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Effect of good and poor landing biomechanics on dynamic knee valgus and jumping performance in early adolescent female basketball players

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Abstract

This study aimed to investigate dynamic knee valgus (DKV) and jumping performance in adolescent female athletes with good and poor landing biomechanics. The study included healthy 52 adolescent female athletes aged between 10–14. Participants were divided into two groups based on LESS (Landing Error Scoring System) scores: poor landing technique group (PLTG) (LESS≤5, n=26) and good landing technique group (GLTG) (LESS>5, n=26). Knee valgus and jumping performance were evaluated with frontal plane projection angle (FPPA), and countermovement jump without arm swing test (CMJT), respectively. All demographic data of the groups were distributed homogeneously (p>0.05) except LESS scores (p=0.001; p<0.05). The LESS score for PLTG was 8.12±2.18, while for GLTG it was 3.19±0.98. All participants had a right-dominant lower extremity. In FPPA and CMJT variables no significant difference was found between the groups (respectively p=0.111, p=0.547; p<0,05). Moreover, no significant correlations were found between LESS scores and FPPA (p=0.374; p>0.05) or CMJT (p=0.470; p>0.05). No difference was found in dynamic knee valgus or jump performance among early adolescent female basketball players with good or poor landing biomechanics.

Keywords: Countermovement jump test, basketball, landing error scoring system, frontal plane projection angle, youth

Introduction

Adolescence, which begins with rapid biological and physical development along with sexual and psychosocial maturation, is defined as a period in which the individual gains independence and social productivity [1]. The World Health Organization defines the adolescence phase as between the age range of 10-19 [2]. Psychosocial maturation in adolescence is categorized into three stages: early (10-14 years), middle (15-17 years), and late (18-21 years) [3].

Almost 50% of all sports injuries belong to adolescents and 8% of adolescent players per year are unable to participate in sports and recreational activities due to injury [4]. Adolescent girls participating in sports such as basketball, which involve sudden stops, direction changes, and jumping, are 4 to 6 times more likely to have lower extremity injuries compared to adolescent boys involved in the same sports [5] and most of the lower extremity injuries in adolescent girls occur non-contact [6].

Landing mechanics after jumping is an important risk factor, particularly for anterior cruciate ligament (ACL) injuries [7-9]. In females, especially when landing after a jump, the load on the knee and hip joints increases, and so, the risk of injury increases [10]. To describe the risk of ACL injuries, four theories have been developed by classifying the landing problems of athletes engaged in high-risk sports. The Ligament Dominance Theory suggests that athletes excessively load their knee ligaments by landing in a valgus position, accompanied by femoral adduction and internal rotation, following a jump. Quadriceps Dominance Theory proposes that landing after a jump increases the shear forces of the anterior tibia by creating a prolonged extension of the knee and overactivity of the quadriceps muscles relative to the hamstrings. The Trunk Dominance Theory suggests that athletes land from a jump with a lack of trunk control. Finally, the Leg Dominance Theory suggests that there are significant symmetrical differences between the legs [11]. Video analyses of ACL injuries confirm all four theories, showing increased knee

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valgus, reduced knee flexion angle, increased lateral trunk shift, and asymmetrical body weight distribution between the legs during ACL tears [12-14]. Therefore, the landing biomechanics of adolescent girls need to be carefully evaluated, considering all high-risk areas collectively [15]. The Landing Error Scoring System (LESS) is a frequently used method that evaluates landing biomechanics from the sagittal and frontal planes for the entire body [16].

Dynamic knee valgus (DKV), a faulty lower extremity movement pattern, is a biomechanical deviation occurring in multiple planes of motion. It involves femoral internal rotation and adduction simultaneously with contralateral pelvic drop [17]. Video analysis of injury cases shows that overloading the knee joint results in increased valgus alignment, which is the primary cause of knee injuries [18-21]. According to a systematic review examining maturation and biomechanical risk factors associated with ACL injuries, knee valgus moment increases with maturation [15]. However, to the best of our knowledge, no study has investigated the relationship between DKV and the quality (poor and good) of landing biomechanics during early adolescence.

The vertical jump is defined as the difference between the height an individual can reach in a static stance and their maximum vertical jump height. In basketball, vertical jumping is a crucial motor skill for executing fundamental basketball-specific techniques such as rebounding, shooting, and blocking shots [22,23]. Also, it is one of the most essential skills for adolescent athletes during their growth and development process, daily life activities, and, most importantly, in sports activities [23]. It has been shown that female adolescent athletes exhibit poor landing biomechanics compared to males [24] but to our knowledge, the factors contributing to poor landing biomechanics have not been studied in detail.

This study aims to compare the DKV and jump performance of female basketball athletes with good and poor landing biomechanics during early adolescence. We hypothesize that athletes with poor landing biomechanics will exhibit higher valgus angles and worse jumping performance.

Material and Methods

General Design

This study has a cross-sectional and prospective design. The evaluations of the participants were conducted between 26.05.2024 and 26.11.2024. The participants were selected from adolescent female basketball players from different sports clubs (Güngören Municipality Sports Complex, Anka Sports Schools). A total of 52 female athletes aged 10-14, involved in basketball, were included in the study. Participants were divided into study groups based on their LESS scores. Those with a LESS score of 5 or higher were classified as "poor landing technique group" (PLTG, n=26), while those with a LESS score between 0-4 were classified as "good landing technique group" (GLTG, n=26) [25]. All assessments were completed on the same day. In the single-leg assessments, the dominant leg was chosen.

The Non-Interventional Clinical Research Ethics Committee of Bahçeşehir University approved our ethics application on 20.12.2023, with decision number 2023-21/04. Before enrolling in the study, all participants were provided with the informed consent form and the informed volunteer consent form, which they were required to read and sign.

Participants

The inclusion criteria for the study were: being female, aged between 10-14 years, having been involved in sports for at least 6 months at a sports club, and not having more than 3 points of pain in the lower extremity according to the visual analog scale. Exclusion criteria for the study included: having a systemic disease, having experienced a musculoskeletal injury or surgery in the lower extremity within the past year, having a congenital anomaly in the lower extremity, having ligamentous hyperlaxity, having a chronic disease, having any injury that would interfere with the assessment, having mental or psychological problems, the presence of a cognitive or psychological condition that would hinder cooperation, and having a history of any orthopedic, neurological, vascular, systemic, or rheumatological disease.

The sample size of the study was calculated based on the effect size value of 1.3, referenced from the study by Fidai et al., which used frontal plane projection angle (FPPA) results [26]. A power of 95% and an error rate of 0.05 were used to calculate the required number of participants using the G-power program (version 3.1.9.7), resulting in a sample size of 46. Considering a possible 10% participant dropout rate, it was planned to include 52 participants in the study.

Evaluations

Landing biomechanics

Landing biomechanics after jumping were assessed using the LESS. LESS is a field assessment method to identify potentially high-risk movement errors during landing after a vertical jump. Padua et al. (2009) reported that LESS has concurrent validity, high inter-rater reliability (intraclass correlation coefficient (ICC)=0.84), and excellent intra-rater reliability (ICC=0.91) [16].

The LESS consists of 17 evaluation items. Between the first and sixth items, the positioning of the legs and trunk at the moment of initial ground contact following a jump is assessed. Between items seven and eleven, foot placement errors are focused on. Items 12 to 14 analyze the movement of the lower extremities and trunk from initial contact to maximum knee flexion. Item 15 evaluates knee valgus. Lastly, items 16 and 17 provide assessments in the sagittal plane [16].

The LESS was recorded during the drop vertical jump (DVJ) task. Participants were allowed to attempt the task twice to successfully complete the DVJ task [27]. The participants began the DVJ by standing on a box 30 cm high. A line was

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drawn at a distance equal to half the participant's height, and the participant was instructed to jump forward and land just in front of this line, then jump to maximum height immediately after landing. If the participants failed to jump vertically from the box or did not reach maximum height after landing, the test was repeated. To capture frontal and sagittal views of all landing attempts, two iPhone 14 Plus phones with iOS 18.2 operating system were placed in front and to the right of the participant, and the videos were recorded. The LESS evaluation is done from video footage by focusing on the dominant leg [16]. LESS scores range from 0 to 17. A score of five or more errors indicates poor jump technique, while a score lower than five errors indicates good jump technique [25].

Dynamic knee valgus

DKV evaluation is made by measuring FPPA during the single-leg squat test (SLST) and the measurement protocol is adapted from Pisirici et al. [28]. During the landing phase of the SLST, an increase of 10° or more in FPPA is defined as DKV [29]. FPPA assessment was conducted using the 2D Spark Motion Pro™, a reliable method for DKV evaluation [30]. The participant stood barefoot on the tested leg. Before the test, participants were instructed to avoid trunk flexion, cross their arms at chest level, and extend the non-tested leg forward while maintaining extension during the squat. An iPad was placed on a tripod three meters away from the participant. FPPA measurement was taken at the maximum squat position. The FPPA value was recorded from the third of five consecutive SLSTs.

Jump performance

Jump performance was evaluated using the Countermovement Jump (CMJ) without arm swing test, utilizing the OptoJump Next System (Microgate, Bolzano, Italy). This measurement system comprises two parallel bars fitted with transmitter and receiver units. The photoelectric sensors integrated at ground level within the bars allow direct detection of the athlete's movements. The OptoJump system has demonstrated outstanding reliability and consistency for jump assessments, with a high intraclass correlation coefficient (ICC: 0.998) [31].

The CMJ without arm swing test is a plyometric movement in which the hands remain on the waist, assessing lower limb power enhanced through the stretch-shortening cycle. During the test, the athlete performs a squat followed by an explosive vertical jump. By eliminating upper body involvement, this test isolates lower limb strength [32].

The test protocol was adapted from Pisirici et al. [33]. Participants were first instructed to perform a light-paced jog for five minutes at a self-selected speed. At the beginning of the test, they stood at the center of the OptoJump platform with their feet approximately hip-width apart. With their hands positioned on their hips, they were instructed to squat until their thighs were parallel to the ground and then execute an immediate upward jump. Throughout the jump, participants were required to keep their hands on their hips, maintain full leg extension, and land in the same posture. The test was performed while wearing athletic shoes. Each participant completed three CMJ without arm swing attempts, with the best result recorded for analysis.

Statistical Analyses

Statistical analyses were conducted using the Statistical Package for Social Sciences version 24. To analyze the data descriptive statistics (including frequency, mean, standard deviation, minimum, maximum, and percentages) were utilized. The Kolmogorov-Smirnov test was applied to assess the normality of data distribution, confirming that the data followed a normal distribution within groups. Categorical variables were compared using the Chi-Square test, while the Independent Samples T-test was used to evaluate differences in quantitative variables between groups. A p-value below 0.05 was regarded as statistically significant.

Results

Demographic Characteristics

The baseline characteristics of the 52 participants included in the study were examined, and no significant differences were observed between the two groups ($p>0.05$). The LESS score for PLTG was 8.12±2.18, while for GLTG it was 3.19±0.98. The mean age of all participants was 12.37±1.24 years, and the mean body mass index (BMI) was 18.93±2.79 kg/m². All participants had right-dominant extremities. The demographic data of the participants is summarized in Table 1.

Table 1. Demographic characteristics of participants

	PLTG (n=26)		GLTG (n=26)		p[a]
	Mean±SD	Min-Max	Mean±SD	Min-Max	
Age (year)	12.40±1.11	10-14	12.34±1.38	10-14	0.744
Kilo (kg)	47.00±9.71	32-64	50.00±9.96	27-65	0.305
Height (m)	1.59±0.09	1.35-1.73	1.59±0.10	1.36-1.76	0.890
BMI (kg/m²)	18.35±2.43	13-22	19.51±3.15	13.78-25.72	0.177
Pain (cm)	0.24±0.66	0-2	0.30±0.78	0-3	0.703
Menarch	65.4%		57.7%		0.569[b]

PLTG: poor landing technique group, GLTG: good landing technique group, BMI: body mass index, Min: minimum, Max: maximum, SD: standard deviation, kg: kilogram, m: meter, cm: centimeter; [a]Independent Samples T-test, [b]Chi-Square Test, $p<0.05$

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Inter-Group Comparisons

The FPPA value of PLTG is 189.58°±18.84°, while the FPPA value of GLTG is 181.53°±15.51°. No statistically significant difference was found between the FPPA values of the groups (0.111; p>0.05). The jump height of PLTG is 24.68±5.98 cm, and the jump height of GLTG is 25.70±6.91 cm. No statistically significant difference was found between the jump heights of the groups (0.409; p>0.05). The inter-group comparisons are summarized in Table 2. No significant relationship was observed between the athletes' landing biomechanics and knee valgus or jump performances (p>0.05) (Table 3).

Table 2. Inter-group evaluations

	PLTG Mean±SD	GLTG Mean±SD	Mean difference (95% CI)	t	p[a]
FPPA (degrees)	189.58±18.84	181.53±15.51	7.82 (-1.87–17.51)	1.621	0.111
CMJT (height in cm)	24.68±5.98	25.70±6.91	-1.08 (-4.65–2.49)	-0.607	0.547

PLTG: poor landing technique group, GLTG: good landing technique group, CMJT: countermovement jump without arm swing test, FPPA: frontal plane projection angle, CI: confidence interval, cm: centimeter, SD: standard deviation; aIndependent Samples T-test, *p<0.05

Table 3. Relationship between landing biomechanics with dynamic knee valgus and performance

		FPPA	CMJT
LESS	r	0.127	0.103
	p	0.374	0.470

LESS: landing error scoring system, FPPA: frontal plane projection angle, CMJT: countermovement jump without arm swing test; r: Pearson Correlation Coefficient, *p<0.05

Discussion

We aimed to examine the lower extremity alignment and jumping performances of adolescent female athletes with good and poor landing biomechanics. According to the results of our study no difference was found between the groups' FPPA and jump heights. Also, there is no significant relationship between the athletes' landing biomechanics and DKV values or jump performance.

Landing mechanics after a jump is a significant risk factor for ACL injuries. In females, during the landing phase, alignment issues such as increased knee valgus are commonly observed as a result of the increased load placed on the knee and hip joints [10]. Female athletes who exhibit increased DKV and high abduction loads are at a higher risk of ACL injuries [10,19]. Similarly, knee valgus emerges as a significant biomechanical factor during landing after a jump in adolescent female athletes, and poor landing biomechanics are often associated with factors such as knee valgus and abduction moment. It has been shown that when the knee is in an excessive valgus position and the abduction moment increases, the risk of injury can significantly rise [19]. Our results showed no significant difference was observed in FPPA values between groups with poor and good landing biomechanics. To the best of our knowledge, there is no study in the literature comparing knee valgus values based on landing biomechanics in early adolescent female basketball players. Our study contributes to the literature in this regard.

The LESS is used specifically to detect biomechanical errors during the landing phase, while the drop jump test is a dynamic movement that includes this phase. The relationship between these two concepts is important for better understanding athletes' injury risk. "Butcher et al. investigated the relationship between maturation and biomechanical characteristics associated with ACL injury. In the results, they reported that LESS scores were significantly associated with contact time but did not show a significant relationship with jump height. Furthermore, it was highlighted that while athletes with moderate to low LESS scores exhibited greater power and a higher reactive strength index, these enhanced performance metrics did not lead to an increase in jump height [34]. Holden et al. aimed to provide normative data for the clinical analysis of landing kinematics using the CMJ test in early adolescent male and female athletes and to determine whether there was a difference between genders. A total of 97 male and 84 female athletes (13±1.41 years) in the first year of high school were included in the study. The findings of the study were understood to indicate that the initial year of high school, when young adolescent girls first engage in high school sports, could be an optimal period to evaluate movement quality during functional activities and, if needed, introduce injury prevention strategies [24]. Another study that may help explain why athletes with better landing biomechanics do not necessarily exhibit higher jump performance was conducted by Pedley et al. [35]. The study results indicated that using general performance outcomes, such as jump height or peak values, to assess the stretching–shortening cycle in young individuals would be insufficient, as these data do not provide information about the timing-based characteristics of jumping and landing movements. They also stated that although female athletes show significant increases in overall strength levels throughout growth, there are only small maturation differences in terms of relative strength or spring-like behavior (the elasticity of muscles and tendons and their capacity to store and release energy). Consequently, they emphasized that most female athletes exhibit poor performance in stretching–shortening cycle function regardless of their maturity level." [35]. In our study, no significant difference was found in jump performance between participants with good and poor landing biomechanics. This result is consistent with the literature. Although jump height is a general performance indicator, it may be insufficient in capturing the nuanced differences in landing

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biomechanics. When examining the relationship between post-jump landing biomechanics and jump performance, we believe that analyzing data such as maximum force and reactive strength index instead of jump height is necessary. Additionally, during early adolescence, assessing movement quality during functional tasks may be a better evaluation option than focusing on jump performance.

Limitations

We consider not using a force platform in the evaluation of jumping performance, and the lack of assessment of the myoelectric activity and flexibility of the muscles contributing to jumping and valgus formation in the lower extremity as limitations of our study. We also considered the inability to inquire about the participants' basketball history, training frequency, and team positions as a limitation.

Conclusion

There is no difference in DKV and jump performance between early adolescent girls with good and poor landing biomechanics. Further studies are needed to examine the factors contributing to landing biomechanics in this age group of athletes.

Conflict of Interests
The authors declare that there is no conflict of interest in the study.

Financial Disclosure
The authors declare that they have received no financial support for the study.

Ethical Approval
The Non-Interventional Clinical Research Ethics Committee of Bahçeşehir University approved our ethics application on 20.12.2023, with decision number 2023-21/04.

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