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Article Title: Kinetics of Badminton Lunges in Four Directions

Authors: Youlian Hong\textsuperscript{1,2}, Shao Jun Wang\textsuperscript{2}, Wing Kai Lam\textsuperscript{3}, and Jason Tak-Man Cheung\textsuperscript{3}

Affiliations: \textsuperscript{1}Changdu Sports University, Chengdu, China. \textsuperscript{2}The Chinese University of Hong Kong. \textsuperscript{3}Li Ning Sports Science Research Center, Beijing, China.

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Kinetics of badminton lunges in four directions

Youlian Hong\textsuperscript{1,2,*}, Shao Jun Wang\textsuperscript{2}, Wing Kai Lam\textsuperscript{3}, and Jason Tak-Man Cheung\textsuperscript{3}

\textsuperscript{1}Changdu Sports University
\textsuperscript{2}The Chinese University of Hong Kong
\textsuperscript{3}Li Ning Sports Science Research Center, Beijing, China

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\textbf{Correspondence Address:} Youlian Hong, PhD; Distinguished Professor, Department of Sports Medicine, Chengdu Sports University; 2 Tiyuan Rd., Chengdu, 610041 China; Mobile phone: 159 2881 0612; Fax: (028) 8509 0545; E-mail: hong.youlian@gmail.com

\textbf{Running Title:} Kinetics of badminton lunges
Abstract

The lunge is the most fundamental skill in badminton competitions. Fifteen university-level male badminton players performed lunge maneuvers in four directions, namely, right-forward, left-forward, right-backward, and left-backward, while wearing two different brands of badminton shoes. The test compared the kinetics of badminton shoes in performing typical lunge maneuvers. A force plate and an insole measurement system measured the ground reaction forces and plantar pressures. These measurements were compared across all lunge maneuvers. The left-forward lunge generated significantly higher first vertical impact force (2.34 ± 0.52 BW) than that of the right-backward (2.06 ± 0.60 BW) and left-backward lunges (1.78 ± 0.44 BW); higher second vertical impact force (2.44 ± 0.51 BW) than that of the left-backward lunge (2.07 ± 0.38 BW); and higher maximum anterior-posterior shear force (1.48 ± 0.36 BW) than that of the left-backward lunge (1.18 ± 0.38 BW). Compared with other lunge directions, the left-forward lunge showed higher mean maximum vertical impact anterior-posterior shear forces and their respective maximum loading rates, and the plantar pressure at the total foot and heel regions. Therefore, the left-forward lunge is a critical maneuver for badminton biomechanics and related footwear research because of the high loading magnitude generated during heel impact.

Keywords: badminton shoe, footwear, ground reaction force, plantar pressure, cushioning

Word Count: 2410 words
Introduction

Badminton is a non-contact racket sport that requires jumps, lunges, quick changes in direction, and rapid arm movements from a wide variety of postural positions.¹ The lunge step accounts for 15% of all movements in a competitive singles match.² The sudden stop-and-go maneuvers producing variable loads on the lower extremity of players have the potential to induce lower extremities injuries, especially by rapid and repetitive lunge steps that involve strenuous impact during heel contact.³

Footwork is the most fundamental skill in badminton competitions and the most critical for skill proficiency.²,⁴ Skilled footwork allows players to reach the shuttlecock as quickly as possible with minimum effort and performance time. Footwork enables players to move into the best position to execute shots while maintaining good balance and body control.⁵ Moving quickly to the net and to the baseline from the center of the court entails four major lunge directions to the corners, namely, right-forward, left-forward, right-backward, and left-backward steps. These lunges are considered as the most fundamental and critical maneuvers for skill proficiency. As footwork skills become more proficient, the length and number of steps needed from the center to all parts of the court can be determined. This movement forms the critical footwork pattern for individual players.⁴

Investigating the kinetics and kinematics between the different lunge directions can provide biomechanical information on enhancing athletic performance, and offer coaches and players useful information on injury prevention during trainings and competitions. A general belief exists that athletic footwear can improve player performance while preventing excessive load and related injuries by providing optimal shock attenuation and movement stabilization. Injury prevention, performance, and comfort are the most important functional design features
for court shoes. Representative movement has been used in the biomechanical testing of an athletic shoe to evaluate its corresponding functional performance. Wei et al compared the kinetic and kinematic characteristics of the metatarsophalangeal joint of participants while executing a right-forward badminton lunge in two shod conditions. Fu et al investigated the difference in plantar pressures among right-forward lunge, left-forward lunge, and one-step jump. However, systematic information concerning biomechanical characteristics of lunges in different directions is lacking.

The current study compares the external and insole load responses of four types of badminton lunges, namely, right-forward, left-forward, right-backward, and left-backward, while two different brands of badminton shoes are worn by the sample. Our hypothesis states that ground reaction force and plantar loading during heel impact would be significantly larger in the right-forward lunge of right-handed players, which could be defined as the most critical lunge step for the biomechanical testing of badminton shoes compared with other lunge directions.

Methods

Participants

Fifteen right-handed male badminton players (age 21.69 ± 1.03 y; height 172.61 ± 5.20 cm; body mass 61.67 ± 7.15 kg) with shoe size of EUR42 participated in this study. The players were all active participants in singles badminton competitions at the university level and had at least five years of badminton game experience. All participants reported they were free from neuromuscular, vestibular, and vision system injuries for at least six months before participation, and were generally in good physical condition. The study was approved by the Ethics Committee of The Chinese University of Hong Kong. All participants signed a written informed consent form before the test.
Procedure

Two pairs of badminton shoes, one pair coming from two brands most commonly used in competitions, were selected for this study. The two pairs of shoes were coded as Y and L. After anthropometric measurements, the participants were asked to perform a 10-minute warm up, including familiarization with testing movements by using a standard-sized racket. Kinetic measurement was conducted with the participants performing right-forward, left-forward, right-backward, and left-backward lunge steps for each shoe brand at their maximum speed. Participants were instructed to perform each test maneuver in three steps, starting from a standardized initial position. The last step must be a lunge with the dominant leg landing on the force plate. Before the actual test trial, each participant was asked to perform continuously each of the four lunge step maneuvers with maximum effort until five successful lunge steps were collected, as deemed by the team coach. The distances of the five lunge step trials were measured and averaged to determine the landing position of the last steps in relation to the center of the force plate for individual participants. The same tester who could consistently perform the respective badminton movements (Figure 1) demonstrated the footwork and foot placements of typical lunge steps in the four directions to all participants. Upon landing on the force plate, the participants were asked to return to their starting positions at their quickest controllable speed. Twenty successful trials were collected for each shoe condition. Participants were provided with 30-second and 5-minute rests between trials and lunge directions, respectively, to minimize fatigue. Both lunge directions and shoe conditions were randomized across participants.

Data collection

A force plate (Kistler 9281C, Switzerland) measured the three-dimensional ground reaction forces of the landing foot. The force plate and the surroundings were covered with
synthetic badminton court floor mats to simulate more realistically the physical properties of the condition of the badminton floor. The ground reaction forces were recorded by using DEWEsoft 6.5 (DEWETRON Ges.m.b.H., Austria) at a sampling rate of 1000 Hz with an analog/digital card (National Instrument PCI-6071E, USA). Lunge directions and foot landing angles were captured by four video cameras (DEWEsoft 6.5, DEWETRON Ges.m.b.H., Austria) with a 100 Hz filming rate and a shutter speed of 1/500 s. The foot landing angle was defined as the shoe sole angle relative to the surface of the force plate during the initial heel contact. The horizontal shear forces were resolved into parallel and perpendicular directions based on the longitudinal foot axis to represent the anterior-posterior and medial-lateral force components.

Foot plantar pressure was measured by using an insole pressure measurement system (Pedar-X system, Novel Electronics, Germany). The instrumented insoles contained 99 capacitive pressure sensors sampled at a rate of 200 Hz. The pressure information of each sensor was transmitted to a computer via Bluetooth wireless communication with the patient unit, which was secured around the waist of the participant. The insoles were inserted in both right and left shoes during data collection, but only the data from the dominant (right) leg were collected. The plantar surface was divided into four regions, namely, rearfoot (30% of foot length), midfoot (30% of foot length), forefoot (25% of foot length), and toes (15% of foot length). These areas were further subdivided into nine regions (Figure 2), namely, medial heel (medial 50% of the rearfoot width), lateral heel (lateral 50% of the rearfoot width), medial midfoot (medial 50% of the midfoot width), lateral midfoot (lateral 50% of the midfoot width), first metatarsal head (medial 30% of the forefoot width), second and third metatarsal heads (middle 40% of the forefoot width), fourth and fifth metatarsal heads (lateral 30% of the forefoot width).
width), great toe (medial 25% of the width of the toes), and lesser toes (lateral 75% of the width of the toes). Peak pressure was extracted for the total foot and each foot mask.

**Data reduction**

Ground reaction force patterns were determined to be similar for all lunge directions, and therefore, the loading profiles of vertical (Fz), anterior-posterior (Fy), and medial-lateral (Fx) ground reaction forces obtained from a typical right-forward lunge measurement were provided for the sake of simplifying variable definition (Figure 3). The ground reaction forces were normalized by body weight (BW). Three local peak forces were clearly identified, which are first vertical impact peak right after heel contact (A), second vertical impact peak (B), and maximum anterior-posterior shear (C). tA, tB, and tC were denoted as the times corresponding to their respective peak forces, while rA, rB, and rC were denoted as the maximum loading rates of their respective peak forces. The peak pressures measured by the insole pressure system at the total foot and at each foot mask were presented. All testing variables were evaluated for all four lunge directions.

**Statistics**

Paired t-tests were used to detect the differences between the two brands of shoes based on each variable. If no significant shoe difference was determined for any specific variable, then the data of the two brands of shoes were pooled and averaged for further analysis. One-way ANOVA with repeated measures was used to examine any lunge effect on each variable. A 5% significance level was adopted, and all data were expressed as mean ± standard deviation.

**Results**

The paired t-tests did not indicate a significant shoe effect for all testing variables, including landing angle, ground reaction forces, and insole plantar pressure variables. Therefore,
all variables of the two brands of shoes in each direction were pooled and averaged to determine any lunge direction effect.

No significant difference exists in the initial landing angles between the lunges in the four directions. The initial landing angle was 45.28° ± 6.04° for the right-forward lunge, 46.90° ± 6.11° for the left-forward lunge, 41.61° ± 8.47° for the right-backward lunge, and 40.04° ± 7.14° for the left-backward lunge.

The mean vertical impact peaks and anterior-posterior shear forces and their respective maximum loading rates of the left-forward lunge direction were the highest between all tested lunge directions (Table 1). The first vertical impact peak (A), the loading rate of first vertical impact peak (rA), and the loading rate of the second vertical impact peak (rB) of the left-forward lunge were significantly higher than those of the right-backward and left-backward lunges. Most kinetic variables for the left-backward lunge had significantly lower magnitudes compared with the other three lunge directions (all \( P < 0.05 \)).

Based on in-shoe plantar pressure measurements, the left-forward and right-forward lunge directions were associated with higher plantar loading at the heel and toe regions, whereas the right-backward lunge direction was associated with higher loading at the midfoot and metatarsal heads regions (Table 2). The left-forward lunge direction had the highest mean peak pressure at the total foot and heel regions, which were significantly higher than that of the other lunge directions. The right-backward lunge direction produced the highest peak pressure at the midfoot and medial metatarsal head regions. This finding was significantly higher than that of the other lunge directions. The peak pressure at the heel was considerably and consistently higher than that of the midfoot and metatarsal head regions.
Discussion

This study examined the effects of four badminton lunge directions on the external loading and in-shoe plantar pressures. Moreover, the research identified the most critical kinetic responses among the studied lunge steps to provide evidence-based guidelines for badminton research and footwear evaluation. Generally, the external loading variables indicated that the left-forward lunge step had higher loadings during heel impact when compared with that of the other directions. The in-shoe pressure results indicated that the first metatarsal head, great toe, medial heel, and lateral heel masks had relatively high peak pressure magnitude during lunge maneuvers. In general, the left-forward lunge had the highest loading in three out of the four high loading regions than that of the other lunge directions. These findings did not support our hypothesis that the right-forward lunge was generally believed as the most critical lunge direction for right-handed participants regarding kinetic responses. Overall, the left-forward lunge produced higher external and insole loadings than those of the other three lunge directions, which could be considered as the most critical lunge movement for badminton biomechanics study.

In badminton, the frequent execution of the lunge step is generally considered as a major risk factor of lower extremity injury. Researchers suggested that the Achilles tendon, plantar fascia, anterior talo-fibular ligament of the specific musculotendon, and ligamentous structures are more susceptible to greater injury risks in badminton than in other sports because of the uniqueness and repetitive nature of badminton movements, especially the high frequency “stop-and-go” maneuvers. Excessive and repetitive external loads of badminton maneuvers are potential mechanical risk factors for joint tissue injuries and development of stress fractures and micro-damage in the cartilage. Repetitive lunge steps may result in ruptures of Achilles tendon.
In addition, excessive shear force would be associated with the risk of ACL injury. Therefore, adequate cushioning in the shoe is important to attenuate high and repetitive loading, especially during the heel impact of lunge movements.

Footwear material and structural properties can be optimized to attenuate external impact forces and potentially reduce the frequency of overuse injuries. Dixon et al suggested that a degraded insole would increase the maximum loading rate of the impact peak force, while Lafortune and Hennig showed that footwear with softer midsoles would result in lower shock transmission from the foot up to the proximal joints. Although the tested shoes in the present study had different external geometric, dimensions, material, and structural designs, the loading responses of both brands of shoes confirmed that the left-forward lunge had either higher or comparable ground reaction forces and plantar pressure than those of the other lunge directions. Therefore, the left-forward lunge movement is recommended as one of the critical maneuvers for evaluating injury mechanics and footwear performance, especially for the impact phase during lunges.

Although the findings of the present study demonstrated that the left-forward lunge is an important badminton testing maneuver, such finding is merely the recommendation from the kinetics perspective. A more comprehensive evaluation that involves kinematics, joint forces, moments, and electromyography of the lower extremities, is necessary to provide further insight into the biomechanics of badminton lunge movements. Although the individual maximum lunge distance was predetermined and used across lunge directions, the influence of lunge distance on the kinetics response could not be fully eliminated. Considering the individualized biomechanical characteristics and the respective functional requirements of badminton footwear, further research should investigate gender and expertise effects on the kinetic and kinematic
variations during lunge maneuvers to establish the evidence-based athletic performance and biomechanics characteristics and related functional needs of badminton footwear.

In summary, an evidence-based testing protocol is prerequisite for an objective and reliable evaluation of athletic and sports gear performance. The current external ground reaction forces and in-shoe plantar pressure data indicated that the left-forward lunge step would generally induce higher ground reaction forces and peak plantar pressure on the dominant leg of badminton players than those of the other tested lunge directions during heel impact. Thus, the left-forward lunge maneuver is recommended as one of the critical movements for evaluating badminton lunge biomechanics and footwear functionality.

Acknowledgments

This research was supported by the Beijing Municipal Commission of Science and Technology.
References


Figure 1 — Illustration of lunges in four directions: (a) right-forward lunge, (b) left-forward lunge, (c) right-backward lunge, and (d) left-backward lunge. The open foot marks represent the foot placements of the right foot, while the solid foot marks represent the foot placements of the left foot. The numbers represent the step sequences.
Figure 2 — Segmented foot masks for in-shoe plantar pressure analysis
Figure 3 — Curves of vertical (Fz), anterior-posterior (Fy), and medial-lateral (Fx) ground reaction forces in a typical right-forward lunge step. A and B represent the first and second vertical impact peaks, respectively, and C represents the maximum anterior-posterior reaction force.
Table 1  Maximum ground reaction forces and loading rates of different lunges. A, B and C represent the first and second vertical impact peaks, and maximum anterior–posterior shear force respectively. tA, tB and tC represent the time to peak force A, B and C respectively. rA, rB and rC represent the maximum loading rate of force A, B and C respectively.

<table>
<thead>
<tr>
<th>Lunge direction</th>
<th>A (BW)</th>
<th>B (BW)</th>
<th>C (BW)</th>
<th>tA (ms)</th>
<th>tB (ms)</th>
<th>tC (ms)</th>
<th>rA (BW/s)</th>
<th>rB (BW/s)</th>
<th>rC (BW/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Right-forward</td>
<td>2.21 ± 0.45</td>
<td>2.36 ± 0.46</td>
<td>1.47 ± 0.40</td>
<td>19.64 ± 5.83</td>
<td>55.56 ± 8.43</td>
<td>52.25 ± 8.03</td>
<td>104.53 ± 41.00</td>
<td>44.5 ± 13.60</td>
<td>27.82 ± 9.60</td>
</tr>
<tr>
<td>Left-forward</td>
<td>2.34 ± 0.52</td>
<td>2.44 ± 0.51</td>
<td>1.48 ± 0.36</td>
<td>21.03 ± 6.23</td>
<td>55.31 ± 8.50</td>
<td>54.65 ± 8.26</td>
<td>113.00 ± 42.64</td>
<td>44.57 ± 12.86</td>
<td>29.22 ± 10.12</td>
</tr>
<tr>
<td>Right-backward</td>
<td>2.06 ± 0.60#</td>
<td>2.37 ± 0.45</td>
<td>1.39 ± 0.33</td>
<td>24.25 ± 2.91</td>
<td>58.72 ± 10.51</td>
<td>57.02 ± 13.94#</td>
<td>89.72 ± 37.94#</td>
<td>39.73 ± 13.94#</td>
<td>29.68 ± 15.42</td>
</tr>
<tr>
<td>Left-backward</td>
<td>1.78 ± 0.41#†</td>
<td>2.07 ± 0.38#†</td>
<td>1.18 ± 0.25#†</td>
<td>20.31 ± 3.88</td>
<td>59.12 ± 10.67</td>
<td>51.69 ± 13.54</td>
<td>67.28 ± 18.99#†</td>
<td>37.13 ± 13.17*#</td>
<td>21.51 ± 7.47*#†</td>
</tr>
</tbody>
</table>

* P < 0.05 vs. Right-forward lunge direction;
# P < 0.05 vs. Left-forward lunge direction;
† P < 0.05 vs. Right-backward lunge direction.
Table 2  Peak pressure (kPa) at each foot mask by different lunge directions.

<table>
<thead>
<tr>
<th>Mask</th>
<th>Right-forward</th>
<th>Left-forward</th>
<th>Right-backward</th>
<th>Left-backward</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Foot</td>
<td>385.03 ± 105.13#</td>
<td>410.30 ± 115.51</td>
<td>379.11 ± 94.76</td>
<td>320.52 ± 88.09*#†</td>
</tr>
<tr>
<td>Medial Heel</td>
<td>350.41 ± 98.19</td>
<td>363.73 ± 101.10</td>
<td>323.14 ± 101.88#</td>
<td>287.05 ± 82.45*#†</td>
</tr>
<tr>
<td>Lateral Heel</td>
<td>378.87 ± 106.83#</td>
<td>399.10 ± 114.76</td>
<td>343.92 ± 121.28#</td>
<td>299.67 ± 91.23*#†</td>
</tr>
<tr>
<td>Medial Midfoot</td>
<td>62.75 ± 22.74†</td>
<td>66.83 ± 23.74</td>
<td>76.65 ± 38.70</td>
<td>61.38 ± 16.05†</td>
</tr>
<tr>
<td>Lateral Midfoot</td>
<td>102.87 ± 27.84†</td>
<td>99.44 ± 19.68†</td>
<td>105.82 ± 28.94</td>
<td>89.35 ± 13.84*#†</td>
</tr>
<tr>
<td>1st Metatarsal Head</td>
<td>174.48 ± 74.55†</td>
<td>183.28 ± 93.29</td>
<td>216.13 ± 89.80</td>
<td>176.73 ± 70.93†</td>
</tr>
<tr>
<td>2nd and 3rd Metatarsal Heads</td>
<td>135.35 ± 49.90#†</td>
<td>139.61 ± 55.96†</td>
<td>166.06 ± 64.01</td>
<td>136.72 ± 47.29†</td>
</tr>
<tr>
<td>4th and 5th Metatarsal Heads</td>
<td>138.90 ± 57.19</td>
<td>130.35 ± 32.09</td>
<td>136.45 ± 59.63</td>
<td>130.23 ± 37.54</td>
</tr>
<tr>
<td>Great Toe</td>
<td>230.60 ± 72.03</td>
<td>218.38 ± 64.82</td>
<td>136.45 ± 62.24</td>
<td>130.23 ± 71.24</td>
</tr>
<tr>
<td>Lateral Toes</td>
<td>162.98 ± 49.74</td>
<td>161.28 ± 44.82</td>
<td>151.69 ± 38.01</td>
<td>149.35 ± 46.59</td>
</tr>
</tbody>
</table>

* P < 0.05 from the Right forward
# P < 0.05 from the Left forward
† P < 0.05 from the Right backward