©Journal of Sports Science and Medicine (2020) **19**, 264-270
http://www.jssm.org

Research article

Influences of Lateral Jump Smash Actions in Different Situations on the Lower Extremity Load of Badminton Players

Chia-Ling Hung [1], Min-Hao Hung [2], Chi-Yao Chang [2], Hsin-Huan Wang [2], Chin-Shan Ho [2] and Kuo-Chuan Lin [3]✉

[1] Department of Physical Medicine and Rehabilitation, Kaohsiung Veterans General Hospital, Kaohsiung, Taiwan, R.O.C.; [2] Graduate Institute of Sports Science, National Taiwan Sport University, Taoyuan, Taiwan, R.O.C.; [3] Office of Physical Education, Chung Yuan Christian University, Taoyuan, Taiwan, R.O.C.

Abstract

Badminton atypical actions and hitting movements often occur during the game; therefore, many special footwork methods have been developed to facilitate the rapid movements required to hit the shuttlecock, including quick turning and jumping and quick directional change movements. Studies have shown that the majority of badminton sport injuries occur in the lower extremity joints of athletes. The purpose of this study was to investigate the influences of hitting motion and unanticipated hitting direction on landing mechanics after backhand lateral jump smashing and landing to analyze joint stiffness and torque changes in three lower extremity joints. Recruited sixteen badminton athletes.The capture frequency of the Vicon Motion System (300Hz), Kistler force platform (1500Hz) and Vicon Nexus Version 1.8.5 software were used simultaneously to capture the kinematic and kinetic parameter of backhand side lateral jump smash footwork. The swing actions were divided into two situations, shadow (footwork and racket swinging practice without targets) and hitting (footwork and stroke shuttlecock) actions, whereas the directions were divided into directional and non-directional. Two-way repeated measures ANOVA with the LSD correction was used to compare the differences among the four conditions. The significance level was set to $a = 0.05$. Results shown that, at the peak of torque, the ankle plantar flexion of the non-directional shadow ($p < 0.05$) were greater than that of directional shadow ($p < 0.05$); meantime, ankle torque change of non-directional shadow ($p < 0.05$) and directional hitting ($p < 0.05$) was lower than that of non-directional hitting, but the non-directional hitting was larger compared to non-directional shadow ($p < 0.05$) at the maximum vertical GRF. The hip extension at peak of torque of directional hitting were larger than that of non-directional shadow ($p < 0.05$). The shadow actions hip flexion angle was larger than that of directional hitting at initial contact, but the non-directional hitting hip abduction was has the significant difference among all the conditioning. The hip flexion angle of non-directional shadow was larger than that of directional hitting ($p < 0.05$), the hip abduction angle of the non-directional hitting was greater than that of non-directional shadow ($p < 0.05$) at the peak VGRF. Elite badminton players execute different training movements; the joint stiffness was in the same state. In the hitting actions has greater ankle and hip joint torque than shadow actions. The badminton player was change joint range of motion to adjust lower limbs stiffness.

Key words: Lower extremity joint stiffness, internal joint torque, footwork training, jump landing.

Introduction

Badminton is an open skill sport where the shuttlecock can not touch the ground during the game. To hit the shuttlecock successfully, players must rapidly change their moving direction (Kuntze et al., 2010; Manrique and Gonzalez-Badillo, 2003; Shariff et al., 2009). Atypical actions and hitting movements often occur during the game; therefore, many special footwork methods have been developed to facilitate the rapid movements required to hit the shuttlecock, including quick turning and jumping and quick directional change movements. Studies have shown that the majority of badminton sport injuries occur in the lower extremity joints of athletes (Goh et al., 2013; Reeves et al., 2015). Badminton players most commonly face knee injury, followed by back, ankle joint, thigh, and calf injuries (Goh et al., 2013; Miyake et al., 2016; Reeves et al., 2015; Yung et al., 2007). Injury of the anterior cruciate ligament is the most common knee joint injury, and 70% of anterior cruciate ligament injuries are noncontact injuries. The major mechanisms of action for these injuries are landing actions and quick directional changes (Dai et al., 2015; Wang, 2011).

Because badminton is a one-sided hitting sport, its action characteristics will produce asymmetric phenomena. Therefore, the lower limber joints mechanisms and risks of injury in both of the forehand side and backhand side are different (Kimura et al., 2012). Lower extremity injuries in badminton players usually occur during jump landing in a lateral (LL) or poster lateral direction (PL) on the play court (Kimura et al., 2010; 2012; Shuhei et al., 2018). During backhand lateral hitting, players will use the rotation, flexion and extension of the torso to achieve the best hitting position. Executing backhand lateral hitting will produce larger hip joint abduction. It is considered that this action strategy will increase the lower extremity joint load (Kimura et al., 2012; Sasaki et al., 2018). Except for studies on the different types of hitting positions, few studies have evaluated action strategies of the same hitting position in different action situations.

A player's reaction ability is important movement ability in badminton. Badminton players should possess excellent selective reaction abilities to assist moving and hitting on the court. Visual reception has a critical impact on selective reaction. Dynamic vision is an important factor affecting the selective reaction of badminton players (Loureiro Jr and Freitas, 2012). The players must rapidly determine the hitting position after the opponent hits the shuttlecock. It has been pointed out that the visual processing system of excellent athletes is better than that of general athletes (Berman, 1988; Abernethy and Neal, 1999; Laby et al., 2011). If players can predict the hitting

Received: 25 July 2019 / Accepted: 19 February 2020 / Published (online): 01 May 2020

position in advance during play, the moving load can be reduced and the active hitting efficiency can be increased to increase the chance of scoring. However, studies on badminton have rarely used selective reaction as a variable to investigate player performance and lower extremity load and injury.

Joint torque and joint stiffness are important indicators for evaluating lower extremity load and injury. Studies that combine imaging and force plates can perform inverse dynamics to estimate the joint torque. Previous studies have shown that the magnitude of knee joint torque during landing is closely associated with the mechanism of anterior cruciate ligament injury (Chappell et al., 2002; Wang et al., 2010; Yu et al., 2006). In addition to joint torque, joint stiffness is also an important reference parameter. Joint stiffness is the adjustment reaction of individuals to the process of dynamic movement and environmental changes. Therefore, joint stiffness is an important parameter for evaluating sport performance and injury risks. Excessively high lower extremity stiffness during movement may cause injuries to the skeletal system (Milner et al., 2007), whereas an excessively low joint stiffness may increase the risk of soft tissue injuries (Granata et al., 2002; Williams et al., 2001). The calculation method of joint stiffness combines joint angle changes and torques; therefore, the analysis of joint stiffness can be used to further investigate sport performance and the mechanism of lower extremity sport injuries.

Previous studies evaluating athletic performance and sports injuries used badminton footwork action, but previous studies have not yet analyzed the actual hitting footwork action. If the actual hitting footwork action were difference of the shadow action, will be reduced the effect of the badminton footwork assessment. Inverse dynamics analysis can more clearly evaluate the risk produced by the action. In view of this, the purpose of this study was to investigate the influences of hitting motion and unanticipated hitting direction on landing mechanics after backhand lateral jump smashing and landing to analyze joint stiffness and torque changes in three lower extremity joints.

Methods

Participants

Sixteen elite Taiwanese male badminton players was recruited; all the players were right handed. All the participants had won in the quarterfinals of tournaments conducted at the national level in Taiwan. The average age, height, body weight, and experience in badminton of the players were 21.1 ± 1.9 years, 1.74 ± 0.04 m, 68.4 ± 6.7 kg, and 10.5 ± 2.4 years, respectively. The participants reported no history of surgery on the lower limbs or musculoskeletal disorders in a span of 1 year prior to data collection. All procedures were approved by the Institutional Review Board of Fu Jen Catholic University.

Instrumentation

Eight high-speed infrared cameras (Vicon MX-T20-S+, Oxford Metrics, UK) were set up in the badminton court, (Figure 1). The image capturing frequency was set at 300 Hz. In the court, the front edge of a Kistler force platform (Kistler 9821, Kistler Instrument, Inc., Swiss) was embedded 150 cm in front of the backcourt boundary. The lateral edge of the platform was aligned with the service line set for playing doubles. The capture frequency of the Kistler force platform was set at 1500 Hz. The racket (Yonex) had a string tension of 29 pounds. The participants used the shuttlecock (Victor) and shoe (Yonex). Reflective markers were affixed on the rackets and shuttlecocks. The markers were used to determine the heights of the strokes. Vicon Nexus Version 1.8.5 software were used simultaneously to capture the kinematic and kinetic parameters while performing the lateral jump smash footwork on the backhand side.

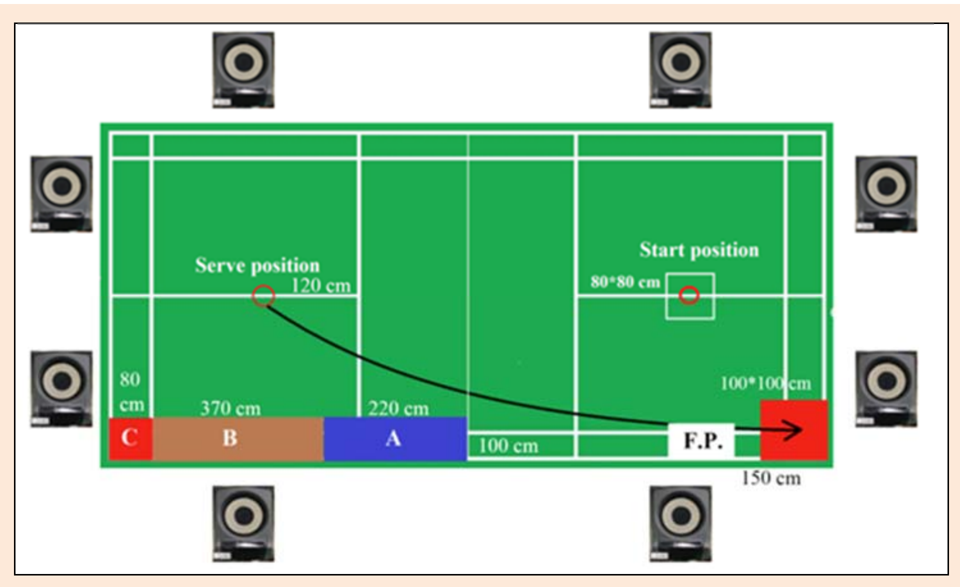

Figure 1. Experimental setup, with the force plate set on the backhand side. The subject starts in the start position area, after starting, make a split step on the backhand side, then jumping and swing the racket. Subjects performed single-leg landing on the force plate and returned to the starting position.

Figure 2. Experimental actions, shadow motion (footwork and racket swinging practice without targets).

Figure 3. Experimental actions, hitting action (footwork and stroke shuttlecock).

Experimental actions

This study analyzed lateral jump smash footwork actions in four different badminton training situations. The swing actions were divided into two situations, shadow (footwork and racket swinging practice without targets, Figure 2) and hitting actions (footwork and stroke shuttlecock, Figure 3), whereas the directions were divided into directional and non-directional. The directional actions of players belong to the simple reaction state; non-directional actions are selective reactions and are more similar to those in actual competitions. For non-directional actions, the players performed lateral jump smash actions after registering a light signal or the serving direction. In this study, simulation of the hitting situation was initiated by using a synchronous light, where LED strip lights were installed on the left and right sides of the net. During the execution of non-directional simulated hitting actions, lateral jump smash actions were performed based on the direction indicated by the light.

The initial position where the participants stood was the center of the right side of the court. A shuttlecock was served from the center line, 120 cm behind the left serving line, toward the left side of the backcourt for the players to hit. The placement of the serve was a block with one square meter, and the height of the serve was the most distant point of the fingertips (the height of the standing position with both upper limbs extended upward) plus 45% to 55% of the maximum vertical jump height plus 25 cm (the length of the central shaft of a badminton racket). He stood and served the shuttlecock at the specific serving location according to the smash height of each player. A successful movement meant that the placement after the maximum jump smash by a player was necessarily in zone B (L370 * W100 cm^2) (Figure1).

Experimental procedures

Before this research was conducted, the experimental procedures and moves were explained to the participants and signed informed consent forms. Once the subjects were familiar with the experimental tasks and understood the start signals of the strokes. Additionally, the parameters of the limbs and the most distant points of the fingertips were measured. The most distant points of the fingertips were measured with the subjects standing with both hands raised to the extreme height and the feet separated by one shoulder width. Before the subjects performed the movement, static data were collected as the subjects stood on the Kistler force platform in the anatomical position. After the subjects completed a voluntary warm-up and practiced the experimental movements for five minutes, the heights of two repetitions of autonomous maximum jump were measured. The greater height was recorded as the height of a vertical jump. After the calculation of the serving height, the servers were allowed sufficient practice to ensure the consistency of the serving height. Once all the above preparations were completed, the formal tests in this experiment were conducted.

Data and statistical analyses

Synchronized trajectory and GRF were estimated using the Nexus Version 1.8.5 Action Analysis System and the Kistler force platform. The Visual3D (C-Motion, Rockville, MD, USA) software was used to calculate the kinematic and kinetic parameters. Static files were used to measure body weight and the angles of the lower-limb joints. The angle of the lower-limb joints was defined as 0 degrees when the subjects statically stood in the anatomical position. The data of the reflective markers were evenly processed using a fourth-order low-pass Butterworth filter set to 10 Hz. After the modules were set by inputting the basic parameters of the participants, the angles of the lower limb joints were calculated. The data of the Kistler force platform were processed using a low-pass filter set at 40 Hz to avoid interference. Analysis of kinematics and kinetic parameters during landing impact phase. (Ward et al., 2019). The joint stiffness calculation method was used peak value of the joint torque and the joint angle change during landing phase. Subject's own weight as a basis for normalization of joint stiffness. (Farley et al., 1998; Ward et al., 2019).

$$K_{joint} = \Delta M_{joint} / \Delta \Theta_{joint}$$

To examine the differences among comparisons, two-way repeated measures ANOVA with LSD adjustment was conducted in the IBM SPSS Package Software 22.0. The parameters in two situations, simulated hitting actions (shadow) and hitting actions, whereas the directions were divided into directional and non-directional during landing impact phase. The comparisons were 1) the sagittal and frontal joint angle of the hip, knee, and ankle at the initial contact (IC) of the landing phase; 2) the sagittal and frontal joint angle and sagittal joint torque in the hip, knee, and ankle at the maximum vertical ground reaction forces (VGRF); 3) the sagittal joint angle ranges of motion and joint torque in the hip, knee, and ankle during initial contact (IC) to peak torque; 4) the maximum of hip, knee, and ankle sagittal joint torque ; 5) The hip, knee, and ankle joint stiffness during landing impact phase. The significance level was set to $a = 0.05$.

Results

The results in this study showed (means ± standard deviations) that when players executed non-directional hitting actions (-3.3 ± 0.1) (Nm/kg), the plantar-flexion torque peak value of the ankle joint was larger than that in directional shadow (-2.8 ± 0.1) (Nm/kg) (p = 0.032) and non-directional shadow (-2.9 ± 0.1) (Nm/kg) (p = 0.001). The degree of torque change in the landing impact period also exhibited the same result, showing that the value in non-directional hitting actions (3.3 ± 0.1) (Nm/kg) was larger than that in directional (2.8 ± 0.1) (Nm/kg) (p = 0.021) and non-directional shadow (2.9 ± 0.1) (Nm/kg) (p = 0.001). At the peak vertical ground reaction force, the plantarflexion torque value in non-directional hitting actions (-3.1 ± 0.1) (Nm/kg) was larger than that in directional shadow actions (-2.4 ± 0.1) (Nm/kg) (p = 0.014). However, the knee joint parameters among all training situations did not show significant differences. For the peak value extension torque in hip joints, the value in directional hitting actions (4.3 ± 0.3) (Nm/kg) was larger than that in non-directional shadow actions (3.3 ± 0.4) (Nm/kg) (p = 0.038). At the torque of landing, the hip joint flexion in directional shadow actions (14.0 ± 0.8) (degree) (p = 0.020) and non-directional shadow actions (14.7 ± 1.1) (degree) (p = 0.018) was larger than that in directional hitting actions (9.2 ± 1.4) (degree). At initial contact the hip joint abduction angle, the value in non-direction hitting actions (40.2 ± 1.0) (degree) was larger than that in directional hitting actions (35. ± 1.1) (degree) (p = 0.003) and in directional (33.8 ± 1.2) (degree) (p = 0.019) and non-directional shadow (32.7 ± 1.2) (degree) (p = 0.001). At the peak vertical ground reaction force, the hip joint flexion angle in non-directional shadow actions (17.8 ± 1.7) (degree) was larger than that in directional hitting actions (23.4 ± 1.1) (degree) (p = 0.026). The hip joint abduction angle in non-directional hitting actions (40.0 ± 1.4) (degree) was larger than that in non-directional shadow actions (32.5 ± 1.6) (degree) (p = 0.001).

Discussion

This study investigated the landing actions of badminton players after they executed a lateral jump smash in different situations. The results showed that the main impacts were to the ankle and hip joints. The hitting actions increased changes in the ankle joint torque and frontal surface angle of the hip joint. Previous study results have shown that the addition of the lateral element into jumping actions affects the knee joint activity (Sinsurin et al., 2013). In addition, a previous study showed that players would perform one-leg landing after lateral hitting, which further increased the unilateral lower extremity joint load (Yeow et al., 2011).

Players must perform many jump hit actions in the course of a badminton competition. Jump landing actions result in a large impact and load in lower extremities. Many previous studies have used biomechanical analysis to investigate jump landing actions, including several kinematic and kinetic parameters such as joint angles and the ground reaction force. Lower extremity joint stiffness is highly associated with sport performance and sport injury (Butler et al., 2003; Granata et al., 2002; Hobara et al., 2010; Milner et al., 2007; Shultz et al., 2010; Williams et al., 2001) and is a presentation of dynamic results. Athletes use lower extremity joint changes to meet movement needs to regulate the lower extremity joint load caused by the ground reaction force. Studies have shown that the risk of lower extremity injuries in female athletes is higher than that in male athletes. During the execution of jump landing actions, male athletes have higher hip joint and knee joint stiffness than female athletes, and a higher lower extremity joint stiffness can provide stability after landing (Hughes and Watkins, 2008; Schmitz and Shultz, 2010). The lower extremity stiffness found in this study was similar to previous study results on jump landing actions, showing that it was the highest in the hip joint, followed by the knee joint and ankle joint (Butler et al, 2003; Ward et al., 2019). However, the results showed that there was no significant difference in the joint stiffness of athletes among four training situations. Joint stiffness is the result of interactions among internal structures in the human body. The badminton players recruited in this study had received 10 years of specialized badminton training on average. The four training situations in this study were performed according to normal training modes; therefore, players might have already achieved a stable state in their action control and sport performance. The results seen in this study might be the best stiffness state adjusted and achieved by players to maintain sport performance and avoid sport injuries.

When the players performed actual hitting, there were smaller hip joint flexion angles at the torque of landing and at the torque of the peak value of the vertical ground reaction force. The results showed that the landing pattern of the players after hitting presented a stiffer landing strategy. Previous studies analyzing the jump landing actions of different genders showed that female athletes and athletes with fatigue presented smaller hip joint flexion. The results suggested that a stiffer landing strategy might increase the lower extremity load and increase the incidence of injury (Bisseling et al., 2007; Schmitz et al., 2007). Furthermore, the previous study showed that the hitting action resulted in a larger hip joint extension internal torque, because the passive torque produced at the impact stage was to avoid the collapse effect (DeVita and Skelly, 1992). The peak value of the extension of the internal torque of hip joints occurred at the landing impact period, which confirmed that hitting actions caused larger hip joint loads.

In addition to differences in sagittal angles and torques, the results in this study showed that the hip joint abduction angle in hitting actions was larger than that in shadow actions at the torque of landing and at the torque of the peak vertical ground reaction force. Previous studies on sport injuries in badminton analyzed the backcourt bilateral shadow actions and showed that the backhand side had larger hip joint abduction and knee joint valgus angles. Therefore, players were considered to have a higher risk of knee joint injury during backhand side shadow actions (Kimura et al., 2012; Sasaki et al., 2018). However, this study showed that there were larger hip joint abduction angles after backhand side hitting actions, but there was no accompanied increase in the knee joint valgus angle. This might be caused by the different genders. The subjects in this study were male badminton athletes. However, previous badminton studies targeted female athletes for the action analyses. The lower extremity Q angle might be different due to the influence of gender. Previous studies also showed that females had larger knee joint valgus angles during the execution of the same action (Hughes et al., 2008; Hughes et al., 2010). Players in this study did not have larger knee joint valgus angles after hitting; however, overly large hip joint abduction angles might cause the production of knee joint valgus torque. The overly large knee joint valgus torque was also an important mechanism affecting anterior cruciate ligament injury (Hughes et al., 2010).

The ankle joint is the first lower extremity joint to receive the impact of the ground reaction force during execution of landing actions. The ankle joint during landing plays an important role in the stabilization of posture and balance maintenance (Lee and Lin, 2007). If the ankle joint has a poor impact absorption ability, loads to the knee and hip joints may increase. In addition, previous studies found that when a lateral element in jump landing actions is present, the knee joint activity is affected, increasing the risk of lower extremity joint injury (Norcross et al., 2010). The current study showed that the peak value of the ankle joint passive torque, the ankle joint torque at the torque of the peak vertical ground reaction force, and the torque variation levels of players in the execution of non-directional hitting actions were larger than that in shadow actions. Because this study analyzed lateral jump smash actions and landing actions, the increase in the ankle joint passive torque after hitting was consistent with previous study results showing that the ankle joints of players should bear larger impacts in non-directional hitting actions. The results showed that if players could effectively predict the hitting direction, the lower extremity load could be effectively reduced. Selective reaction training could be added to routine practice to increase the judging ability of players to further reduce the lower extremity joint load and increase sport performance.

Conclusion

Elite badminton players execute different training movements the joint stiffness was similar. However, when the peak hip joint and ankle joint passive torques in the hitting actions were higher than those in shadow actions, a larger lower extremity joint load was produced in order to stabilize the center of gravity and enable the players to rapidly change directions. The results showed that the ankle joint and hip joint load increased when players executed hitting actions.

Acknowledgements
This research was supported by the National Science Council in Taiwan (MOST 108-2410-H-179-007-). The experiments comply with the current laws of the country in which they were performed. The authors have no conflict of interest to declare.

References

Abernethy, B. and Neal, R. J. (1999) Visual characteristics of clay target shooters. *Journal of Science and Medicine in Sport* **2(1),** 1-19.

Berman, A. M. (1988) Skill development techniques: Identifying and developing sports vision skills. *Strength and Conditioning Journal* **10(5)**, 59-60.

Bisseling, R. W., Hof, A. L., Bredeweg, S. W., Zwerver, J. and Mulder, T. (2007) Relationship between landing strategy and patellar tendinopathy in volleyball. *British Journal of Sports Medicine* **41(7)**, e8.

Butler, R. J., Crowell, H. P. and Davis, I. M. (2003) Lower extremity stiffness: Implications for performance and injury. *Clinical Biomechanics* **18(6)**, 511-517.

Chappell, J. D., Yu, B., Kirkendall, D. T. and Garrett, W. E. (2002) A comparison of knee kinetics between male and female recreational athletes in stop-jump tasks. *The American Journal of Sports Medicine* **30**, 261-267.

Dai, B., Garrett, W. E., Gross, M. T., Padua, D. A., Queen, R. M. and Yu, B. (2015) The effects of 2 landing techniques on knee kinematics, kinetics and performance during stop-jump and side-cutting tasks. *The American Journal of Sports Medicine* **43(2)**, 466-474.

DeVita, P. and Skelly, W. A. (1992) Effect of landing stiffness on joint kinetics and energetics in the lower extremity. *Medicine and Science in Sports and Exercise* **24(1)**, 108-115.

Farley, C. T., Houdijk, H. H., Van Strien, C. and Louie, M. (1998) Mechanism of leg stiffness adjustment for hopping on surfaces of different stiffnesses. *Journal of applied physiology* **85(3)**, 1044-1055.

Goh, S. L., Mokhtar, A. H. and Mohamad Ali, M. R. (2013) Badminton injuries in youth competitive players. *Journal of Sports Medicine and Physical Fitness* **53(1)**, 65-70.

Granata, K. P., Padua, D. A. and Wilson, S. E. (2002) Gender differences in active musculoskeletal stiffness. Part II. Quantification of leg stiffness during functional hopping tasks. *Journal of Electromyographyand Kinesiology* **12(2)**, 127-135.

Hobara, H., Inoue, K., Gomi, K., Sakamoto, M., Muraoka, T. and Iso, S. (2010) Continuous change in spring-mass characteristics during a 400 m sprint. *Journal of Science and Medicine in Sport* **13(2)**, 256-261.

Hughes, G. and Watkins, J. (2008) Lower limb coordination and stiffness during landing from volleyball block jumps. *Research in Sports Medicine* **16(2)**, 138-154.

Hughes, G., Watkins, J. and Owen, N. (2008) Gender differences in lower limb frontal plane kinematics. *Sport Biomechanics* **7(3)**, 333-341.

Hughes, G., Watkins, J. and Owen, N. (2010) Differences between the sexes in knee kinetics during landing from volleyball block jumps. *European Journal of Sport Science* **10(1)**, 1- 11.

Kimura, Y., Ishibashi, Y., Tsuda, E., Yamamoto, Y., Hayashi, Y. and Sato, S. (2012) Increased knee valgus alignment and moment during single-leg landing after overhead stroke as a potential risk factor of anterior cruciate ligament injury in badminton. *British journal of sports medicine* **46(3)**, 207-213.

Kimura, Y., Ishibashi, Y., Tsuda, E., Yamamoto, Y., Tsukada, H. and Toh, S. (2010) Mechanisms for anterior cruciate ligament injuries in badminton. *British journal of sports medicine* **44(15)**, 1124-1127.

Kuntze, G., Mansfield, N. and Sellers, W. (2010) A biomechanical analysis of common lunge tasks in badminton. *Journal of Sports Sciences* **28(2)**, 183–191.

Laby, D. M., Kirschen, D. G. and Pantall, P. (2011) The visual function of olympic-level athletes—an initial report. *Eye and Contact Lens* **37(3)**, 116-122.

Lee, A. J. Y. and Lin, W. H. (2007) The influence of gender and somatotype on single-leg upright standing postural stability in children. *Journal of Applied Biomechanics* **23**, 173-179.

Loureiro Jr, L. D. F. B. and Freitas, P. B. D. (2012) Influence of the performance level in badminton players in neuromotor aspects during a target-pointing task. *Revista Brasileira de Medicina do Esporte* **18(3)**, 203-207.

Manrique, D. C. and Gonzalez-Badillo, J. J. (2003) Analysis of the characteristics of competitive badminton. *British Journal of Sports Medicine* **37(1)**, 62-66.

Milner, C. E., Hamill, J. and Davis, I. (2007) Are knee mechanics during early stance related to tibial stress fracture in runners? *Clinical Biomechanics* **22(6)**, 697-703.

Miyake, E., Yatsunami, M., Kurabayashi, J., Teruya, K., Sekine, Y., Endo, T., Nishida, R., Takano, N., Sato, S. and Kyung, H. J. (2016) A prospective epidemiological study of injuries in Japanese national tournament-level badminton players from junior high school to university. *Asian Journal of Sports Medicine* **7(1)**, e29637.

Norcross, M. F., Blackburn, J. T., Goerger, B. M. and Padua, D. A. (2010) The association between lower extremity energy absorption and biomechanical factors related to anterior cruciate ligament injury. *Clinical Biomechanics* **25(10)**, 1031-1036.

Reeves, J., Hume, P., Gianotti, S., Wilson, B. and Ikeda, E. (2015) A retrospective review from 2006 to 2011 of lower extremity injuries in badminton in New Zealand. *Sports* **3(2)**, 77-86.

Sasaki, S., Nagano, Y. and Ichikawa, H. (2018) Loading differences in single-leg landing in the forehand-and backhand-side courts after an overhead stroke in badminton: A nov-el tri-axial accelerometer research. *Journal of Sports Sciences* **36(24),** 2794-2801.

Schmitz, R. J. and Shultz, S. J. (2010) Contribution of knee flexor and etensor strength on sex-specific energy absorption and torsional joint stiffness during drop jumping. *Journal of Athletic Training* **45(5)**, 445-452.

Schmitz, R. J., Kulas, A. S., Perrin, D. H. and Riemann, B. L. (2007) Sex differences in lower extremity biomechanics during single leg landings. *Clinical Biomechanics* **22(6)**, 681-688.

Shariff, A. H., George, J. and Ramlan, A. A. (2009) Musculoskeletal injuries among Malaysian badminton players. *Singapore Medical Journal* **50(11)**, 1095- 1097.

Shuhei, N., Urabe, Y., Tekeuchi, T., Sasadai, J. and Maeda, N. (2018) P 179–Analysis of dynamic knee motion during lateral and posterolateral jump landing in female badminton players. *Gait and Posture* **65**, 537-539.

Shultz, S. J., Schmitz, R. J., Nguyen, A. D. and Levine, B. J. (2010) Joint laxity is related to lower extremity energetics during a drop jump landing. *Medicine and Science in Sports and Exercise* **42(4)**, 771-780.

Sinsurin, K., Vachalathiti, R., Jalayondeja, W. and Limroon-greungrat, W. (2013) Altered peak knee valgus during jump-landing among various directions in basketball and volleyball athletes. *Asian Journal of Sports Medicine* **4(3),** 195-200.

Wang, L. I. (2011) The lower extremity biomechanics of single-and double-leg stop-jump task. *Journal of Sports Science and Medicine* **10(1)**, 151-156.

Wang, L. I., Gu, C. Y., Chen, W. L. and Chang, M. S. (2010) Potential for non-contact ACL injury between step-close-jump and hop-jump task. *Journal of Sports Science and Medicine* **9**, 134-139.

Ward, R. E., Fong Yan, A., Orishimo, K. F., Kremenic, I. J., Hag-ins, M., Liederbach, M., Hiller, C.A. and Pappas, E. (2019) Comparson of lower limb stiffness between male and female dancers and athletes during drop jump land-ings. *Scandinavian Journal of Medicine and Science in Sports* **29(1)**, 71-81.

Williams, D. S., McClay, I. S., Hamill, J. and Buchanan, T. S. (2001) Lower extremity kinematic and kinetic differences in runners with high and low arches. *Journal of Apply Biomechanics* **17,** 153-163.

Yeow, C. H., Lee, P. V. S. and Goh, J. C. H. (2011) An investigation of lower extremity energy dissipation strategies during single-legand double-leg landing based on sagittal and frontal plane biomechanics. *Human Movement Science* **30(3)**, 624-635.

Yu, B., Lin, C. F. and Garrett, W. E. (2006) Lower extremity biomechanics during the landing of a stop-jump task. *Clinical Biomechanics* **21**, 297-305.

Yung, P. S. H., Chan, R. H. K., Wong, F. C. Y., Cheuk, P. W. L. and Fong, D. T. P. (2007) Epidemiology of injuries in Hong Kong elite badminton athletes. *Research in Sports Medicine* **15(2)**, 133-146.

Key points

- In different training situations will exhibit the same joint stiffness, because badminton player was change joint range of motion to adjust lower limbs stiffness.
- From the joint angle and joint torque, the hitting action will have a greater risk of injury and high lower extremity load.

AUTHOR BIOGRAPHY

Chia-Ling HUNG
Employment
Physical Medicine and Rehabilitation Department, Kaohsiung Veterans General Hospital, Kaohsiung, Taiwan.
Degree
MD
Research interests
Orthopedics Rehabilitation, Sports Biomechanics.
E-mail: clhung1989@gmail.com

Min-Hao HUNG
Employment
Graduate Institute of Sports Science, National Taiwan Sport University, Taoyuan, Taiwan.
Degree
PhD
Research interests
Locomotor simulation, Sports Biomechanics, Training system design and development, Badminton training.
E-mail: a2822180@gmail.com

	**Chi-Yao Chang** **Employment** Graduate Institute of Sports Science, National Taiwan Sport University, Taoyuan, Taiwan. **Degree** PhD **Research interests** Locomotor simulation, Sports Biomechanics, Training system design and development, Badminton training. **E-mail:** anthonychang1124@gmail.com
	**Hsin-Huan WANG** **Employment** Graduate Institute of Sports Science, National Taiwan Sport University, Taoyuan, Taiwan. **Degree** PhD **Research interests** Sports Biomechanics, Motion analysis. **E-mail:** timmyw711@gmail.com
	**Chin-Shan HO** **Employment** Graduate Institute of Sports Science, National Taiwan Sport University, Taoyuan, Taiwan. **Degree** PhD **Research interests** Locomotor simulation, Sports Biomechanics, Training system design and development, Motion analysis. **E-mail:** kilmur33@gmail.com
	**Kuo-Chuan LIN** **Employment** Office of Physical Education, Chung Yuan Christian University, Taoyuan, Taiwan. **Degree** PhD **Research interests** Sports Biomechanics, Training system design and development. **E-mail:** misvbeverydayc@gmail.com

✉ **Kuo-Chuan Lin**
Office of Physical Education, Chung Yuan Christian University, Taoyuan, Taiwan. 200, Chung Pei Rd, Chung Li, Taiwan 32023, R.O.C