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The Landing Biomechanics in Youth Female Handball Players Does Not Change When Applying a Specific Model of Game and Weekly Training Workload

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Abstract: This study aimed to explore the effects of competitive match play and subsequent training during typical competitive microcycle on landing biomechanics in female youth handball players. A group of 11 elite female youth players (age: 14.3 ± 0.6 years; stature: 165.9 ± 8.1 cm; body mass: 58.4 ± 10.6 kg; maturity offset: 0.4 ± 0.8 years) were tested prior to a competitive match, immediately after the match, 48 h after the match, 96 h after the match, and before the next match. The players performed two analyzed trials of a single leg (preferred) counter movement jump. The "Landing Error Scoring System" (LESS) was used to analyze the participants' landing biomechanics. Results: There was no significant effect of a competitive handball match on LESS ($Z = 0.28$; $p = 0.78$). No statistically significant difference in LESS was found between the first and the last measurement ($Z = 1.01$; $p = 0.31$). No significant main effect of time was found for landing biomechanics in the observed eight-day period ($\chi^2 = 4.02$; $p = 0.40$). The results of the study indicate that a model of weekly loading during in-season, including competitive match play, does not decrease lower limb biomechanics during landing and does not contribute to an increased risk of anterior cruciate ligament injury in female youth handball players during a competitive microcycle.

Keywords: fatigue; landing error scoring system; injury; ACL; risk factor; maturation

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1. Introduction

Handball is a team sport of an intermittent character with frequent physical contacts between players in which players perform a significant number of sudden accelerations and decelerations, changes in speed, unanticipated rapid changes in directions, and jumping and landing tasks [1,2]. Although differences in gender, age category, and performance levels in game load exist [3], all handball players are exposed to a high risk of injury when the hours of athlete exposure are taken into account [3,4]. In youth female players, the reported incidence was 6.8 injuries/h of exposure in a recent systematic review by Gonzales et al. [5]. In the case of anterior cruciate ligament (ACL) injury, which represents one of the most serious and frequent injuries in youth female players [6,7], the risk of injury during handball matches was found to be thirty times higher compared to training, while 90% of ACL injuries were non-contact injuries [8,9]. One of the reasons is that the biomechanics of the abovementioned specific movements may be greatly influenced by both external and internal factors, including the contact nature of the game and its specific requirements, female gender, and muscle fatigue [10–12]. As frequently suggested by the available literature, ACL injuries seem to be more prevalent in the later stages of handball matches, when muscle fatigue is present [8,13,14] and movement biomechanics and neuromuscular functions are altered [15–17]. Impaired activity of the muscles that maintain a centered position in the knee joint during dynamic activities is manifested by changes in landing biomechanics associated with an increase in ACL loading and thus increased susceptibility to ACL injury [18,19].

Especially in young players, it is important to systematically develop the training status, including players' physical qualities during the whole season [20,21]. However, not only in adult sport but also in youth sport, due to the unequal training and/or game workload, the accumulation of muscle fatigue may appear in training microcycles and consequently reduce the efficiency of the training process or match performance and increase the acute risk of injury. Therefore, it is surprising that only a few studies appear to have explored the potential of the accumulated effects of game load and the subsequent training week load on injury risk mechanisms in female youth sport. In team sports, most attention has been paid to youth soccer. One study has suggested that physical stress (determined as a weekly total of minutes in match play and training) and the session rate of perceived exertion are related to injury incidence in youth soccer players and female youth basketball players [22]. It has also been identified that higher accumulated workloads are associated with a greater injury risk [23]. The findings of recent studies on female youth soccer players [24,25] suggest that neuromuscular functioning may still be compromised at least 4 days after match play and may therefore increase the risk of injury. A recent study on male youth soccer players by Lehnert et al. [26] shows that a weekly load including competitive match play may compromise performance and increase injury risk in players.

It has been proved that jump landing is one of the most common movement patterns for ACL injury [27]. It has also been demonstrated that a proper biomechanical strategy may reduce ACL loading during jump landing and decrease the risk of knee injury [28–30], and that lower limb movement kinematics during jump landing is a modifiable risk factor of ACL injury [12,23,31,32]. The knee-extension moment, proximal anterior–tibial shear force, knee valgus–varus moment, and knee internal–external rotation moment are frequently involved in ACL injury [20]. Numerous studies have demonstrated that females land more frequently with increased knee valgus, reduced knee and hip flexion, increased tibial shear and tibial rotation [33,34]. Moreover, it was suggested that increasing neuromuscular fatigue was reflected in the change in the position of the lower limbs during jump landing [26,31,35]. For this reason, different movement patterns during the early landing phase are monitored and evaluated to identify biomechanical deficits and reduce the risk of injury in players [26,36,37]. In this context, a video-based analysis is used to identify potential ACL risk factors related to movement parameters [29,38,39] and the "Landing Error Scoring System" (LESS) is a valid and reliable screening tool which identifies landing-related movement patterns associated with non-contact ACL injuries [12,29,31,40]. In the referred study Padua et al. [26], the authors reported good sensitivity of 86% and acceptable specificity of 64% to identify the risk of non-contact ACL injury in youth female and male soccer players. The authors also found out that the relative risk of sustaining an ACL injury was nearly 11 times higher in players with a LESS score five and more in comparison with players who had scored less than five.

The available findings, albeit limited, suggest that the accumulated effects of competitive match play and subsequent training prior to next competitive match play need to be explored in team sports to determine the risk of injury during training microcycles as well as the readiness to reperform. As far as we are aware, limited number of studies assessed neuromuscular and biomechanical deficits in youth female handball [26,36,41]. However, no study has observed the changes in lower limb movement biomechanics during landing as a modifiable risk factor of ACL injury in youth handball during the training microcycle. This knowledge may improve our understanding of age-specific responses to training load, help determine the periods with an increased risk of injury and consequently help optimize the training and game load during training microcycles. For this reason, the objective of the present paper was to investigate the effects of competitive match play and subsequent training during a typical competitive microcycle on landing biomechanics in female youth handball players.

2. Materials and Methods

2.1. Participants

This study included a group of 11 elite female youth handball players (age: 14.3 ± 0.6 years; stature: 165.9 ± 8.1 cm; body mass: 58.4 ± 10.6 kg; maturity offset: 0.4 ± 0.8 years) from a female elite handball club. All players had 6–7 years of experience with a regular training process. In the current annual training cycle, players participated on average in a total of three training sessions per week (one 90 min fitness session included; total training load, 270 min) and played 44 competitive matches and 20 friendly matches in the competitive season. All players participated in the competitive match and completed all training sessions during the following microcycle. Players completed a health questionnaire, and only players free of musculoskeletal lower-extremity injury in the previous 4 weeks or serious injury in the previous 6 months were included in the research. The study was approved by the Institution's ethics committee and conformed to the Declaration of Helsinki regarding the use of human subjects. All tested players were fully informed about the aim of the study and the testing procedures that would be employed. Before the study, a written informed parental consent and players' verbal assent to the testing procedures were obtained.

2.2. Procedures

The study was of a cross-sectional design. The players were tested in the gym five times over an eight-day period during the second part of the competitive season. The testing was performed prior to a competitive match (the match time was 50 min; player match time was similar as a result of regular rotation of the players controlled by the coach), immediately after match play, and during the following training microcycle, specifically 48 h, 96 h, and 168 h after match play (prior to the next competitive match). Before the 1st testing, players undertook a familiarization session and carried out the test in training sessions a week before the testing to avoid the learning effect of the test. The training content of the observed female players during the competitive microcycle is shown in Table 1.

Table 1. Training content of the observed group of female handball players.

Special Training Indicators	Minutes per Week
Warm-up	45
Anaerobic endurance	30
Strength	25
Speed	20
Coordination	20
Individual attacking actions	20
Individual defensive actions	20
Offensive combinations	20
Defensive combinations	20
Offensive systems	10
Defensive systems	10
Training game	30

2.2.1. Anthropometry

Body mass measures were taken at the beginning of the 1st testing session, using a weight scale, Tanita UM-075 (Tanita, Tokyo, Japan). For the purpose of biological maturity assessment, leg length, tibia length, and standing and sitting height measures were taken at the beginning of each measurement, using a stadiometer, A-226 Anthropometer (Trystom, Olomouc, Czech Republic). Biological maturity was predicted by the calculation of maturity offset, using the sex-appropriate equation [42].

2.2.2. Landing Mechanics

The participants performed three trials of a single leg counter movement jump (one practice and two analyzed trials), with a 1-min rest between the trials. The average value of the two trials was used in a subsequent analysis [43]. The participants were instructed to take two steps forward; immediately jump as high as possible off one leg (preferred), imagining that they were reaching for a ball above their head; and land on two feet. This stop-jump task is considered more game-specific compared with the previously used drop-jump task off a box and is a convenient testing tool particularly for female athletes and increases the ecological validity of testing [44–46]. Furthermore, the practice of jumping from a box in the context of the LESS has encountered criticism, with concerns raised about its sport-specificity, its efficacy in detecting landing biomechanics linked to lower limb injuries, and its utilization in predicting ACL injuries [47–49]. Recordings from two high-definition video cameras, SONY HXR-MC2000 and SONY HXR-NX5E (SONY Corporation, Tokyo, Japan; frequency 25 Hz), were used for the purpose of a two-dimensional biomechanical landing analysis. The cameras were positioned on tripods 3.5 m from the marked landing area in the frontal and sagittal plane. For the evaluation of images, the ImageJ software 1.50i (National Institute of Health, Bethesda, MD, USA) was used. The videos of the participants were scored retrospectively by the same experienced rater [50]. The LESS, a 17-item scale devised by Padua et al. [40], was applied to evaluate the landing mechanics of the participants. The initial set of observable criteria pertains to the alignment of the lower limbs and the trunk during the moment of the first contact with the ground (Items 1–6). The second set of criteria aims to evaluate inaccuracies in foot positioning (Items 7–11). The third set of criteria is dedicated to examining the motion of the lower extremities and trunk from the point of initial ground contact to the instance of either maximum knee flexion angle (Items 12–14) or maximum knee valgus angle (Item 15). The final two "comprehensive" criteria encompass the overall movement in the sagittal plane and the rater's general assessment of landing quality (Items 16 and 17). The LESS is a comprehensive, valid, and reliable procedure which includes a comprehensive assessment of multiplanar biomechanics which could be used to identify individuals at a risk of sustaining a non-contact ACL injury [31,43], where the landing is evaluated by analyzing the records of landing in the sagittal and frontal planes. The scoring is based on the presence or absence of kinematic characteristics, using a standardized checklist where a higher LESS score suggests poor landing technique, while a lower score is indicative of a proficient jump-landing technique [40]. The overview of the LESS specific errors is presented in Table 2 (adopted from Hanzlíková and Hébert-Losier [51], with permission of authors).

Table 2. Landing Error Scoring System's specific errors.

No.	Item	Definition of Error
1.	Knee flexion at IC	Knee flexion < 30°
2.	Hip flexion at IC	Thigh is in line with the trunk (hips not flexed)
3.	Trunk flexion at IC	Trunk is vertical or extended at the hips (i.e., not flexed)
4.	Ankle plantar flexion at IC	Heel-to-toe or flat foot landing at initial contact
5.	Knee valgus at IC	Center of the patella is medial to the midfoot at initial contact
6.	Lateral trunk flexion at IC	Midline of the trunk is flexed to the left or the right side of the body at initial contact
7.	Stance width (wide)	Feet are positioned greater than shoulder-width apart (acromion processes) at initial contact
8.	Stance width (narrow)	Feet are positioned less than shoulder-width apart (acromion processes) at initial contact
9.	Foot position (toe-in)	Foot is externally rotated more than 30° between initial contact and maximum knee flexion

Table 2. *Cont.*

No.	Item	Definition of Error
10.	Foot position (toe-out)	Foot is internally rotated more than 30° between initial contact and maximum knee flexion
11.	Symmetric foot contact at IC	One foot lands before the other foot, or one foot lands heel to toe and the other foot lands toe to heel
12.	Knee flexion displacement	Knee flexes less than 45° between initial contact and maximum knee flexion
13.	Hip flexion at MKF	Thigh does not flex more on the trunk between initial contact and maximum knee flexion
14.	Trunk flexion at MKF	Trunk does not flex more between initial contact and maximum knee flexion
15.	Knee valgus displacement	At the point of maximum medial knee position, the center of the patella is medial to the midfoot
16.	Joint displacement	Joint displacement: soft (0), average (1), stiff (2)
17.	Overall impression	Overall impression: excellent (0), average (1), poor (2)

Abbreviations: IC, initial contact; MKF, maximum knee flexion.

2.2.3. Statistical Analysis

The data analysis was performed in the Statistica program (version 12; StatSoft, Inc., Tulsa, OK, USA). The distribution of raw data sets was analyzed for homogeneity and skewness by means of the Kolmogorov–Smirnov test. Basic descriptive statistics (means and standard deviations and medians) were used to describe the LESS measure. The one-way Friedman ANOVA was used to investigate the effect of time on the LESS score because of ordinal nature of data and normality violation of the variables measured. The Wilcoxon paired test was applied to perform a comparison of the results before and after the competition and a comparison of the results at the beginning and end of the microcycle. Statistical significance was accepted at $p \leq 0.05$ for all statistical tests.

3. Results

The mean (±SD) and median values of the LESS score for the observed female handball players are shown in Table 3. No significant effect of match play on LESS was evident ($Z = 0.28$; $p = 0.78$). No statistically significant difference in LESS was found between the first and the last measurement (i.e., before the next match) ($Z = 1.01$; $p = 0.31$). No significant main effect of time was evidenced for landing biomechanics indicated by means of the LESS score in a competitive microcycle ($\chi^2 = 4.02$; $p = 0.40$).

Table 3. Landing Error Scoring System—mean (±SD) and median values during the observed periods in U14 female handball players ($n = 11$).

Measurement	Mean (±SD)	Median
Prior to 1st match play	6.36 ± 0.42	6.00
Post 1st match play	6.50 ± 1.16	6.00
48 h post 1st match play	5.82 ± 1.15	5.50
96 h post 1st match play	6.72 ± 1.09	6.50
Prior to 2nd match play	5.95 ± 1.04	5.50

4. Discussion

This study was deliberately designed in an applied ecological setting so as to investigate changes in players over a "typical" weekly cycle. The findings from the study indicate that landing biomechanics was not compromised after the competitive match, during the following weekly competitive microcycle, and before the next competitive match. After the match, there was a non-significant increase in the LESS score by 2.2%, and a comparison of the first measurement (before the first competitive match) and the measurement at the end of the competition microcycle (before the second competitive match) showed a non-significant decrease in the LESS score by 6.5%.

4.1. Changes in Post-Game Landing Biomechanics

After the first match, the landing biomechanics based on the LESS test did not indicate potential acute related match effects that would compromise the landing technique [31]. Thus, the coordinated activity of the large muscle groups that help to control knee joint stability during landing after the jump was probably not compromised, and neuromuscular performance was maintained, thus reducing the risk of injury [18].

The finding of the current study after the match play is not consistent with the results of the previous studies involving youth athletes. These studies have demonstrated a deterioration of most of the observed parameters after match play and/or after a specific fatigue protocol both in youth females [24,52] and males [16,53–56] soccer players. The finding of the current study suggesting no significant decrease in landing biomechanics after match play could be explained, in particular, by the equally distributed match workload among eleven players, which lowered match-related fatigue. Other reasons for the difference between the findings of the current study and the abovementioned studies could be the differences in age and gender of the players, the differences between game performance in handball and soccer, and the differences between real match-play workload and a specific fatigue protocol.

4.2. Changes in Landing Biomechanics during the Competitive Microcycle

The data suggest that, also during the following weekly competitive microcycle, players' landing movement pattern did not change. This result indicates that there were no accumulated effects on the LESS score. As landing mechanics was not compromised before the second competitive match and was similar to baseline levels (before the first match), players were probably ready to reperform at the end of the observed competitive microcycle with a typical training load. The results show that the applied model of game and weekly training workload is proportional to the training status of the players and provides enough space for recovery of the players and elimination of residual muscle fatigue. On the contrary, the question is whether three training units per week represent a sufficient workload for 14-year-old handball players on their development pathway.

It is not possible to compare the results of the current study with other findings in female youth handball players, as no available studies have examined changes in the landing biomechanics during a microcycle. Nevertheless, these data do not correspond to the findings of a few studies on youth soccer players which showed that some observed indicators of the risk of injury were compromised during a competitive microcycle. Specifically, a study on female youth soccer players indicated that, 96 h later, the eccentric fatigue task torque returned to pre-fatigue levels, but the electromechanical delay was still significantly compromised post fatigue [24]. Also in soccer, Hughes et al. [25] reported significantly elevated creatine kinase levels in 13–16-year-old female players 80 h post-match play and during the training week. In another study by Lehnert et al. [26] on U14 and U16 male youth soccer players, the LESS and other injury risk indicators were not compromised at the end of the observed microcycle (before the next competitive match) in the U14 category; nevertheless, there were significant changes during the microcycle in most of the indicators. In the U16 age group, players demonstrated reductions in the reactive strength index and increases in the creatine kinase level at the end of the observed microcycle.

Although no changes in the landing biomechanics in youth female players were found in the current study, the LESS score in all of the measurements indicated that the players had poor landing mechanics, which might place them in the high-risk category (value range 5.95 to 6.72; average score 6.27 $\pm$ 1.17) and consequently could point to an increased risk of injury during the match play and training process, not only in the observed period. According to the authors of the LESS scale, the key cutoff value suggested for high injury risk is five points [40]. The performance of the tested person is evaluated as good if below five points, while a score above five points is associated with a higher risk of ACL [40,43]. Padua et al. [31], in their study involving 348 boys and 481 girls (soccer players) whose average age was similar to the players in our study (13.9 years vs. 14.3 years), proved that a LESS score equal to or greater than six was associated with a greater risk of injury as opposed to individuals with a value equal to or lower than four. Although the conditioning program designed for the group of female adolescent handball players included plyometric training, they did not take part in systematic training of landing and/or neuromuscular training program. As preventive training programs have been shown to reduce the risk of lower limb injuries in youth athletes [57,58], we believe that a preventive training program, which would also encompass movement skills, including jumping and landing, would be useful for the observed female handball players to improve their landing biomechanics [59]. This applies not only to female players of the observed age category but also to other categories, including prepubescent players. This could potentially contribute to a decrease in the relatively high rate of lower limb injury in female youth handball players, particularly those around and/or after Peak Height Velocity (PHV).

It should also be noted that the participants in this study were female, which is considered one of the main risk factors for developing ACL injuries [60]. Higher LESS values in females compared to males, indicating an increased risk of ACL injury, were found in several studies in which the average LESS values in females were in the risk zone for ACL injury [31,40,61]. Previous studies have shown differences in lower limb biomechanics between men and women [37], particularly in the position of the hip and knee joint during flight and land. The reduced abductor muscle force in females (especially musculus gluteus medius) may be one of the causes of the occurrence of non-contact ACL injury, as it contributes to insufficient stabilization and excessive adduction and internal rotation in the hip joint. This has an impact not only on the hip position itself but also on the knee joint, where the abduction angle increases. These variables increase the forces on ACL, thereby increasing the risk of injury [62].

Moreover, the age of the subjects in this study was 14.3 ± 0.6 years, and the maturity offset was 0.4 ± 0.8 years, indicating that the subjects were around and/or after PHV. Previous studies [63,64] showed that girls after PHV had the largest increase in tibial abduction moment after landing, which has significant implications for the biomechanics of knee joint loading. Also, Hewett et al. [63] consider the period of PHV or post-PHV a risk factor of ACL rupture due to impairment of knee landing biomechanics. In this regard, we can consider the observed female players as an "at-risk" group.

4.3. Limitations

One of the limitations of the current study was that only 11 female youth players from the U14 competitive age group from a professional handball club were observed. Therefore, the results of this study should only be generalized to similar groups of players. Moreover, it was not possible to determine the weekly load using GPS, as this was not available to the research team. Another limitation is that the study design did not allow testing prior to a subsequent weekly training session. In future studies, it would also be appropriate to monitor the effects of competitive match play and subsequent training during training microcycles not only on landing kinematics but also on other parameters obtained by both objective (e.g., force platform) and subjective (e.g., the Visual Analogue Scale) diagnostic methods.

5. Conclusions

It appears that this study is the first to show that landing biomechanics, as one of the ACL injury risk factors, is not impaired after competitive match play in youth female handball players around and/or after PHV provided that the match time is similar as a result of regular rotation of the players controlled by the coach during the game. Similarly, landing biomechanics does not change during the subsequent competitive microcycle with three team training units (which is typically applied in handball youth female academies in the Czech Republic). This suggests players' readiness to reperform at the end of the competitive microcycle. These results indicate that this model of weekly loading during the in-season, which includes competitive match play, does not increase susceptibility to ACL injury in 14-year-old female players during a competitive microcycle. However, in the observed group of handball players, the LESS score suggests that the players may be considered an "at-risk" group, and, therefore, more attention should be paid to the jump-landing technique of these players during their long-term development.

Although the results of the current study cannot be generalized, considering the high incidence of injuries in female youth sport, handball included, the findings of the current study have implications for weekly training strategies, especially in competitive microcycles. Coaches are recommended to consider the presented training load and match load strategy, which seems to provide enough time for recovery, and also pay attention to the quality of landing mechanics and other handball-specific movements of individual players. Coaches should also pay attention to the technique of fundamental movement skills, including takeoff and landing skills, particularly in preadolescent players, introducing players to, e.g., low-impact hopping and jumping. Moreover, specific intervention programs should be applied to reduce neuromuscular and biomechanical deficits in players and contribute to the optimization of players' developmental pathway.

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Data Availability Statement: The data presented in this study are available upon request from the corresponding author. The data are not publicly available, due to ethical and privacy restrictions.

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