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Single leg landing movement differences between male and female badminton players after overhead stroke in the backhand-side court

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ABSTRACT

Females showed higher anterior cruciate ligament (ACL) injuries rate on the opposite side of dominant hand compared with males during single leg landing in the backhand-side court after overhead stroke. The purpose of this study was to conduct biomechanics testing including kinematics and kinetics to provide some insights on the ACL injuries risks during single leg landing in the backhand-side court after overhead stroke between females and males. Twenty collegiate badminton players (10 females, 10 males) voluntarily participated in this study. Sagittal plane kinematic and kinetic data of the lower limb, and their ground reaction forces during the single leg landing in the backhand-side court after overhead stroke were collected. Results shown that, at the peak posterior ground reaction force (GRF) moment, the ankle dorsiflexion, knee and hip flexion angles of the female were lower than that of male. Meantime, the knee extension moment of the female was lower than that of males but the hip extension moment of the female was larger compared to males at the peak posterior GRF moment. The peak vertical and posterior GRF of female badminton players were larger than that of males. Decreased hip, knee, and ankle flexion angles at the peak posterior GRF moment and greater peak vertical and posterior GRF may expose female badminton players to the higher risk ACL injuries compared to males during single leg landing after overhead stroke in the backcourt-side. Preventative training programs designed to prevent the ACL injuries rate of female badminton players should take these factors into consideration.

1. Introduction

Badminton is one of the most popular sports in the world, with 200 million adherents (Phomsoupha & Laffaye, 2015). The popularity of badminton is growing rapidly, individuals of varying ages, physical abilities and socioeconomic conditions can easily participate in this sport (Zhang et al., 2016). However, the large participation in sports is associated with high injuries (Shephard, 2003). Nearly one third of the badminton injuries occurred in the lower limb especially the knee (Goh, Mokhtar, & Mohamad Ali, 2013). According to the epidemiology study of badminton injuries, the lower limb accounted for more than 50% of the injuries also with high correlations of the knee injuries (Yung et al., 2007) ACL injuries are quiet common in badminton, which accounted for 2.7% of the total ACL injuries in fifteen normal sports (Gupta et al., 2016). The incidence rate in terms of injuries per person per year

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for male (0.09) was lower than female competitive badminton players (0.14) (Hensley & Paup, 1979). Females who participate in pivoting and jumping sports had a higher incidence of ACL injuries compared with males in the same sports (Horita et al., 2002). Moreover, previous epidemiology study about badminton injuries pointed out that females had a high incidence of experiencing ACL injuries compared with males during the single leg landing after overhead stroke (Six male and fifteen female badminton players) (Kimura et al., 2010).

The most common ACL injuries are non-contact ACL injuries, and ACL injuries often occur in sports during cutting or pivoting maneuvers and single leg landing (Michaelidis & Koumantakis, 2014). These movements are basic movement patterns in the competitive badminton. However, little attention has been paid to the high incidence of knee injuries in the badminton (Kimura et al., 2012). This might be due to badminton as a racket sport which is believed to have a lower risk of injury (Lees, 2003). ACL injuries occur with most or all of the weight shifted to a single foot (Olsen et al., 2004; Sun et al., 2016). In the badminton movement, all overhead power strokes were played while the body elevating, this was evidenced by the force platform "unweighted" (Waddell & Gowitzke, 2000). That means the players must land their lower limb with one leg or two legs after overhead stroke, with the single leg landing in many cases. This landing pattern in the badminton movement is relatively associated with knee injuries as the knee was the dominant shock absorber for both genders during the single leg landing (Decker et al., 2003). An epidemiological study showed that most common ACL injuries in badminton were single leg landing after overhead stroke (Kimura et al., 2010). Furthermore, the latest finding found that single leg landings after an overhead strokes (520) account for about 21.07% of the whole badminton game events (2468), about half of them are single-leg landings in the backhand-side courts (221) which are reported to be associated with a high knee injury rate (Sasaki, Nagano, & Ichikawa, 2018).

The mechanisms of ACL injuries could be divided into extrinsic and intrinsic variables (Boden et al., 2000). For the intrinsic variables, anatomical, hormonal, and neuromuscular are the main contributions to the gender disparity observed in ACL injury rates. As the first two items are difficult to be modified or nearly could not be modified, there is an increasing trend to consider that poor or abnormal neuromuscular control of the lower limb biomechanics, especially in the knee joint, is a primary contributor to ACL injuries (Hewett et al., 2005). Previous study pointed out that neuromuscular control strategies employed by females during movement account for abnormal knee joint loading, which places females at greater risk for ACL injury (Chappell et al., 2002). The biomechanical studies have identified several potential mechanisms of ACL injury during the high-risk sports. Sagittal plane factors have been identified as important contributors to ACL injury mechanisms (Hashemi et al., 2011; Julie et al., 2008). The risk of ACL injuries may depend on the sagittal plane body positions during landing (Shimokochi & Meyer, 2011). The nature of the non-contact ACL injuries indicates that the ACL injury risks can be reduced through specific neuromuscular training to modify lower extremity biomechanics in athletic tasks, especially for landing tasks (Myklebust et al., 2003). Thus it is important to identify what biomechanics characteristics of the female during landing, especially the single leg landing after overhead stroke in the backhand-side court, might be risk factors for the ACL injury. That would help coaches and physiotherapists develop effective prevention programs of ACL injury for female badminton players. Thus it is necessary to explore what biomechanics factors contributed to the higher ACL injury rate in females while single leg landing after the overhead stroke compared to males. The purpose of this study was to conduct biomechanics testing including kinematics and kinetics to provide some insights on the ACL injuries risks during single leg landing in the backhand-side court after overhead stroke between females and males. The hypothesis was that female athletes would display a lower knee and hip flexion angles and higher knee extension moments compared to males during the single leg landing after overhead stroke.

2. Materials and methods

2.1. Participants

Ten collegiate female badminton players (age: 22 ± 2.5 years, height: 162 ± 2.8 cm, body mass: 52 ± 3.75 kg, and playing years: 6.5 ± 2.6 years) and ten collegiate male badminton players (age: 23 ± 2.5 years, height: 178 ± 3.5 cm, body mass: 64 kg ± 4.25 kg, and playing years: 6.8 ± 2.2 years) voluntarily participated in this study. All participants were recruited from Ningbo University. All players were right-handed and participated in an organized badminton club currently. Each participant had played the badminton at least three times per week (6.7 ± 2.3 h for males, 6.4 ± 3.1 h for females) and had been active in badminton games (at least twice per month). All subjects were free from lower limb injuries and surgery treatment for at least six months before the experiment, and were in good health. Informed consents were obtained from all participants with signed written informed consent form to participate this study before the test. This research was also approved by the Ethics Committee of the Ningbo University (File number: NB20180601).

2.2. Experimental protocol

Same rackets were provided by our laboratory to reduce the errors in the experiment. Before the test, the participants were asked to perform fifteen minutes warming up (running, static stretch, and several badminton overhead strokes) and familiarize to the experiment environment without markers. Participants were instructed to perform each test at a predefined starting point then back to the same point with maximum effort after contact the shuttlecock from a standardized initial position (Fig. 1). Participants had a 30-s rest between each trial to minimize the influence of fatigue. At the actual test, each participant was asked to perform the forehand overhead stroke with maximum effort in the backhand-side court for six successful actions.

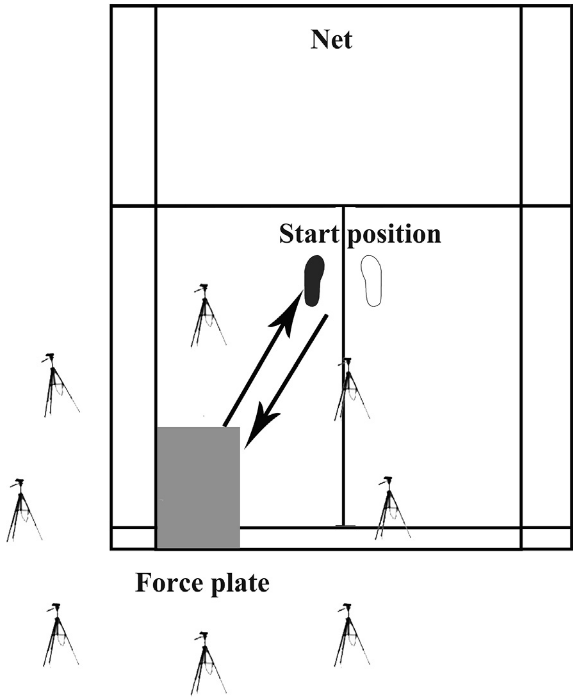

Fig. 1. Illustration for the movement and devices position. Participants were instructed to perform each test at a predefined starting point then back to the same point with maximum effort after contact the shuttlecock from a standardized initial position.

2.3. Data collection and processing

Eight infrared cameras 3-dimensional motion analysis system (Oxford Metrics Ltd., Oxford, UK) at 200 Hz was used to collect the kinematic variables of the participant during left leg landing after overhead stroke in the backhand-side court. Ground reaction forces were collected at 1000 Hz using an AMTI force plate (model OR6; AMTI, Watertown, Massachusetts, USA) embedded in the floor and synchronized with the Vicon system for simultaneous collection. The marker placement set is based on the previous literature (Yang et al., 2017), None-contact ACL injuries typically occur in the early phase of landing (Boden et al., 2000). The retroreflective marker trajectories of the left lower limbs were filtered through a Butterworth filter at a cut-off frequency of 6 Hz and the ground reaction force (GRF) signals were smoothed at 50 Hz in the visual 3D software (4.00.20, C-Motion Inc., USA). The intersegmental dynamics model was used to calculate kinematics and internal joint moment values at the ankle, knee and hip in the sagittal plane from the filtered marker coordinate data and force data in an inverse dynamics solution (Huang et al., 2013). A right-hand rule was used to determine the polarity of the angular variables. Landing phase in this study was defined as the time interval between initial contact and peak posterior GRF (Lin et al., 2012). The ankle, knee and hip angle in sagittal plane at initial contact and peak posterior GRF moments, external moments of the ankle, knee and hip in sagittal plane and peak GRF in vertical and posterior directions were selected in this study as these parameters are the main detrimental factors related to ACL injuries (Lin et al., 2012; Podraza & White, 2010; Schmitz et al., 2007). Ground reaction force and joint moment were normalized by the body weight (BW).

2.4. Statistical analyses

The statistical results were analysed in the SPSS19.0 (SPSS Inc., Chicago, IL, USA). The shape of distribution of the raw data collected was checked using the Kolmogorov–Smirnov test and demonstrated that all data had a normal distribution ($p > 0.05$). Homogeneity with Levene's test showed homogeneous. An independent sampled *t*-test was applied for analysing the differences of the lower limb kinematics and kinetics data between the female and male badminton players at the initial contact moment and the peak posterior GRF moment during the left limb landing after an overhead stroke. The significance level was set at 0.05. In addition, the effect size of changes in each variable was calculated using the Cohen’s d effect size, and it was interpreted with the following standards: 0–0.19 trivial, 0.2–0.59 small, 0.6–1.19 moderate, 1.2–1.99 large, and ≥2 very large (Cohen, 1988).

3. Results

In this study, no significant differences were found between female and male in ankle, knee and hip angles at the initial contact moment (Table 1, Fig. 2). But at the peak posterior GRF moment, the ankle dorsiflexion angle of the female was lower than that of male (p = 0.000, Table 1, Fig. 2). Meantime, the knee and hip flexion angles of the female were smaller compared to the males

Table 1
Comparison of joint angles in the sagittal plane at the moment of initial landing and peak posterior GRF, joint angle moments in the sagittal plane and peak GRF values at the moment of peak posterior GRF between female and males, mean ± SD.

Variables	Female	Male	Confidence intervals	*p*	*d*
Initial landing moment					
Ankle dorsiflexion angle (deg)	44.73 ± 1.91	45.16 ± 1.46	(−1.16,2.04)	0.573	0.26
Knee flexion angle (deg)	29.40 ± 2.07	30.9 ± 2.89	(−1.67,3.01)	0.549	0.60
Hip flexion angle (deg)	19.60 ± 1.63	20.08 ± 2.03	(−1.25,2.22)	0.565	0.26
Peak posterior GRF moment					
Ankle dorsiflexion angle (deg)	86.36 ± 1.48	92.95 ± 2.29	(4.77,8.39)	0.000	3.41
Ankle plantarflexion moment (Nm/kg)	−1.53 ± 0.12	−2.11 ± 0.27	(−0.76,−0.36)	0.000	2.78
Knee flexion angle (deg)	41.23 ± 1.93	50.75 ± 4.37	(6.35,12.70)	0.000	2.82
Knee extension moment (Nm/kg)	−1.26 ± 0.25	−2.2 ± 0.25	(−1.17,−0.71)	0.000	3.84
Hip flexion angle (deg)	30.66 ± 2.14	39.10 ± 3.22	(−0.76,−0.37)	0.000	3.08
Hip extension moment (Nm/kg)	−2.81 ± 0.10	−2.65 ± 0.17	(0.03,0.29)	0.000	1.39
Peak posterior GRF (BW)	1.15 ± 0.10	0.95 ± 0.15	(0.08,0.31)	0.003	1.57
Peak vertical GRF (BW)	2.95 ± 0.17	2.57 ± 0.27	(0.17,0.59)	0.001	1.68

(p = 0.000, Table 1, Fig. 2).

The ankle plantarflexion moment of the female was smaller than that of males at the peak posterior GRF moment (p = 0.000, Table 1, Fig. 2). The knee extension moment of the female was lower than that of males (p = 0.000, Table 1, Fig. 2) but the hip extension moment of the female was larger than that of males (p = 0.000, Table 1, Fig. 2) at the peak posterior GRF moment. The peak vertical GRF of female were larger than that of males (p = 0.003, Table 1, Fig. 2). The peak posterior GRF of female were also larger than that of males (p = 0.001, Table 1, Fig. 2).

4. Discussion

At the initial landing moment, there were no significant difference between female and male in ankle, knee and hip angles. This is in agreement with previous study that showed no differences in ankle dorsiflexion, knee and hip flexion angles between genders at ground contact during single-leg landings (Schmitz et al., 2007). At the peak posterior GRF, less ankle dorsiflexion, knee and hip flexion angles may expose the females in higher risk of ACL injuries compared with males. The ankle dorsiflexion angle of the female was lower compared with males at the peak posterior GRF. Previous study found out that people with ACL injury shown lower ankle dorsiflexion compared to the people without ACL injury but no significant difference was found in the uninjured leg (Wahlstedt & Rasmussen-Barr, 2015). In the current study, the knee flexion angle and extension moment was less in the female badminton players. ACL strain has been found to be greatest when the lower limb is landed in full extension, and ACL strain significantly decreases with knee flexion (Beutler et al., 2009). Various studies have pointed out that the knee flexion angle for females was lower that for males in athletic tasks (Boden et al., 2000; Malinzak et al., 2001; Mei et al., 2016). Furthermore, previous study indicated that in the simulated injured trials, both male and female athletes had significantly smaller knee flexion angles in comparison to the simulated uninjured trials (Lin et al., 2012).

Podraza and White (2010) concluded that the net knee extensor moment increased significantly with increasing degrees of knee flexion at landing during an impact-like deceleration. This is consistent to our results, we found less knee flexion angle coupled with less knee extension moment in females at peak posterior GRF compared with males. What's more, one study even stated that limited hip and knee flexion during landing is associated with increased frontal plane knee motion and moments, the results of that study shown that athletes with low knee and hip flexion angles demonstrated increased knee valgus angles and increased knee adductor moments when compared to athletes in the high flexion group during the deceleration phase of landing (Pollard, Sigward, & Powers, 2010). The result of this study also supports the theoretical speculation of Hashemi et al., that the ground reaction force is relieved by the co-flexion of knee and hip during a jump landing activity (Hashemi et al., 2011). The larger hip extensor moment of the female found in this study may also induce the abnormal condition which knee is forced to flex but hip is forced to extend (Hashemi et al., 2011). This might lead to females have higher ACL injuries rate compared the males.

The peak vertical and posterior GRF of female were larger than that of males. A lack of absorption of ground reaction forces at landing may be a factor in ACL injury (Boden et al., 2009). Lin et al., found athletes with ACL injuries had greater peak vertical and posterior GRF in comparison to the simulated uninjured trials (Lin et al., 2012). Vertical GRF decreased while knee extensor moments increased significantly increased with degrees of knee flexion at landing (Podraza & White, 2010). We found the similar results in this study that male badminton players had greater knee extensor moment and knee flexion and less vertical GRF than female badminton players. A smaller knee flexion angle combined with a high vertical GRF during landing place individuals at increased risk of ACL injury (Beutler et al., 2009; Boden et al., 2000).

There are some limitations of this study. First of all, this study only recruited 20 subjects (groups had only 10 women and men) which means the sample size of this study was limited. Secondly, we let the subjects wear their own shoes to do the experiment because of the individual differences of the subjects, but previous studies have shown that the different design and type of shoes have a certain impact on the athletic activities. The future study can try to control this variable. In addition, this study only examined the sagittal plane kinematics and kinetics. Future studies kinematics and kinetics analysis of the lower limb can be at three dimensional

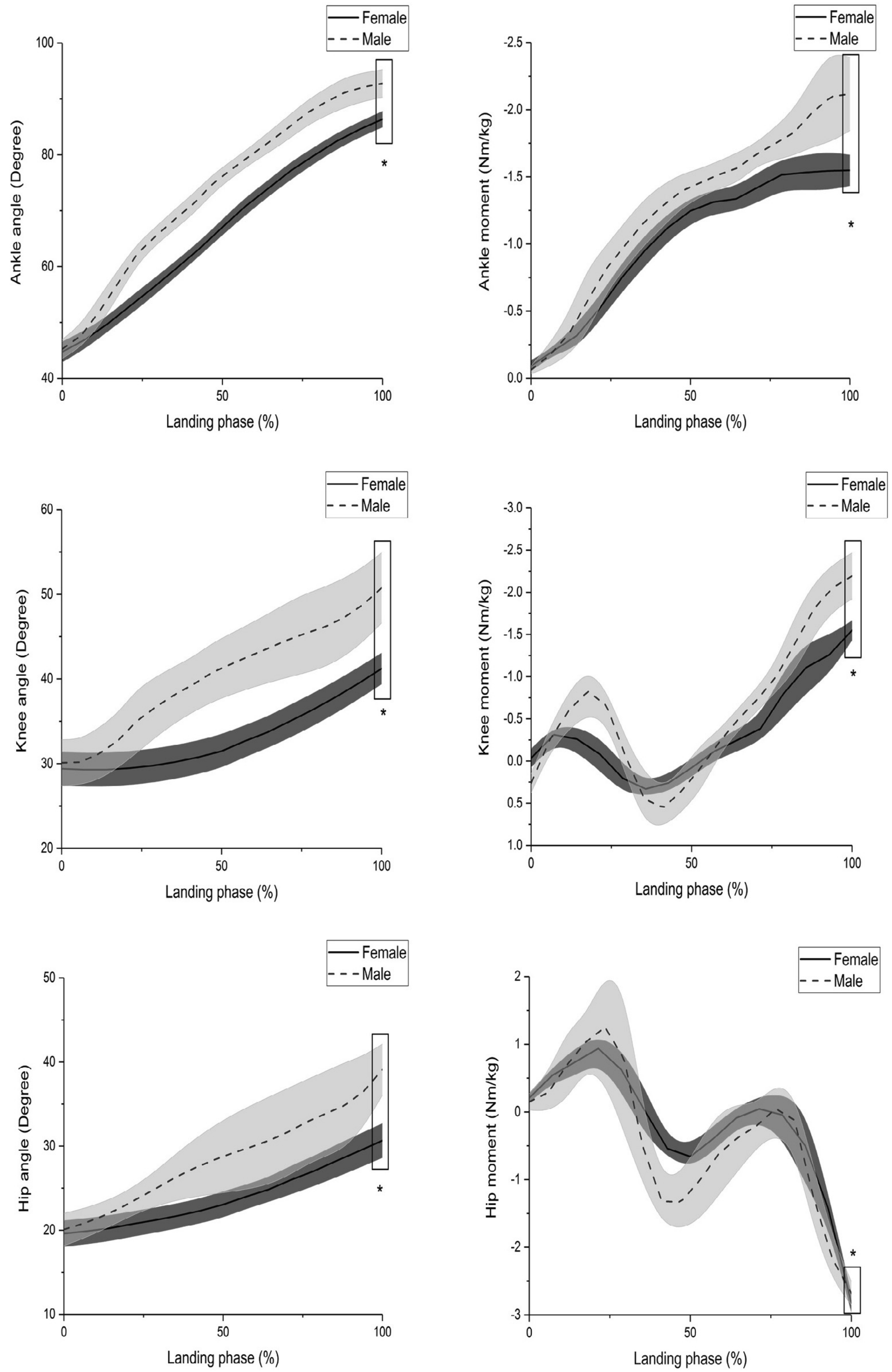

Fig. 2. The kinematics and kinetics comparison of the left lower limb during left lower limb landing in the backhand-side court after overhead stroke between females and males (Statistically significant results were highlighted with rectangles. *indicates $p < 0.05$.

planes (Kimura et al., 2012) or integrated musculoskeletal system modelling techniques (Podraza & White, 2010) are desired to find the gender differences in left lower limb landing after overhead stroke to explore the high ACL injuries in the female badminton players.

5. Conclusion

The present study found the smaller ankle dorsiflexion, knee and hip flexion angles at the peak posterior GRF, and larger vertical and posterior GRF of the female badminton players, might lead to them with an increased rate of ACL injuries during left lower limb landing in the backhand-side court after overhead stroke than males. Therefore, the neuromuscular control training programs designed to decrease the ACL injuries rate of female badminton players should take these factors into consideration.

Conflict of interest

The authors have no conflict of interest to disclose.

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Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.humov.2019.04.007.

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