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Lower limb landing mechanics of scissor-kick jumps in elite badminton players

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Abstract

Scissor-kick jumps are frequently employed by elite badminton players when performing forehand jump strokes from the rear court forehand side. The joint loads experienced during the landing phase may contribute to the high number of lower limb injuries, yet our understanding of these loads is limited. This exploratory study comprehensively evaluates the lower limb joint mechanics during scissor-kick jump landings in elite male badminton players. Ten Danish national male players performed three variations of the scissor-kick jump in a biomechanical laboratory: submaximal jumps from a static position, maximal jumps from a static position, and jumps with game-like backward chassé steps. We recorded the landing 3-dimensional joint kinematics and kinetics of the racket-leg using a 10-camera motion capture system and a force platform. Our analysis using statistical parametric mapping one-way repeated measures ANOVA revealed no significant differences in the hip, knee, and ankle joint angles, moments, and power waveforms during the landing phase across the three jump variations. Indicating that elite male badminton players landing mechanics are not altered by increased jump height or the inclusion of preceding game-like footwork. We observed that the triceps surae muscles absorb 41% of the total eccentric joint work during the landing phase, indicating their crucial role in managing landing impacts. Additionally, the initial landing phase is characterized by high external knee and hip extensor and adductor moments. These findings highlight the importance of incorporating exercises targeting the triceps surae muscles and Achilles tendons in badminton-specific training programs to prepare players for the high eccentric loads during scissor-kick jump landings. The high hip, knee and ankle joint loads identified in this study may contribute to the high incidence of lower limb injuries in elite badminton.

Keywords: *Forehand stroke, jump height, footwork, joint loading.*

Resumen

Los saltos con patada de tijera son frecuentemente usados por los jugadores de bádminton de élite cuando realizan golpes de derecha en salto desde la parte trasera de la cancha. Las cargas articulares que se producen durante la fase de aterrizaje pueden contribuir al elevado número de lesiones en las extremidades inferiores, pero nuestro conocimiento sobre estas cargas es limitado. Este estudio exploratorio evalúa de forma exhaustiva

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la mecánica articular de las extremidades inferiores durante los aterrizajes de saltos con patada de tijera en jugadores de bádminton de élite. Diez jugadores daneses de la selección nacional masculina realizaron tres variaciones del salto con patada de tijera en un laboratorio biomecánico: saltos submáximos desde una posición estática, saltos máximos desde una posición estática y saltos con pasos *chassé* hacia atrás similares a los del juego. Registramos la cinemática y la cinética tridimensionales de la articulación de la pierna de la raqueta durante el aterrizaje utilizando un sistema de captura de movimiento de 10 cámaras y una plataforma de fuerza. Nuestro análisis, realizado mediante un mapa paramétrico estadístico y un ANOVA unidireccional de medidas repetidas, no reveló diferencias significativas en los ángulos, los momentos y las ondas de potencia de las articulaciones de la cadera, la rodilla y el tobillo durante la fase de aterrizaje en las tres variaciones de salto. Esto indica que la mecánica de aterrizaje de los jugadores de bádminton de élite no se ve alterada por el aumento de la altura del salto o la inclusión de pasos similares a los del juego. Observamos que los músculos tríceps surales absorben el 41 % del trabajo excéntrico total de las articulaciones durante la fase de aterrizaje, lo que indica su papel crucial en la gestión de los impactos del aterrizaje. Además, la fase inicial de aterrizaje se caracteriza por altos momentos externos de extensión y aducción de la rodilla y la cadera. Estos hallazgos resaltan la importancia de incorporar ejercicios dirigidos a los músculos tríceps surales y los tendones de Aquiles en los programas de entrenamiento específicos para el bádminton, con el fin de preparar a los jugadores para las altas cargas excéntricas durante los aterrizajes de saltos con patada de tijera. Las altas cargas en las articulaciones de la cadera, la rodilla y el tobillo identificadas en este estudio pueden contribuir a la alta incidencia de lesiones en las extremidades inferiores en el bádminton de élite.

Palabras clave: *golpe de derecha, altura del salto, juego de pies, carga articular.*

INTRODUCTION

Badminton players perform a range of badminton-specific movements, including jumps, lunges, sidestepping and changes in direction to reach the shuttlecock (Cabello Manrique & González-Badillo, 2003; Phomsoupha & Laffaye, 2015). The repetitive high-intensity actions do however place high demands on the players' lower limbs. In fact, a recent study by Nagano et al. (2020) revealed that adolescent female badminton players perform 7.72 actions with trunk accelerations above 4g per minute during games, (Nagano et al., 2020). Generating body accelerations at this level is likely an important contributor in the high incidence of lower limb injuries, particularly the knee and ankle joints, are prevalent among elite and recreational badminton players (Goh et al., 2013; Miyake et al., 2016; Reeves et al., 2015).

The high loads experienced during single-leg landings, following forehand and overhead jump strokes, have been associated with increased risk of anterior cruciate ligament injuries (Kaldau et al., 2024; Kimura et al., 2010, 2012) and Achilles tendon ruptures (Fahlström et al., 1998; Kaalund et al., 1989), and may in general contribute to the high incidence of lower limb injuries in badminton (Goh et al., 2013; Miyake et al., 2016; Reeves et al., 2015). Thus, existing biomechanical literature have focus on differences in lower limb landing mechanics between genders (Hu et al., 2023; Zhang et al., 2023; Zhao & Gu, 2019), and playing level (Kaldau et al., 2022; Nedergaard et al., 2022; Zhao & Li, 2019). Whereas the impact of jump intensity levels and inclusion of pre-jump footwork are not represented in the existing literature, despite its potential influence on lower limb mechanics and injuries.

The scissor-kick jump (SKJ) is a frequently utilised technique among badminton players when returning the shuttlecock from the rear-court forehand side (Kaldau et al., 2022), but also a frequent ACL injury situation (Kaldau et al., 2024). The SKJ involves a backward jump with a 180 degrees body rotation along the player's longitudinal axis, resulting in the characteristic crossing of the legs in mid-air. The in-air rotation allows players to generate more power in their stroke and the ability to swiftly push off the ground and return to the court's center (Brahms, 2014). We have recently demonstrated that recreational badminton players can reduce Achilles tendon forces by 25% when employing the SKJ technique during forehand jump strokes (Kaldau et al., 2022) and that the knee joint loads, during the initial contact phase of SKJs with submaximal intensity, are similar between elite and recreational male badminton players (Nedergaard et al., 2022). Nevertheless, despite its frequent use in elite badminton, a comprehensive understanding of the lower limb joint loads experienced during the initial landing phase after a SKJ, and the impact of jump intensity and match-like footwork remains limited.

In this exploratory study, we aimed to evaluate the lower limb joint landing mechanics that elite badminton players experience following SKJs. Considering the dynamic nature of badminton, where players constantly adjust their movement patterns, such as altering jump height or footwork to reach the shuttlecock, we specifically aimed to explore how increased jump intensity and inclusion of chasse steps prior to the SKJ alter lower-limb landing mechanics.

MATERIALS AND METHODS

Participants

Ten elite male badminton players (age: 28.2 ± 7.6 yr., height: 180.5 ± 48.6 cm, mass: 72.4 ± 6.6 kg), all competing at the highest level in Denmark, volunteered to participate in this study. All players were injury-free 6 months prior to testing and had no history of severe lower limb injuries. The study was approved by the local ethics committee (VD-2019-40) and written consent was obtained prior to testing for all players.

Experimental Protocol

After a 15-minute standardized warm-up routine, including an individual number of SKJ_s, players were instructed to complete three variations of the SKJ: 1) a set of submaximal SKJs (SKJ_{SubMax}) initiated from a fixed static start position in front of the force platform, corresponding to 50% of the players' leg length (measured from the anterior superior iliac spine to the medial malleolus); 2) another set of SKJ_s as described above, but with the instruction to jump as high as possible (SKJ_{max}) to simulate a jump-smash; 3) a set of SKJ_s following three backward chasse-steps (SKJ_{chasse}), simulating the frequent match situation where players move backward toward the rear court as part of the SKJ sequence. For all SKJ variations, players were instructed to accelerate forward immediately upon on landing and reach a target placed 3 meter in front of the force platform (Figure 1).

Due to the limited floor-to-ceiling height in the biomechanical laboratory, players were instructed to perform the SKJs without a racket. To facilitate a natural upper-body movement, players were instructed to hit a target with their normal racket-hand. The target was placed approximately 30 cm above their standing reach height. The players completed an individual series of SKJs until five successful trials were obtained for each condition (hitting the target and landing with their none-racket leg within the force platform). To avoid fatigue, time between trials was kept at minimum 45 seconds.

Data Collection

The SKJ_s and subsequent landing phases were captured at 200 Hz with an 8-camera Vicon motion capture system (T40 cameras, Vicon Motion Systems Ltd, Oxford, UK), with simultaneous recording of landing ground reaction forces (GRF) of the non-racket leg at 1000Hz (OR-6-7, AMTI, Massachusetts, USA). Lower limb kinematics were computed from a modified Helen Hayes marker set including 24 retroreflective markers (Bencke et al., 2013). Kinematic marker trajectory data were filtered using a Woltering cubic spline filter (Woltring, 1986), with a predicted mean square error of 10 mm, whilst GRF data were filtered using a zero-lag fourth order low-pass Butterworth filter at 50 Hz cutoff.

Subsequently, hip, knee and ankle joint kinematics and kinetics (external joint moments and instantaneous net joint power) in the sagittal, frontal, and transverse planes were calculated for the participant's non-racket leg using inverse dynamics in Vicon plug-in-gait software (Nexus 2.9, Vicon Motion Systems Ltd, Oxford, UK). Only joint kinematics and kinetics from the landing phase were analysed in this study. Touchdown and take off were identified when the vertical GRF exceeded and subsequently fell below a 10 N threshold, respectively. Net positive and negative joint work for each joint was calculated by integrating the positive and negative portions of the instantaneous joint power curves,

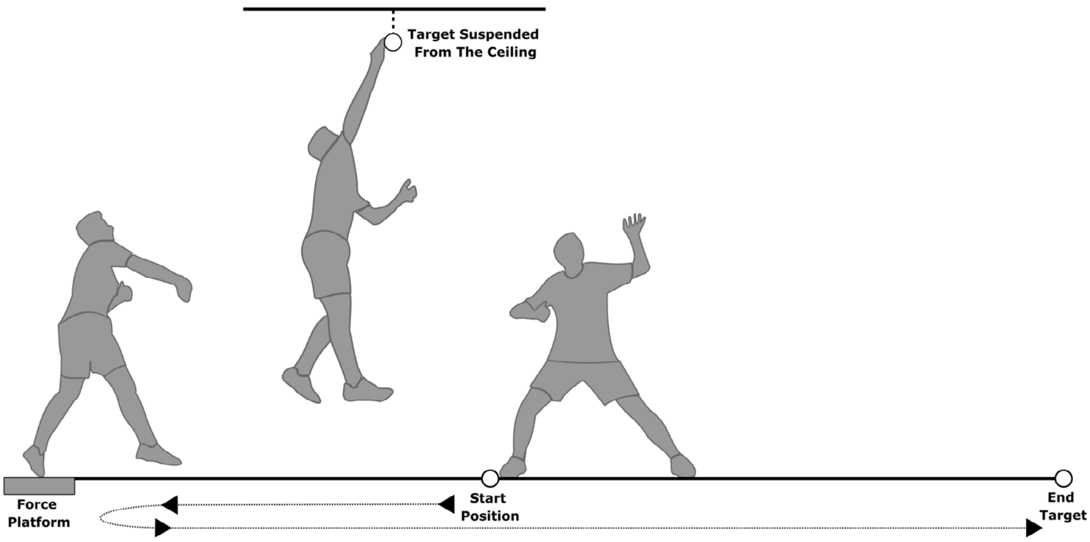

Figure 1
Illustration of the laboratory setup. For both the SKJ_{SubMax} and SKJ_{max} conditions, players' starting position was in front of the force platform, at a distance equal to 50% of their leg length. Individual start positions were employed for the $SKJ_{chassé}$ condition. During the SKJ, players were instructed to hit a ceiling-suspended target with their racket arm to promote natural upper-body movement. Immediately upon landing, players ran forward to reach a target positioned 3 meters from the force platform.

respectively, with respect to time. The total amount of positive and negative lower limb joint work produced by the non-racket leg during the landing phase was subsequently calculated as the sum of the individual joint's (hip, knee, and ankle) work. Finally, jump height and average forward velocity ($V_{Forward}$) upon landing were calculated as described in Kaldau et al. (2022).

Statistical analysis

The average of five trials was calculated for each participant and used for the statistical analysis and all kinetic data were normalised to the players' body mass. A one-way repeated measures ANOVA ($\alpha = 0.05$) was used to compare jump height, contact time, $V_{Forward}$ and joint work between the three SKJs variations in SPSS (version 22.0, SPSS Inc. Chicago, IL, USA). In cases of significance, a Bonferroni corrected post-hoc test ($\alpha = 0.0167$) was performed for pairwise comparisons.

Furthermore, one-dimensional statistical parametric mapping (SPM) (Friston et al., 2007; Pataky, 2012) one-way repeated measures ANOVA was computed using open-source SPM1D software (v0.4, www.spm1d.org, (Pataky, 2012)) in Matlab (version R2019a, The MathWorks, Inc., Natick, MA, USA) to compare joint moment and power waveforms for the landing phases. In cases with significant main effects, post-hoc testing using a one-sample SPM t-test, with a Bonferroni adjustment ($\alpha = 0.0167$), was used to compare waveforms between the individual SKJs

RESULTS

The repeated measures ANOVA revealed that jump height was significantly different between the three SKJ variations ($F_{(1.253,\ 11.273)} = 35.401$, $p < 0.001$). Post-hoc analysis showed that jump height was significantly higher for SKJ_{Max} (48.6 ± 7.2 cm) compared to both SKJ_{SubMax} (30.6 ± 9.8 cm, $p < 0.001$) and $SKJ_{Chassé}$ (33.9 ± 8.5 cm, $p = 0.001$). Furthermore, contact time for the landing phase was significantly different between SKJ variations ($F_{(1.899,\ 17.088)} = 8.543$, $p = 0.003$), with post-hoc analysis showing that the SKJ_{Max} (389 ± 56 ms) had significantly longer contact time than the SKJChassé (342 ± 42 ms, $p = 0.012$) but not the SKJ_{SubMax} (368 ± 48 ms, $p = 0.086$). There was no significant difference in $V_{Forward}$ ($p = 0.639$) between the three SKJ variations (SKJ_{SubMax}: 4.85 ± 0.46 ms; SKJ_{Max}: 4.93 ± 0.37 ms; $SKJ_{Chassé}$: 4.98 ± 0.40 ms).

Only minor differences were observed in the joint angles and moments across the three SKJ variations (Figure 2). In general, the SKJ_{Max} and $SKJ_{Chassé}$ variations displayed greater hip and knee joint moments in the frontal and transverse plane, and greater plantar flexor moments compared to the SKJ_{SubMax}. Nevertheless, the one-way repeated-measures SPM ANOVA found no significant difference in hip, knee, ankle joint angles and moments between the three SKJ variations.

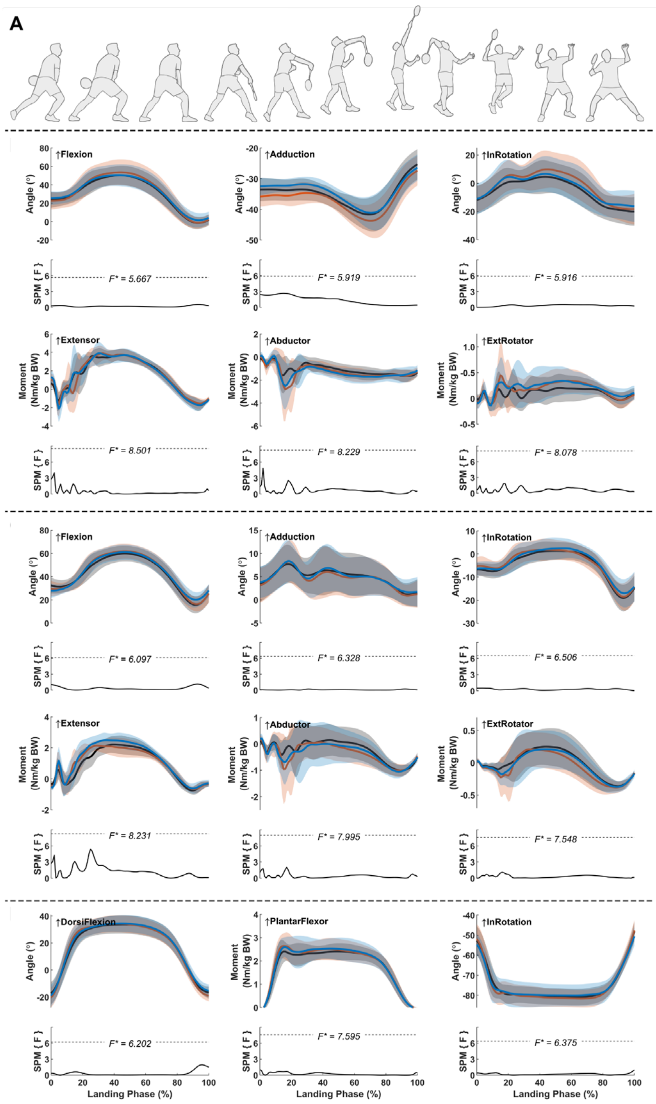

Figure 2
(A) Silhouette representation of the SKJ movement, with the sequence of movements shown from right to left, starting with the jump phase and transitioning to the landing phase. (B) Mean ± SD clouds for hip joint angles and moments across all planes. (C) Mean ± SD clouds for knee joint angles and moments across all planes. (D) Mean ± SD clouds for sagittal ankle joint angles, moments, and foot progression angles. The average waveform plots, displaying only the landing phase, include three SKJ variations: SKJ_{SubMax} (black line), SKJ_{Max} (orange line), and $SKJ_{Chassé}$ (blue line). Below the waveform plots, Statistical Parametric Mapping (SPM{F}) results from the one-way repeated measures ANOVA are shown. Significant main effects between SKJ variations are indicated where the F-curve (grey line) exceeds the critical threshold (horizontal dashed line). All curves are normalized to the landing phase (%).

The total amount of joint work absorbed by the non-racket leg was significantly affected by SKJ variations ($F_{(1.796,\ 16.167)} = 4.493$, $p = 0.031$), but without any significant differences at a post-hoc level (Figure 3). The percentage of joint work absorbed at the knee was significantly affected by SKJ variations ($F(_{1.915,\ 17.239)} = 7.895$, $p = 0.004$). More specifically, the post-hoc analysis revealed that the work absorbed by the knee was significantly higher for the SKJ_{Max} (30.8 ± 5.3%) compared to the SKJ_{SubMax} (27.1 ± 3.7%, $p = 0.011$). Similarly, the percentages of joint work generated by the knee during the push-off phase were significantly different between SKJ variations ($F_{(1.966,\ 17.694)}$ = 7.444, p = 0.005). More specific, the post-hoc analysis revealed that the work generated by the knee was significantly higher for the SKJ_{Max} (23.0 ± 3.5%) compared to the $SKJ_{Chassé}$ (19.9 ± 4.3%, p = 0.017).

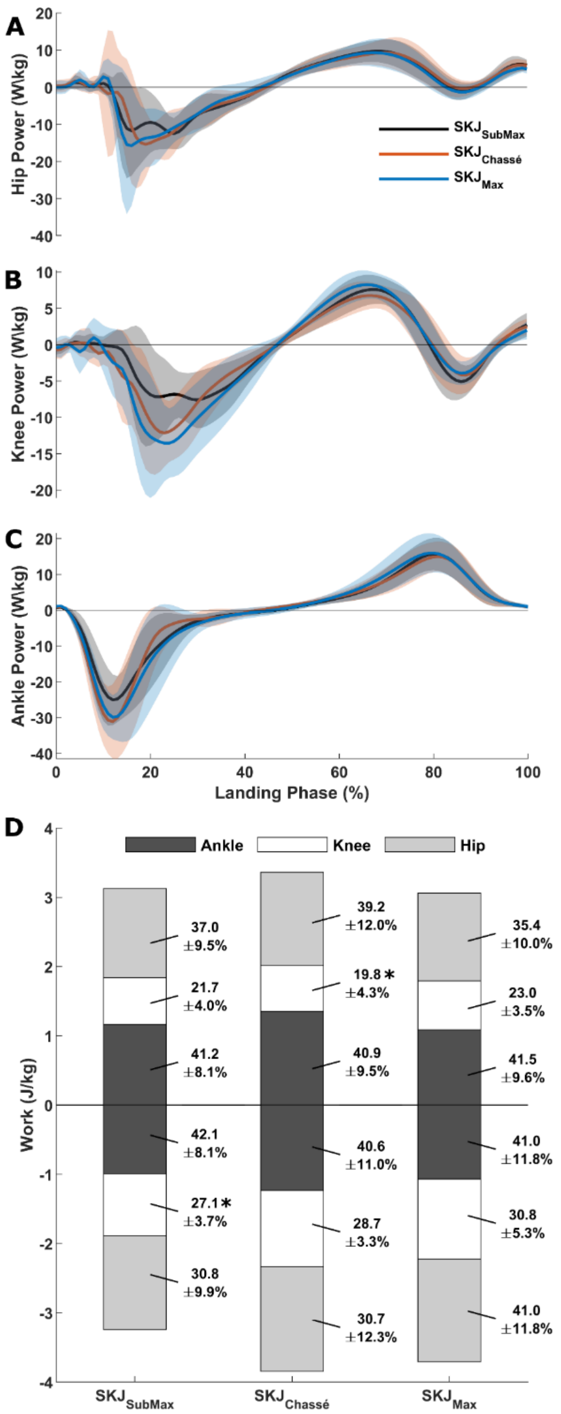

Figure 3
Mean ± SD clouds for the hip (A), knee (B), ankle (C) joint power for the landing phase (normalized to 100%) of the three SKJ variations. D) Average positive and negative joint work (absolute and percentage) for the three SKJ variations. * Indicates that the joint work is significantly different from the SKJ_{SubMax} (P < 0.0167).

DISCUSSION

In the present study we demonstrate that elite male badminton players exhibit great ankle plantar flexor moments together with large hip and knee extensor and adductor moments during landings following SKJs. Particularly the triceps surae muscles are exposed to high eccentric loads accounting for ~41% of the total joint work absorbed by the non-racket leg during the landing phase. Finally, our results illustrate that landing mechanics (joint moments, powers and work) of elite badminton players is largely unaffected by SKJ intensity or the inclusion of backward chassé steps.

Only the percentage of eccentric joint work absorbed at the knee, and concentric joint work generated at the knee significantly differed between SKJ variations in the presented study. The increased jump height in the SKJ_{Max} resulted in higher peak knee eccentric power (Figure 2B) compared to SKJ_{SubMax}, which is in line with previous studies that showed increased landing impacts and eccentric knee joint work with increased drop height (Ali et al., 2014). The greatest differences in concentric knee joint power (Figure 2B) were observed between the SKJ_{Max} and $SKJ_{Chassé}$ which in turn can explain the significant difference observed in the concentric knee joint work between these two. Previously, it has been shown that single-leg horizontal jumps for distance significantly increased the percentage of eccentric work at the knee, compared to vertical jumps with maximal effort (Kotsifaki et al., 2021). Nevertheless, the inclusion of the horizontal chassé footwork component prior to the SKJ in the presented study did not alter the elite players landing mechanics, most likely because all SKJ variations included a horizontal component with the players jumping horizontally onto the force plate. The lack of differences between SKJ variations observed in the present study demonstrate that minor alterations in jump strategies do not alter landing mechanics in elite male badminton players.

The lower limb landing mechanics observed for the SKJ in the present study generally resemble those previously described for single-leg landings following overhead strokes (Hung et al., 2020; Kimura et al., 2012; Zhao & Gu, 2019). In short, the peak plantar flexor moments of the SKJ were within the range of those previously presented for overhead backhand strokes in male badminton players (Hung et al., 2020; Zhao & Gu, 2019). However, the knee and hip extensor moments observed in the present study were higher than those previously reported for male badminton players during single-leg landings following overhead strokes. (Hung et al., 2020; Zhao & Gu, 2019), likely because all players in the present study competed at the highest level in Denmark. The peak external knee abduction moments, a well-known risk factor for anterior cruciate ligament injury during single-leg landing in badminton (Kimura et al., 2010), observed in the present study exceed those previously reported during overhead strokes for female players (0.42 + 0.26 Nm/kg)

(Kimura et al., 2012) and for a mixed group of male and females players (0.89 ± 0.46 Nm/kg/m) (Hu et al., 2022). This indicates the importance of strong and active knee adductors to counteract the high external knee abduction moment (Zebis et al., 2022). Nevertheless, the current literature on single leg landing mechanics in badminton lacks sufficient data on joint moments in the frontal and transverse planes. Hence, we strongly encourage researchers to incorporate the non-sagittal kinetics when exploring the loading demands of other badminton specific jump landings and their association with injury risk.

This study was conducted on 10 elite male badminton players; thus, the findings may not be generalizable to female or non-elite players. Previous research has identified gender differences in single-leg landings following a backhand overhead stroke from the rear-court. For instance, female badminton players show smaller ankle, knee, and hip flexion angles, and higher ground reaction forces during landing (Zhao & Gu, 2019). They also display lower leg and knee stiffness, indicating reduced dynamic stability (Zhang et al., 2023), and different lower-limb neuromuscular control strategies during the pre-landing phase (Hu et al., 2023). Similar differences may for the rear-court forehand SKJ examined in this study, which potentially could explain the higher incidence of ACL injuries reported among female players on the rear-court forehand side compared to males (Kaldau et al., 2024). Further research is needed to determine whether the differences in peak eccentric and concentric knee joint power observed across SKJ conditions here are gender specific.

A limitation with this study is that the players performed the SKJs without a racket and shuttlecock, due to the limited laboratory floor-to-ceiling height. Furthermore, we acknowledge that landing mechanics differ between shadow and actual hitting actions (Hung et al., 2020). Nevertheless, since all the players included in this study were familiar with the SKJ movement, we strongly believe the players were able to reproduce the movement pattern from practice/games. Another limitation with our study design and the joint mechanics presented is that ground reaction forces only was measured for the non-racket leg, though players had double support in the last part of the SKJ landing. We did however focus on joint kinetics of the non-racket leg in this study because it indisputably is exposed to the highest loads during the SKJ landing. Moreover, the non-racket leg is generally more exposed to severe injuries (e.g. knee injuries) during jump landings than the racket leg in badminton (Kaldau et al., 2024; Kimura et al., 2010).

The landing mechanics of the SKJ described in the present study is similar to that previously observed during side-cutting (Bencke et al., 2013). This highlights the importance of simultaneous muscle activation of the hip extensor, adductors, and external rotators to counteract the high loads forcing the hip into internal rotation and abduction. Also, knee extensor activation is necessary for absorbing impact forces and stabilizing the knee. Additionally, activation of the knee adductors (i.e., the medial hamstrings) before landing is crucial to counteract the high external knee abduction moment during the initial landing phase. These musculoskeletal loads may contribute to the high knee injuries rates in badminton players (Goh et al., 2013; Miyake et al., 2016; Reeves et al., 2015). Similarly, our findings highlight the significant workload undertaken by the plantar flexors, which may contribute to the high incidence of Achilles tendon injuries in badminton. Previously, we demonstrated that novice players experience greater Achilles tendon forces, which can be significantly reduced by adopting the SKJ landing technique used by elite players (Kaldau et al., 2022). This highlights the importance of proper landing mechanics in mitigating stress on both the Achilles tendon and the knee (Kaldau et al., 2022; Kimura et al., 2010). In recreational players with lower fitness levels, the high plantar flexor and Achilles tendon loads during intense movements impose a relatively greater strain, even with correct technique. Hence, coaches should consider moderating the intensity of such actions to prevent overuse injuries. Additionally, the high horizontal landing velocity of the SKJ challenges knee and ankle joint stability, especially in less fit or skilled players. This supports recommendations for a progressive increase in exercise intensity during badminton-specific jump skill development, such as the SKJ, alongside target strengthening of the stabilizing musculature around the knee and ankle.

Whilst the direct association between SKJ landing mechanics and lower limb injury incidence in elite badminton remains unknown, physiotherapists and strength and conditioning coaches can benefit from the information on lower limb muscle/joint loads found in this study when designing injury prevention programs for elite badminton players. Ultimately, contributing to the overall goal by reducing the high incidence of lower limb injuries in competitive badminton.

Conclusions

In conclusion, we found that the triceps surae muscles absorb 41% of the total joint work in the non-racket leg during the landing phase of SKJs. This highlights the importance of strong triceps surae muscles and Achilles tendons, which should be a focus in badminton-specific training programs to help players tolerate the high eccentric loads of forehand SKJ landings. The high joint moments in the knee and hip's sagittal and frontal planes also emphasize the need for strong hip and knee extensors and adductors to improve knee joint stability. Finally, aside from minor changes in knee joint work, our results show that neither jump height nor the inclusion of preceding footwork altered the SKJ landing mechanics of elite male badminton players.

DISCLOSURE STATEMENT

The authors declare that there are no conflicts of interest.

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CONTRIBUTIONS

Niels Jensby Nedergaard, Niels Christian Kaldau, Per Hölmich and Jesper Bencke conceptualised and designed the study. Niels Jensby Nedergaard and Niels Christian Kaldau collected the data. Niels Jensby Nedergaard and Jesper Bencke analysed and interpreted the data. Niels Jensby Nedergaard drafted the manuscript. All authors critically revised the manuscript and approved the final version.

AI USE STATEMENT

AI tools (ChatGPT) were used for proofreading to identify grammatical errors. All suggestions from the AI tools were critically reviewed by the first author.

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