EFFECT OF TOE WEDGES ON THE BIOMECHANICS OF THE FORWARD LUNGE IN BADMINTON

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The badminton lunge movement accounts for 15% of all actions in a competitive single match. The purpose of this study was to assess the effects of different toe wedges during a forward badminton lunge. Eighteen healthy male subjects participated in the study where the biomechanics and performance of three different wedge conditions were evaluated (0 mm, 4 mm and 8 mm toe elevation). Ground reaction forces and kinematic data were in a laboratory. Results showed an increased peak ankle moment for the 8-mm wedge compared to 0-mm (P=0.003) and 4-mm (P=0.028) wedges along with a reduced hip flexion moment (P=0.049 and P=0.034, respectively), while the time to task completion remained unchanged. Results indicate that joint moments may be altered by badminton footwear with implications for fatigue.

KEY WORDS: Badminton, lunge performance, ground reaction force, kinematics, musculoskeletal model

INTRODUCTION: Badminton is a popular sport with 200 million participants worldwide and an increasing popularity since its inclusion in the Olympic games in 1992 (Cabello & Badillo 2003, Laffaye 2015). Badminton is a rapid racket sport that requires jumps, lunges and quick changes in direction, whereas lunge movements account for 15% of all actions in a competitive match. The lunge movement is considered an advanced movement skill which allows the players to stop the progression of their bodies while returning the shuttlecock and then revert to the court centre to prepare for the next shot (Kuntze et al. 2010, Cronin et al. 2003). Previously, lunge performance has been defined as the ability to complete the manoeuvre within the shortest time which is an important factor for success in badminton (Cronin et al. 2003). Despite the popularity of badminton and the importance of the lunge movement within the game, little information is available about the biomechanics of the lunge movement on the badminton field (Kuntze et al. 2010, Fu et al. 2009).

Cronin et al. (2003) investigated the strength qualities during a fixed forward lunge to determine their effect on lunge performance. Whereas Hu et al. (2015) investigated the plantar loads with an insole pressure system to compare the insole load during maximum forward lunge. Alkjær et al. (2012) investigated kinetics and kinematics in a forward lunge with a musculoskeletal model. While such fundamental studies are important to understand the mechanics of the lunge movement it may be of particular interest to footwear developers to assess the potential effects of footwear modifications on lunge performance in a badminton-specific context.

The plantar aponeurosis (PA) is a part of the plantar fascia and is thought to play important roles in maintaining the longitudinal arch of the foot. Dynamically, a stiffening of the arch during push-off was described by the windlass mechanism (Griffin et al. 2015). If such a stiffening could be provoked by footwear modifications it appears plausible the contact mechanics may be improved.

The purpose of this study was to assess the effects of different toe wedges aiming at raising the phalanges within the shoe during a badminton lunge. Joint loading, indicated by ankle, knee and hip moments, derived from a musculoskeletal model, and time to complete (TTC) were investigated to quantify biomechanical and performance-related outcomes.

METHODS: Eighteen healthy male subjects (age: 25.78 ± 6.97 years, weight: 67.96 ± 6.98 kg, height: 174.63 ± 3.50 cm) participated in the study. The inclusion criteria for participation in the study were: Shoe size US 9.0 ±0.5; Competitive playing experience > 3 years; right hand dominant. All subjects signed informed consent before testing with procedures following the principles of the Declaration of Helsinki for ethical research in human subjects.
The three evaluated shoes were based upon the same model (Li Ning AYAE011, Beijing, China). Shoe A was an unmodified shoe used as a reference. Shoe B and C were modified by inserting an inclination toe wedge (EVA), of 4 mm and 8 mm heights, respectively. The wedge was placed from the MTP alignment towards the tip of the shoe to increase the inclination of the proximal phalanges (Figure 1).

Figure 1. Sagittal cut trough of the 0 (A) and 8 mm (C) shoes. The wedge is observed as the black part on top of the base sole for shoe C; shoe B was similar with a wedge of only half this height.

Badminton lunge measurements were performed on a badminton court constructed within the laboratory. Both left and right sides were investigated. The sequence of the three different shoe conditions was randomized. A fourth control condition was implemented as a repetition of the initial condition specific to the test order for each subject to exclude fatigue effects (i.e., comparison between the first and forth condition). Prior to the measurements, the subjects were instructed to perform a standardized warm-up and six familiarization trials for each side. For each shoe condition three further familiarization trials were executed to each side. Subjects were instructed to begin the badminton lunge movement from within a start zone. The specific position within the start zone was estimated in the familiarization trials and marked to ensure consistency. The subject was instructed to perform the lunge at maximal effort without any loss of balance, hitting the shuttlecock and executing the lunge within the step-in and lunge zones. If the subject was not able to perform the movement in accordance with the instructions, the trial was discarded and subsequently repeated until five lunge trials were recorded for each side.
Thirty-eight retroreflective markers were attached on the subject and secured with adhesive tape. These consisted of 30 markers placed on the skin and four markers placed on each shoe. The three-dimensional marker trajectories were obtained using a stereo photogrammetric motion capture system consisting of 12 infrared cameras operating at 200 Hz (Nexus 1.8.5-T20, Vicon Motion Systems Ltd, T-Series, UK). The ground reaction forces were obtained using four AMTI force plates (Advanced Mechanical Technology, Inc., Watertown, MA, US) sampling at 3000 Hz.
Marker trajectories and force plate data were low-pass filtered using a 2^{nd} order Butterworth filter with cut-off frequencies of 10 and 35 Hz, respectively. Inverse dynamics analysis was performed in the AnyBody Modelling System (AMS; V. 6.0, AnyBody Technology A/S, Aalborg, Denmark). The model was based on the GaitFullBody template containing 21 degrees of freedom (DOF) in total. Following the kinematic optimization procedure and model parameter identification (Andersen et al., 2009) the centre of mass (CoM) movement was extracted and TTC calculated based on the CoM in relation to a start line parallel to the net, just in front of the start zone. The three fastest trials were selected for further analysis. Ground reaction forces (GRF) and joint moments of the ankle, knee and hip of the leading leg were calculated and peak values extracted for statistical analysis.
A paired-sample t-test was performed in order to identify movement adaptation or fatigue between the initial condition and the final control condition ($P<0.05$). An analysis of variance

(ANOVA) for repeated measures was used to analyze the difference in the variables between the three shoe conditions. A least-squares difference (LSD) test was used as a post hoc test if a significant F-value was found. The level of significance was defined as $P<0.05$. The statistical analysis was performed in SPSS (IBM Corp. Released 2015. IBM SPSS Statistics for Windows, Version 23.0. Armonk, NY: IBM Corp).

RESULTS: Three subjects were excluded since these had a significantly lower TTC in the fourth control condition compared to the initial condition. The following analysis was performed only on the remaining 15 subjects. Results for the left sided trials only are presented in this manuscript.
Peak values of the vertical GRF (VGRF) and horizontal GRF (HGRF) did not show any significant differences between shoes. Furthermore, contact time and TTC were not different between the shoes. There was a significant difference in timing of the peak VGRF which occurred 3.6 ms earlier for shoe B compared to C. The peak hip flexion moment was significantly reduced (6.3%) for shoe C compared to the two other shoe conditions while the peak ankle flexion moment was significantly higher (10.5%) for shoe C compared to shoe A (Table 1).

Table 1: RMS and peak values ± 1 SD for selected variables during the contact phase of the badminton lunge. Shoe condition *A*(0 mm), B(4 mm) and C(8 mm) are presented. * Indicates significant difference (p < 0.05) compared to control condition *A*. † Indicates significant difference (p < 0.05) compared to condition *B*.

Variable	Shoe A	Shoe B	Shoe C
VGRF Peak (N)	3660.4 ± 800.4	3692.6 ± 918.67	3623.8 ± 845.0
Time to peak (ms)	54.0 ± 12.9	51.1 ± 11.8	53.7 ± 12.3 †
HGRF Peak (N)	2073.7 ± 455.5	2081.0 ± 522.7	2031.5 ± 481.2
Hip Flexion Moment Peak (Nm)	284.7 ± 29.7	284.8 ± 28.5	266.9 ± 27.7*†
Knee Flexion Moment Peak (Nm)	221.8 ± 9.0	220.6 ± 44.5	224.4 ± 45.9
Ankle Flexion Moment Peak (Nm)	86.4 ± 14.5	88.6 ± 14.5	95.1 ± 16.8*
Time to completion (ms)	1351.3 ± 98.3	1340.7 ± 87.9	1343.4 ± 77.8
Contact time (ms)	574.3 ± 80.0	564.7 ± 68.9	581.1 ± 77.4

DISCUSSION: In this study, the influence of different toe wedge conditions on the biomechanics of a maximal badminton lunge was investigated. The results showed no difference in performance among the three shoe conditions but an increased ankle moment and a decreased hip moment was observed when lunging with an 8-mm toe wedge.
The results for TTC and contact duration timing of the peak showed only one significant difference between the shoe conditions which was less than 4 ms and may be considered clinically irrelevant. The fact that the execution was not slower and that derived parameters from the force plate measurements, such as horizontal and vertical impulse (not shown in Table 1), remained unchanged may indicate that the selected shoe modifications had no positive or detrimental effect on performance opposed to claims made in the literature (Cronin et al. 2003). It has to be noted that the introduced alterations were minimal and, therefore, more drastic footwear changes may affect performance. It is also possible that the performance effect of the inclination wedge would be more significant if the subjects did repetitive lunges, i.e., would be wearing these shoes through a hole match.
This study showed similar ankle, hip and knee angle characteristics as those presented in Kuntze et al. (2010). Peak angles for hip, knee, and ankle did not show any significant difference between the shoe conditions (not shown in Table 1). This indicates that the intervention did not change the movement pattern of the subjects. This could also be observed for the angle curves, which showed very close resemblance amongst the three

wedge conditions. These negligible changes in joint kinematics between the conditions could be due to the minor differences between wedges.
It is remarkable that despite the minimal alterations in movement technique and reaction force a significant increase in ankle moment (10.5%) was occurring. As a result of this, a decreased external hip flexion moment was seen for the shoe C (6.3%). Considering the fact that an external hip moment would have to be counteracted by the hip extensor muscles during the lunge movement it is conceivable that such a reduction may lead to a decreased, likely eccentric muscle action over repeated sets of lunges and therefore over a whole match. This may contribute to a reduction of hip muscle fatigue over longer playing sessions. At the same time an increase activity of the plantar flexors may lead to an increase of fatigue in this muscle group over time. It remains difficult to extrapolate which of these factors would play the greater role in regard to performance in a match situation against maintenance of stability and safety.
While this study only included one specific shoe modification it is important to note that a comparably small shoe alteration shows notable and significant effects on load distribution along a whole kinetic chain. It will be interesting to investigate other shoe manipulations biomechanically and physiologically in the future.
A limitation in this study was the explosive lunge movement which could have affected the accuracy of the markers. The GRF peak measures within this study were generally higher compared to other badminton related lunge studies (Kuntze et al. 2010, Hong et al. 2014). This difference was most likely due to a more powerful execution of the lunge movement within this study. The implementation of the control condition enabled the researchers to exclude subject with signs of fatigue or movement adaptations, amongst the different conditions. Therefore, it is expected that these factors should not affect the relative comparison between conditions.

CONCLUSION: This study did not show any performance changes by subtle footwear modifications but demonstrated the potential of influencing biomechanical loading characteristics along the whole kinetic chain by a minimal intervention around the foot. Future studies should evaluate further modification strategies, including the change of material and midsole properties and similarly evaluate how these alterations affect game situations and injuries.

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