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The effect of a six-week plyometric training on dynamic balance and knee proprioception in female badminton players

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Objective: *Non-contact anterior cruciate ligament (ACL) injury is one of the most common severe injuries among female badminton players. Dynamic balance (DB) and knee proprioception (KP) are critical in preventing this injury. The purpose of this study was to investigate the effect of a six-week plyometric training (PT) program on DB and KP in female badminton players.*

Methods: *Twenty-two healthy beginner female badminton players were randomly assigned to either control (CG) or experimental group (ExG). The ExG went through PT for six weeks. Pre- and post-intervention Y balance and photography tests were used to assess DB and KP, respectively.*

Results: *There was no difference between groups prior to PT in DB (p=0.804) and KP (at 45°, p=0.085 and at 60°, p=0.472 angles; p>0.05). However, after the PT only ExG improved significantly in DB (p=0.003)*

Objectif : *La rupture sans contact au ligament croisé antérieur (LCA) est l'une des blessures graves les plus courantes chez les joueuses de badminton. Un équilibre dynamique (ED) et une proprioception du genou (PG) sont essentiels dans la prévention de cette blessure. L'objectif de cette étude était d'évaluer les effets d'un entrainement pliométrique d'une durée de six semaines sur l'ED et le PG chez les joueuses de badminton.*

Méthodologie : *Vingt-deux joueuses de badminton novices et en bonne santé ont été réparties au hasard entre le groupe de contrôle (GC) et le groupe expérimental (GE). Les joueuses du groupe expérimental ont suivi un entrainement pliométrique pendant six semaines. Des tests d'équilibre Y avant et après l'intervention et des tests photographiques ont été utilisés pour évaluer l'ED et le PG, respectivement.*

Résultats : *Aucune différence n'a été constatée entre les groupes avant un EP dans l'ED (p=0,804) et le PG (à 45°, p=0,085 et à 60°, p=0,472) Toutefois, après l'EP seul le GE a fait état d'une amélioration de manière*

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and KP (at 45°, p=0.004 and at 60°, p=0.010 angles; p<0.05).

Conclusion: *Female badminton players' dynamic balance and knee proprioception improved significantly after plyometric training (PT). These results may be important in preventing non-contact anterior cruciate ligament (ACL) injury, which requires further investigation.*

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KEY WORDS: badminton, anterior cruciate ligament, dynamic balance, knee proprioception, plyometric training, female players

significative en ED (p=0,003) et PG (à 45°, p=0,004 et à 60°, p=0,010 angles ; p<0,05).

Conclusion : *L'équilibre dynamique et la proprioception du genou des joueuses de badminton se sont améliorés de manière significative après un entrainement pliométrique. Ces résultats peuvent être considérables dans la prévention des ruptures sans contact du ligament croisé antérieur (LCA) qui nécessitent un examen plus approfondi.*

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MOTS CLÉS : badminton, ligament croisé antérieur, équilibre dynamique, proprioception du genou, entraînement pliométrique, joueuses

Introduction

Participation by women in intercollegiate and international competitions has increased significantly in recent years. Female athletes involved in jumping and cutting (quick direction maneuvers) activities are at higher risk of non-contact anterior cruciate ligament (ACL) injury than their male counterparts.[1] Approximately 250,000 people injure their ACL each year in the United States alone, with the most important potential mechanism being reduced knee proprioceptive ability.[2] Mechanoreceptors (i.e. muscle spindles or the fascial system) have been found in ACL tissue.[3,4] Interestingly, the deep fascia has also been shown to have a prominent role in proprioception and peripheral motor coordination.[4] ACL rupture, the most common severe knee ligament injury, is more prevalent among young athletes (15 to 25 years of age), with 70% due to non-contact injury mechanism.[5] The rate of this injury is higher in female athletes compared to male athletes due to the intrinsic factors such as anatomical, hormonal, neuromuscular, and biomechanical differences.[6] In addition to the high cost of treatment, ACL injury can lead to the loss of athletic participation and other complications such as osteoarthritis, physical, and psychological problems.[7]

Badminton is one of the most popular racket sports in the world that attracts many recreational and competitive athletes. Badminton is a sport suitable for all people of all ages and levels. Badminton requires frequent jumps, lunges, quick changes of direction, rapid arm movements, rapid eye-hand coordination, and adequate body position sense.[8,9] Høy *et al*. reported that 5% of all sports injuries are reported in badminton.[10] Among them, ACL is likely the most common severe knee ligament injury in badminton.[11,12] Kimuraet *et al*. reported that these injuries accounted for 37% of all badminton injuries.[11] In the London Summer Olympic Games in 2012, badminton was one of the most injurious non-contact sports, with non-contact ACL injury as the most common injury reported.[13] In the Rio Summer Olympic Games in 2016, the most injured region in badminton players was the lower limb (mostly knee joint and non-contact ACL injury).[14] The most common injury mechanism in badminton was a single-limb landing after an overhead stroke (smash or clear shot), whereas sudden deceleration with change of direction (plant-and-cut) was the second most common injury mechanism.[10,15] Reeves *et al*. reported intrinsic factors to be the main causes of this injury in badminton.[15]

Badminton players require a high level of dynamic balance during quick movements around the court to perform well and prevent injury.[16] The capability to maintain the body's base of support with minimal movement when standing (static balance) and during movement (dynamic balance) is defined as balance, whereas dynamic balance involves some levels of expected movement around the center of gravity projection.[17] The regulation of balance depends on the sources of the visual, vestibular, and proprioceptive stimulus.[18] The proprioceptive system includes mechanoreceptors (i.e. muscle spindles, Golgi tendon organs, Ruffini nerve endings, Paccini corpuscles, Meissner's corpuscles, nociceptors, and Merkel's discs[19]) which are located in muscles, tendons, joints, fascia[20], and skin. Muscle spindles, as the most important source of proprioception, provide important sensory information regarding muscle tension or length of muscle fibers and the velocity of change of muscle displacement.[21] Golgi tendon organs usually have a protective function against excessive tensile loads in the muscle.[22] Recent research shows that fascia exhibits a high density of mechanoreceptors. The fascial system is rich in proprioceptors, particularly the Ruffini and the Paccini corpuscles, which play a significant role in conveying mechanical tension, in order to control an inflammatory environment.[20] Mechanoreceptors are specialized sensory neurons that respond to mechanically applied pressure or tissue deformation.[23] The mechanoreceptors provide important afferent information, regarding position (static) and movement (dynamic), to the central nervous system by transforming the mechanical energy created by physical deformation of the joint and muscles to electrical energy of nerve action potential for processing.[24,25] This system is an important component of balance.[18] The contribution of visual cues is essential during the establishment of static balance, while the contribution of proprioceptive input is necessary in dynamic balance.[26] Generally, proprioception is referred to as the ability to know where the body is in space without using the eyes, either consciously or unconsciously.[27,28] Proprioception can be divided into two components: joint movement (kinaesthesia) (the dynamic sense of movement, including joint acceleration, force, and velocity) and joint position sense (the static sense of movement).[29] Awareness of posture, movement, joint position, limb velocity, changes in balance and weight, and resistance of objects in relation to the body increases by proprioception and their associated neurological systems.[27,28] Knee joint proprioception contributes to joint stability, postural and motor control through conscious or unconscious information arising from proprioception receptors in the capsules, ligaments, and muscle spindles.[30]

Several different ACL injury prevention programs have been attempted and each is based on different design concepts and emphasize different components of a preventive program. They include plyometric, strengthening, balancing, endurance, and stability programs.[31] Hewett *et al*. reported that the effectiveness of preventive programs in different athletes can differ as it is dependent on enhancing neuromuscular control and preventing ACL injuries.[32] Plyometric training can be introduced as an effective training modality in improving joint awareness, balance, and neuromuscular properties.[33] Plyometrics are a type of exercise that uses the stretch-shortening cycle of musculotendinous tissue which uses the energy stored during the eccentric loading phase and stimulation of the muscle spindles to facilitate maximum power production during the concentric phase of movement known as reactive neuromuscular training.[31] Multiple studies demonstrate that plyometric training may have a significant effect on knee stabilization and prevention of non-contact ACL injury among female athletes.[22,34,35] Corina *et al*. introduced stretching, proprioception coordination, and plyometric exercises to prevent common musculoskeletal injuries (sprain and strain) in badminton. Power is an important factor in performance and success in badminton.[12] Plyometric training improves athletic power and develops neuromuscular adaptability.[36] It improves athletic performance and may also prevent knee injury by increasing neuromuscular adaptations and correcting faulty jumping or cutting mechanics by developing suitable landing technique, helping to increase knee-flexion angles, and decreasing hip adduction/knee valgus angles at landing.[22,37] Plyometric training may facilitate neural adaptations that enhance proprioception, kinesthesia, and muscle performance characteristics.[38] These adaptations are created by the repeated stimulation of mechanoreceptors near the end range of motion. In addition, the relationship between plyometric training and balance has been attributed to development of neuromuscular adaptability.[39] Hence, due to the prevalence of non-contact ACL injuries in female badminton players and the significance of dynamic balance and knee proprioception in preventing this injury, this study aimed to investigate the effect of six-week plyometric training on the dynamic balance and knee proprioception of female badminton players.

Methods

Participants

This semi-experimental study recruited 22 healthy beginner female badminton players, ranging from 15 to 25 years of age, through purposive and convenience sampling. Beginner players were defined as having maximum three years of experience in playing badminton at club level with irregular exercises. Inclusion criteria were participants with less than three years of irregular participation in club level badminton, with no history of lower limb, knee joint, and particularly ACL injuries. Exclusion criteria were the presence of any injuries, experimental group participants could not have taken part in plyometric training in the four consecutive weeks prior to the study, and control group participants could not engage in plyometric training during the six-week period of the study.

Participants were randomly divided into experimental (N=12) and control groups (N=10) (Table 1). The experimental group received plyometric training 20 minutes per session, three sessions per week for six weeks; whereas the control group continued with their own routine exercises. The Ethics Committee of Arak University, Medical Sciences division approved the tests and training program. The subjects signed a consent form prior to participation. To minimize learning effects, three days prior to the intervention, participants viewed an instructional video about dynamic balance and knee proprioception tests and then practiced the tests. The examiners also viewed the instructional video to standardize the test assessment. To eliminate the effect of fatigue, participants were asked to avoid intense exercises 48 hours before performing the tests. The dominant limb was used to perform tests (dynamic balance and knee proprioception) and for limb length measurement. When the six-week training period was completed, the tests were recorded one-day after the last session of training.

Table 1.
Baseline physical characteristics

Variable	Group	N	Mean + SD
Age (y)	Experimental Control	12 10	22.00± 1.30 22.00 ± 0.84
BMI (kg/m^2)	Experimental Control	12 10	22.95 ± 3.07 22.60 ± 1.98
Sport experience (y)	Experimental Control	12 10	2.50 ± 1.00 3.00 ± 0.94

Dynamic balance assessment

Pre- and post-intervention the Y balance test was conducted in both groups to assess dynamic balance. This test has been shown to be a reliable measure and has validity as a dynamic test to predict risk of lower extremity injury.[17,40] The Y balance test device consists of a stance platform from which three pieces of polyvinylchloride pipe project in the anterior, posteromedial, and posterolateral reach directions. The participant stands on a center footplate to perform the test. While maintaining single-limb stance on the dominant limb, the participant reaches with the other limb in the anterior, posteromedial, and posterolateral directions in relation to the stance foot by pushing a reach indicator as far as possible. The participant pushes the reach indicator along the pipe with their dominant limb, and the reach indicator remains over the tape measure after performance of the test to allow for easy measurement. The test was completed in the order of anterior, posteromedial, and lastly posterolateral direction. Three consecutive trials were performed to push the reach indicator in each direction and a short rest break (10 to 15 seconds[41]) was allowed to reduce fatigue. Attempts were discarded and had to be repeated if the participant failed to maintain unilateral stance on the platform or failed to maintain reach foot contact with the reach indicator in the target area while the reach indicator was in motion, used the reach indicator for stance support, or failed to return the reach foot to the starting position under control. Each participant was allowed maximum of six attempts to obtain three successful trials for each direction. Maximum and average distance (to the nearest 0.5 cm) over the three trials were recorded and analyzed for the dominant limb in all directions. The participant's lower limb reach was normalized to limb length. The limb length was measured from the anterior superior iliac spine to the most distal portion of the medial malleolus. The normalized value was calculated as the reach distance, divided by the limb length, and then multiplied by 100%, which was to express reach distance as a percentage of limb length. Total reach distance was the sum of the three successful reach directions divided by three times limb length, and at the end, multiplied by 100%.

Knee proprioception assessment

Pre- and post-intervention photography was conducted for both groups to assess knee proprioception. The

Table 2.
Plyometric training protocol used in experimental group.

Phase 1	Sets	Reps	Phase 2	Sets	Reps	Phase 3	Sets	Reps
Wall jumps	1	15	Wall jumps	1	15	Wall jumps	1	15
Squat jumps	1	15	Squat jumps	1	15	Tuck jumps	1	15
180° jumps	1	30	Tuck jumps	1	15	180° jumps – speed	1	15
Bounding	1	15	180° jumps	1	15	Triple broad – vert	2	5
Front/back jumps	1	15	Front/back jumps	1	15	Hop, hop, hop-stick	2	6
Side/side jumps	1	15	Side/side jumps	1	15	Crossover hop, hop, hop-stick	2	6
Broad jumps	1	5	Broad jumps – stick	1	15	X-hops	2	6
Triple broad – vert	1	5	Triple broad – vert	1	5	Scissor jumps	2	6
Scissor jumps	1	6	Hop, hop, hop and stick	2	6	Box jumps	2	6
Hop, hop, hop and Stick	1	6	Crossover hop, hop, hop and Stick	2	6	Box drops	2	6
Box jumps	1	6	180° jumps – ball catch	1	6	Depth jumps	2	6
			Scissor jumps Box jumps Box drops	1 2 2	6 6 6	Box-depth-180° – box-depth-vertical	1	6

Phase – 1 low level of difficulty; Phase 2 – intermediate level of difficulty; Phase 3 – advanced level of difficulty (for detailed explanations of each exercise please refer to Appendix 1).

photography method consisted of a digital photograph (Nikon D3300), non-reflective markers, and AutoCAD software.[42] This test has high validity and reliability to assess knee proprioception.[43] Having been introduced to the test method, the participants were asked to wear shorts to paste the markers on the desired points. The markings were made in a sitting position, four skin markers were attached to the external aspect of the dominant limb. Participants' limb length was measured with a standard tape measure. Four red square markers (4x4 cm) were attached to dominant limb at the following locations: over the proximal 1/4 distance between the tip of greater trochanter and the lateral knee joint line, the neck of fibula, and over the proximal of lateral malleolus. Then the participant bent her knee at 90º angle, and the fourth marker was attached over the iliotibial tract adjacent to the superior border of the patella in this position. The locations of markers were based on previous studies.[44-47] The authors chose mid-knee joint range of motion as the goal angle (40–80˚of flexion) to measure knee proprioception since most of the performance of muscle spindles is in the midrange of joint motion.[48] Accordingly, in the present study, knee flexion angles of 45° and 60° were used to measure knee proprioception in the sitting position (sitting position is preferred to a prone position[49]). After skin marking, the participants were asked to sit on the seat with their eyes closed. The seat height was set so that participant's limb did not touch the ground. Initially, the examiner set each participant's knee at 45° flexion using a goniometer (MSD model) without changing the ankle position, the participant was then asked to hold the position for five seconds. In this position, the first photograph was taken of the lateral side

Table 3.
Independent samples test statistical analysis of change in dynamic balance and knee proprioception of training and control group over a 6-week.

Variable	Time	Mean + SD	t	p
Dynamic balance	Pre–test – experimental group	91.32 ± 7.56	0.252	0.804
	Pre–test – control group	90.52± 7.28		
	Post–test –experimental group	99.12 ±7.60	3.357	0.003*
	Post–test –control group	88.20 ± 7.59		
45° knee flexion	Pre–test –experimental group	2.41 ± 1.06	–1.813	0.085
	Pre–test –control group	3.55 ± 1.83		
	Post–test –experimental group	1.54 ± 1.03	–3.477	0.004*
	Post–test –control group	3.90 ± 1.92		
60° knee flexion	Pre–test–experimental group	2.83 ± 1.15	–.733	0.472
	Pre–test –control group	3.20 ± 1.18		
	Post–test–experimental group	2.00 ± 1.10	–2.826	0.010*
	post–test –control group	3.45 ± 1.30		
* = significant difference (p<0.05).				

of the knee. The participants were asked to return their knees to the resting position. After seven seconds of rest, the participants were asked to actively reconstruct the knee flexion at 45° angle at a desired speed and hold the angle. This process was repeated three times and photographed at each time. In order to eliminate the possible effects of reconstruction, as well as fatigue, the participant was asked to walk at an angle of 45° for one-minute. The whole process was repeated to measure knee proprioception at a 60° angle. The photos were then transferred to a computer. The angle of each photograph was calculated by AutoCAD software and compared with the target angle (target angle was the angle that the examiner set the participant's knee at 45° flexion using a goniometer). Finally, the composite angular difference (angle difference between target angles and reconstruction angles), at three times' repeat and regardless of the sign ± of scores, was recorded as the knee articular angle reconstruction absolute error of each participant.

Training protocol

Initially an educational video of the plyometric training program was shown to the experimental group. In addition, all the exercises were demonstrated and explained by a trainer. All movements of plyometric training protocol were performed and recorded by a plyometric trainer. Athletes were verbally encouraged to increase knee-flexion angles and decrease hip adduction/knee valgus angles at landing. To prevent potential injury and gradual improvement of participants, the training was designed in three phases from beginner to advanced levels of difficulty (Table 2, Appendix 1). The training protocol was also explained to the control group so that they would not engage in the same exercises. The experimental group performed 20 minutes of plyometric training, with 10 minutes warm up and cool down, three times per week for six weeks. The control group continued with their usual badminton practice and training.

Statistical analysis

Data were analyzed using SPSS software version 22, with a 95% confidence level ($p \leq 0.05$). A test of normal distribution (Shapiro-Wilk) was conducted on all data before the analysis ($p<0.05$). All data were normally distributed. An Independent Sample T test was used to test the difference between groups (experimental and control; $p<0.05$).

Results

The dynamic balance was significantly improved in the experimental group versus the control group post intervention (p=0.003) (Table 3). The knee articular angle reconstruction absolute error was significantly improved in the experimental group compared to control after plyometric training (at 45°, p=0.004 and at 60°, p=0.010 angles) (Table 3).

Discussion

Dynamic balance

The aim of the present study was to test the effects of a six-week plyometric training intervention on the dynamic balance and knee proprioception in female badminton players. Six weeks of plyometric training produced significant positive changes in dynamic balance of female badminton players. Plyometric training has an important role in improving lower-body stability.[12] These training regimens develop suitable landing techniques and improve dynamic control of the center of mass (COM), which ultimately develops neuromuscular adaptability. Myer *et al*. showed that female high-school volleyball players decreased their medio-lateral center of pressure after seven weeks of plyometric training.[50] Majeed *et al*. reported a significant difference in the dynamic balance of male badminton players after six weeks of plyometric training.[51] Cherni *et al*. observed that eight weeks of in-season plyometric training by top-level female basketball players reduced the risk of falls and injuries by improving dynamic postural control.[52] However, Arazi and Asadi found no significant improvement in the dynamic balance of semi-professional male basketball players following eight weeks of high-intensity plyometric training.[39] These discrepancies could be due to differences in intensity of training, number of contacts, plyometric drills, methods of assessment of dynamic balance, sex, age, and years of experience of the sample population. Improving dynamic balance has been reported to enhance functional adaptations, feed-forward adjustments that activate appropriate muscles before landing and proprioceptive input, as well as reduction of lower extremity injury risk.[52]

Knee proprioception

Our findings suggest that a six-week plyometric training program improves the knee proprioception of female beginner badminton players in active flexion angles of 45° and 60°. Zamani *et al*. found that eight weeks of plyometric training enhanced the knee proprioception of male college students at 30°, 45°, and 60° angles.[53] Byoung-Do *et al*. reported considerable improvements after a period of lower extremity plyometric training on the proprioception and postural stability of collegiate soccer players with postural instability.[54] Other studies have reported improved proprioception after plyometric training.[33,35,55] Plyometric training reduces the sensitivity of Golgi tendon organs against excessive tensile loads in the muscle allowing the elastic components of muscles to undergo greater stretch.[22] Lephart *et al*. believe that decreasing the sensitivity of Golgi tendon organ results in an increase in the performance of muscle spindles and consequently improves proprioception.[56] Plyometric training, through enhanced neural recruitment of motor unit or neural firing frequency, enhances reflex potentiation, and/or changes elastic properties of the muscle and connective tissue, which in turn increases neuromuscular adaptability.[57] Cug *et al*. tested the effect of a four-week dynamic balance training program on recreationally active participants (male and female) and contrary to the present study, found no significant influences on the ankle and knee joint position sense.[58] This disagreement may be due to the differences in duration and/or type of training. On the other hand, plyometric training consists of concentric and eccentric contractions with a high level of tension and force which may cause injury. As such one may assume that the best time to train polymetrically and avoid injury would be during preseason training. However, Michaelidis *et al*. stated that in-season plyometric training was more effective than the preseason training in ACL injury prevention.[59]

Conclusion

Badminton players require significant dynamic balance and knee proprioception for satisfactory performance and prevention of musculoskeletal injuries, especially non-contact ACL injuries. The results of this study demonstrated that a six-week plyometric training program improved dynamic balance and knee proprioception in beginner female badminton players. Hence, plyometric training can be utilized by badminton coaches and players to improve dynamic balance and knee proprioception, which in turn may reduce non-contact ACL injuries. Further investigation of the effect of plyometric training on reduction of injuries in badminton at various skill levels, is highly recommended.

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Appendix 1.
Glossary of exercises training

1. Wall jumps: With knees slightly bent and arms raised overhead, jump up and down off toes.
2. Squat jumps: Standing jump raising both arms overhead, land in squatting position touching both hands to floor then takes off into a maximum vertical jump.
3. 180° jumps: Two-footed jump. Rotate 180° in mid-air. Hold landing for 2 seconds and then repeat in reverse direction.
4. Bounding: Start bounding in place and slowly increase distance with each step, keeping knees high.
5. Front/back jumps: Two-footed jump on mattress, tramp or other easily compressed device. Perform front–to back.
6. Side/side jumps: Two-footed jump on mattress, tramp or other easily compressed device. Perform side-to-side
7. Broad jumps: Two-footed jump as far as possible. Jumping horizontally and vertically to achieve maximum horizontal distance.
8. Triple broad-vert: Three broad jumps with vertical jump immediately after landing the third broad jump.
9. Scissor jumps: Start in stride position with one foot well in front of other.
10. Hop, hop, hop and Stick (Hold): Single-legged hop (Three successive jumping). Stick second landing for 5 seconds. Increase distance of hop as technique improves.
11. Broad jumps-stick (Hold): Two-footed jump as far as possible. Hold landing for 5 seconds.
12. Crossover hop, hop, hop and Stick (Hold): Start on a single leg and jumps at a diagonal across the body, lands on the opposite leg with the foot pointing straight ahead, and immediately redirects the jump in the opposite diagonal direction.
13. Tuck jump: From standing position jump, and bring both knees up to chest as high as possible. Repeat quickly.
14. 180° jumps-ball catch: Two-footed jump. Rotate 180° in mid-air and catch of ball which thrown towards her.
15. Box drops: Landing portion of a depth jump. Step from a box and stick the landing.
16. 180° jumps-speed: Two-footed jump. Rotate quick 180° in mid-air.
17. X-hops: Begins faces a quadrant pattern stands, on a single leg. Hops diagonally, lands in the opposite quadrant, maintains forward stance and holds the deep knee flexion landing for 3 seconds and then hops laterally into the side quadrant and again holds the landing. Next hops diagonally backward and holds the jump. Finally, hops laterally into the initial quadrant and holds the landing.
18. Depth jumps: Stand on a box, step off, hit the ground, and immediately jump up as high as possible at ground contact.