reduces knee abduction torques and valgus collapse tendency during landing (41).

Loading rate is a measure of the magnitude of impact applied to tissues (15); an increase in loading rate indicates a low ability to absorb shock and indicates high pressure applied to the limb over a short time (42, 43). Muscles respond to changes in loading rate or external force magnitude by making appropriate changes in the magnitude and direction of muscular forces in a short time. Within 50 ms after initial foot contact, a shock wave is transmitted into the body due to energy and momentum exchange from the foot striking the ground (44). Shocks generated by ground reaction force impacts can be absorbed and neutralized by structures such as joint capsules, menisci, intervertebral discs, and muscles (44). It is believed that the muscular mechanism is more important in shock absorption (44).

In the present study, after eight weeks of functional training, knee flexion angle increased significantly in the experimental group. This contradicts Jackson's findings, which reported a decrease in knee flexion angle following both plyometric and functional training (45). This discrepancy may be due to the limited number of training sessions and the different sports the subjects play. Athletes can learn new movement patterns and preprogram them in a safer, more optimal manner (46). Therefore, it can be inferred that, in the present study, due to improved feed-forward muscle activity and the use of a correct hopping technique, the knee flexion angle increased. As mentioned earlier, training can increase core stability and improve muscle activation patterns, so it is expected that after eight weeks of functional training, knee flexion angle in the experimental group would be significantly greater than in the control group.

Limitations

This study had limitations, including age, sex, and dietary control.

Recommendations

It is suggested that, in a similar study, other influential factors, such as knee muscle strength and their ratios, be examined.

Conclusion

The results of the present study showed that eight weeks of functional training can produce positive changes in some kinetic and kinematic variables of the lower limb. These changes included reductions in peak ground reaction force and loading rate, and an increase in knee flexion angle during hopping. Based on the findings of this study, it can be stated that the functional training, by increasing body stability, likely improved the muscle recruitment strategy in this region during hopping. Therefore, it may be concluded that functional training can help reduce modifiable risk factors for ACL injury, including biomechanical and neuromuscular factors during dynamic movements in young basketball players.

Acknowledgments

All participants in this study are thanked and acknowledged.

Authors' Contribution

Project design and ideation: Morteza Sadeghi, Gholam Ali Ghasemi

Providing financial resources for the project: -

Providing financial resources for the project: Mostafa Awad, Shahram Lenjannejadian

Providing equipment and statistical sample: Mostafa Awad

Data collection: Mostafa Awad, Morteza Sadeghi, Gholam Ali Ghasemi, Shahram Lenjannejadian

Analysis and interpretation of the results: Mostafa Awad, Morteza Sadeghi, Gholam Ali Ghasemi, Shahram Lenjannejadian

Specialized statistics services: Morteza Sadeghi
Manuscript preparation: Mostafa Awad, Morteza Sadeghi, Gholam Ali Ghasemi, Shahram Lenjannejadian
Specialized scientific evaluation of the manuscript: Mostafa Awad, Morteza Sadeghi, Gholam Ali Ghasemi, Shahram Lenjannejadian
Approving the final manuscript to be submitted to the journal: Mostafa Awad, Morteza Sadeghi, Gholam Ali Ghasemi, Shahram Lenjannejadian
Maintaining the integrity of the study process from the beginning to the publication, and responding to the reviewers' comments: Mostafa Awad, Morteza Sadeghi, Gholam Ali Ghasemi, Shahram Lenjannejadian

Funding

This study is derived from Mustafa Awad's doctoral dissertation with ethics code IR.UI.REC.1402.015 and has no financial support.

Conflict of Interest

The authors did not have a conflict of interest.

References

1. Aoki A, et al. Biomechanical Risk Factors for Anterior Cruciate Ligament Injury in a Young Female Basketball Player: A pilot Study. medRxiv, 2022: p. 2022.07. 11.22277460.
2. Russell KA, Palmieri RM, Zinder SM, Ingersoll CD.Sex differences in valgus knee angle during a single-leg drop jump. Journal of athletic training, 2006; 41(2): 166-71.
3. Trimble MH, et al. The relationship between clinical measurements of lower extremity posture and tibial translation. Clinical Biomechanics, 2002; 17(4): 286-90.
4. LaBella CR, et al. Anterior cruciate ligament injuries: diagnosis, treatment, and prevention. Pediatrics, 2014; 133(5): e1437-e50.
5. Hewett TE. Neuromuscular and hormonal factors associated with knee injuries in female athletes. Sports medicine, 2000; 29(5): 313-27.
6. Hewett TE, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes a prospective study. The American journal of sports medicine, 2005; 33(4): 492-501.
7. Malinzak RA, et al. A comparison of knee joint motion patterns between men and women in selected athletic tasks. Clinical biomechanics, 2001; 16(5): 438-45.
8. Sell TC, et al. Predictors of proximal tibia anterior shear force during a vertical stop-jump. Journal of Orthopaedic Research, 2007; 25(12): 1589-97.
9. Olsen OE, Myklebust G, Engebretsen L, Bahr R. Injury mechanisms for anterior cruciate ligament injuries in team handball a systematic video analysis. The American journal of sports medicine, 2004; 32(4): 1002-12.
10. Walsh MC. The relationship between lower extremity muscle activity and knee flexion angle during a jump-landing task. 2008: ProQuest.
11. Yu B, Lin CF, Garrett WE. Lower extremity biomechanics during the landing of a stop-jump task. Clinical Biomechanics, 2006; 21(3): 297-305.
12. DeMorat G, et al. Aggressive quadriceps loading can induce noncontact anterior cruciate ligament injury. The American journal of sports medicine, 2004; 32(2): 477-83.
13. Beynnon BD, Fleming BC. Anterior cruciate ligament strain in-vivo: a review of previous work. Journal of biomechanics, 1998; 31(6): 519-25.
14. Markolf KL, et al. Combined knee loading states that generate high anterior cruciate ligament forces. Journal of Orthopaedic Research, 1995; 13(6): 930-5.
15. Hargrave MD, Carcia CR, Gansneder BM, Shultz SJ. Subtalar pronation does not influence impact forces or rate of loading during a single-leg landing. Journal of athletic training, 2003; 38(1): 18.
16. Leetun DT, et al. Core stability measures as risk factors for lower extremity injury in athletes. Medicine & Science in Sports &

Exercise, 2004; 36(6): 926-34.
17. Hewett T, Zazulak B, Myer G, Ford K. A review of electromyographic activation levels, timing differences, and increased anterior cruciate ligament injury incidence in female athletes. British journal of sports medicine, 2005; 39(6): 347-50.
18. Zazulak BT, et al. The effects of core proprioception on knee injury. The American Journal of Sports Medicine, 2007; 35(3): 368.
19. Washabaugh EP, Brown SR, Palmieri-Smith RM, Krishnan C. Functional Resistance Training Differentially Alters Gait Kinetics after Anterior Cruciate Ligament Reconstruction: A Pilot Study. Sports Health, 2023; 15(3): 372-81.
20. Araujo S, Cohen D, Hayes L. Six Weeks of Core Stability Training Improves Landing Kinetics among Female Capoeira Athletes: A Pilot Study. Journal of human kinetics, 2015; 45(1): 27-37.
21. Hart JM, et al. Gender differences in gluteus medius muscle activity exist in soccer players performing a forward jump. Research in Sports Medicine, 2007; 15(2): 147-55.
22. Gribble PA, Mitterholzer J, Myers AN. Normalizing considerations for time to stabilization assessment. Journal of Science and Medicine in Sport, 2012; 15(2): 159-63.
23. Afonso MP. Modelling the gait of healthy and post-stroke individuals. 2015, Universidade do Porto.
24. Ali N, Robertson DGE, Rouhi G. Sagittal plane body kinematics and kinetics during single-leg landing from increasing vertical heights and horizontal distances: Implications for risk of non-contact ACL injury. The Knee, 2014; 21(1): 38-46.
25. Yu B. Effect of external marker sets on between-day reproducibility of knee kinematics and kinetics in stair climbing and level walking. Research in Sports Medicine, 2003; 11(4): 209-18.
26. Zhan SN, Bates BT, Dufek JS. Contributions of lower extremity joints to energy dissipation during landings. Medicine and Science in Sports and Exercise, 2000; 32(4): 812-9.
27. Willardson JM. Developing the core. 2014: Human Kinetics.
28. Wu HW, et al. Biomechanics of ankle joint during landing in counter movement jump and straddle jump. 2009. IEEE.
29. Mcnitt-Gray JL. Kinematics and Impulse Characteristics of Drop Landing From Three Heights. International journal of sport biomechanics, 1991; 7(2): 201-24.
30. Decker MJ, et al. Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. Clinical Biomechanics, 2003; 18(7): 662-9.
31. Devita, P. and W.A. Skelly, Effect of landing stiffness on joint kinetics and energetics in the lower extremity. Med Sci Sports Exerc, 1992; 24(1): 108-15.
32. McKinley P, Pedotti A. Motor strategies in landing from a jump: the role of skill in task execution. Experimental brain research, 1992; 90(2): 427-40.
33. McNair PJ, Prapavessis H, Callender K. Decreasing landing forces: effect of instruction. Br J Sports Med, 2000; 34(4): 293-6.
34. Hodges PW, Richardson CA. Contraction of the abdominal muscles associated with movement of the lower limb. Physical therapy, 1997; 77(2): 132-42.
35. Zazulak BT, et al. Gender comparison of hip muscle activity during single-leg landing. Journal of Orthopaedic & Sports Physical Therapy, 2005; 35(5): 292-9.
36. Okubo Y, et al. Abdominal muscle activity during a standing long jump. Journal of orthopaedic & sports physical therapy, 2013; 43(8): 577-82.
37. Decker MJ, et al. Gender differences in lower extremity kinematics, kinetics and energy absorption during landing. Clinical biomechanics, 2003; 18(7): 662-9.
38. Iida Y, Kanehisa H, Inaba Y, Nakazawa K. Short-term landing training attenuates landing impact and improves jump height in landing-to-jump movement. The Journal of Strength & Conditioning Research, 2013; 27(6): 1560-7.
39. Zazulak BT, et al. Deficits in neuromuscular control of the trunk predict knee injury risk a prospective biomechanical-epidemiologic study. The American journal of sports medicine, 2007; 35(7): 1123-30.
40. Hewett TE, Lindenfeld TN, Riccobene JV, Noyes FR. The effect of neuromuscular training on the incidence of knee injury in female athletes a prospective study. The American journal of sports medicine, 1999; 27(6): 699-706.
41. Myer GD, Ford KR, Brent JL, Hewett TE, The effects of plyometric vs. dynamic stabilization and balance training on power, balance, and landing force in female athletes. The Journal of Strength & Conditioning Research, 2006; 20(2): 345-53.
42. De Wit B, De Clercq D, Lenoir M. The effect of varying midsole hardness on impact forces and foot motion during foot contact in running. Journal of Applied Biomechanics, 1995; 11: 395-406.
43. Cook TM, et al. Effects of Restricted Knee Flexion and Walking Speed on the Vertical Ground Reaction Force during Gait. Journal of Orthopaedic & Sports Physical Therapy, 1997; 25(4): 236.
44. Coventry E, et al. The effect of lower extremity fatigue on shock attenuation during single-leg landing. Clinical Biomechanics, 2006; 21(10): 1090-7.
45. Jackson, K.R., The effect of different exercise training interventions on lower extremity biomechanics and quality of movement in high school female athletes. 2011, University of Virginia.
46. Hewett TE, et al. Biomechanical Measures of Neuromuscular Control and Valgus Loading of the Knee Predict Anterior Cruciate Ligament Injury Risk in Female Athletes. The American Journal of Sports Medicine, 2005; 33(4): 492-501.