THE DYNAMIC CHARACTERISTICS OF THE PLANTAR PRESSURE IN THREE TYPICAL BADMINTON FOOTWORK PATTERNS

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The purpose of this study was to investigate the dynamic characteristics of plantar pressure in the three-badminton footwork patterns (left-forward lunging step, LFLS, right-forward lunging step, RFLS, backward revolve to jump, BRJ). Twelve elite national-level male badminton athletes were recruited while performing the three typical footwork patterns tests in a laboratory-simulated badminton court. The results of the present study demonstrate that the normalized mean peak pressures (MPP) were significantly higher under the hallux and the 1st to 2nd metatarsals than other areas in the toe-off (TO) phase when performing the three footwork patterns. In the process of touching down (TD), both LFLS and RFLS showed significantly higher loads on the rearfoot and the lateral of the foot. Thus, the badminton players should be paying attention to modulating the load strategies on the front-foot, rear-foot, and lateral of the foot regions when performing the different footwork patterns, and select the appropriate footwear that can disperse the higher loads of the target areas to avoid excessive concentration of the plantar pressures.

KEYWORDS: footwork patterns, badminton, plantar pressure, pressure distribution.

INTRODUCTION: The regular lower-limb movements in badminton performers were generally called footwork patterns (Fu, 2011), which required the ability of the body balance, aerobic stamina, and sophisticated motor coordination simultaneously to hit the shuttlecock properly and efficiently (Phomsoupha & Laffaye, 2015). However, many studies have shown that badminton-related injuries tend to occur in the lower extremities, because of the landing actions and quick directional changes with a high rate of greater impact (Hung, Hung, Chang, Wang, & Lin, 2020).

As a typical footwork pattern, the lunging movement (over 15% of all badminton movements) was categorized into left-forward, right-forward, left-backward, and right-backward based on movement directions (Hong, Wang, Lam, & Cheung, 2014). This task generally consists of two phases (braking and acceleration) and forms the pattern of the “start-stop-recover cycle” (Kuntze, Mansfield, & Sellers, 2010). The footwork patterns of repetitive, consecutive, and rapid lunges can cause a powerful impact on the foot, the rear foot, particularly during a touch-down (TD) phase, which can induce a high risk of sports injuries in the lower extremities (Fu, 2011).

METHODS: Twelve elite national-level male badminton athletes (age: 20.1 ± 1.9 years old; height: 179.1 ± 3.4 cm; weight: 71.1 ± 7.6 kg; training period: 10.7 ± 2.5 years) from the badminton team of the Shanghai University of Sport volunteered to participate in the study. All

participants were right-handed style and free from any previous lower limb injuries and surgery or foot diseases, and had no injury for at least six months.

To obtain the kinetic data of the plantar pressure, the Medilogic insole measurement (Germany) with a frequency of 60 Hz was used in this study. The plantar region was divided into three anatomical parts: forefoot, mid-foot, rear-foot.

Before the test, all participants were required to warm up for 15 min at the badminton training gymnasium of the Shanghai University of Sport. Then the participants performed multi-shuttle training for 10 min incorporated with the three types of footwork patterns, respectively. All were required to perform the three sets of footwork patterns movements five times (3×5), and the internal time was 2 min after each test.

We selected two key phases (toe-off, TO, and touch-down, TD) for analysis in detail based on the characteristics of badminton footwork patterns. The mean peak pressure (MPP), the transformation rate (TR), and the pressure-time curve of plantar divisions were processed for subsequent analysis.

All statistical analyses were performed using SPSS 19.0 (SPSS Inc., Chicago, IL, USA). After the Shapiro-Wilks normality test, one-way ANOVA analysis with LSD adjustment was used to evaluate the statistical differences in kinetics among the three types of badminton footwork patterns. The significance level was set at $P < 0.05$.

RESULTS: The normalized MPP was shown in Table 1, and the transformation rate (TR) represents the percentage of MPP changing in the footwork patterns from the TO to TD process.

$$\text{Transformation rate} = \frac{(\text{MPP}_{\text{TD}} - \text{MPP}_{\text{TO}})}{\text{MPP}_{\text{TO}}} \times 100\%$$

Except for BRJ ($p = 0.003$), the size of MPP value showed no statistical difference between LFLS and RFLS ($p = 0.641$, $p = 0.402$) during TO and TD as well as at transformation rate because of the similar footwork patterns techniques (Table 1). Contrarily, the MPP of BRJ was significantly larger in TO and TD phases than the other two types of footwork patterns, respectively. Transformation rate showed a negative value (-) in RFLS and LFLS movements, but a positive value (+) while performing BRJ action.

Table 1: The normalized MPP of plantar in the three footwork patterns (N/kg×cm^2).

Footwork	MPP		
patterns	TO	TD	TR (%)
LFLS	0.087 ± 0.01*	0.080 ± 0.01*	-8.4 ± 0.07*
RFLS	0.089 ± 0.01*	0.081 ± 0.01*	-8.3 ± 0.09*
BRJ	0.093 ± 0.01	0.109 ± 0.02	+16.9 ± 0.18

* significant difference with BRJ, $p < 0.05$.

As shown in Table 2, a distinct peak value appeared under the forefoot in the TO phase for the three footwork patterns. LFLS and RFLS showed no significant difference in the peak pressure on each of the three areas of interest during the TO, but BRJ showed significantly larger on the three areas compared with the other two types of footwork patterns. Meanwhile, the peak

pressures on the forefoot area were larger than mid-foot and rare-foot areas among the three different typical footwork patterns (Table 2).

Table 2. Normalized peak pressures on the three areas among the three footwork patterns (N/kg×cm^2).

Plantar Divisions		TO			TD		
		LFLS	RFLS	BRJ	LFLS	RFLS	BRJ
Forefoot		0.184 ± 0.02*	0.185 ± 0.02*	0.200 ± 0.02	0.077 ± 0.02*	0.078 ± 0.01*	0.139 ± 0.02
	ES	0.51^	0.71^^	0.70^^^	0.52^	0.99^^	0.99^^^
Mid-foot		0.040 ± 0.01*	0.039 ± 0.01*	0.023 ± 0.01	0.037 ± 0.01*	0.039 ± 0.01*	0.058 ± 0.01
	ES	0.53^	0.89^^	0.87^^^	0.56^	0.93^^	0.91^^^
Rare-foot		0.074 ± 0.01*	0.075 ± 0.01*	0.061 ± 0.01	0.115 ± 0.02	0.120 ± 0.02	0.123 ± 0.02
	ES	0.53^	0.82^^	0.84^^^	0.57^	0.61^^	0.54^^^

* significant difference with BRJ, $p < 0.05$.
^ means the comparison between LFLS and RFLS;
^^ means the comparison between LFLS and BRJ;
^^^ means the comparison between RFLS and BRJ.

DISCUSSION: LFLS and RFLS had a similar characteristic pattern in plantar pressure, by combining with the similar skillful performance and pressure distribution, based on the analysis of transformation rate of normalized mean peak pressure from toe-off to touch down process. Thus, the results of both them showed no significant difference during badminton performance. However, the MPP and transformation rate of backward revolve to jump (BRJ) exhibited significantly larger than LFLS and RFLS. Additionally, the BRJ movement showed a positive correlation between TO and TD.

In the TO phase, peak pressures in the three regions for BRJ action were significantly larger compared with LFLS and RFLS, particularly on the medial forefoot and the hallux. This result was similar to previous findings that the greater loads on those areas were related to the regulation of body balance after the forward swing process of table tennis cross-step movement (Shao et al., 2020). In other words, BRJ action had a better balance than LFLS and RFLS, which can contribute to completing the transition to the next stage smoothly. In the TD phase, both LFLS and RFLS showed significantly larger peak pressure under rare-foot than other areas, this result coincides with previous studies (Hu, Li, Hong, & Wang, 2015), but BRJ action was on the forefoot area. The significant differences in plantar pressure can be due to the landing modes, LFLS, and RFLS movements landed on rare-foot, while BRJ landed on the forefoot area. Importantly, badminton lunge that combines jumping and swift direction changes with a higher plantar pressure while running is most possibly associated with lower extremity injuries (Hung et al., 2020). Therefore, both LFLS and RFLS in comparison with BRJ had a higher risk of sports-related injuries in the lower extremity during the game.

CONCLUSION: The results showed that the peak pressures on the hallux and 1st to 2nd metatarsal areas for the three footwork patterns were significantly higher than other areas during the TO, which contributed to pedal and stretch (acceleration phase) to gain more strength for a smooth transition to the next phase. When landing on the ground, LFLS and RFLS movements focused the plantar pressure on the rare-foot and the lateral of the foot, while BRJ focused on the hallux and the 1st to 2nd metatarsal areas. Therefore, athletes should adjust the TD modes reasonably according to different footwork patterns to avoid injury.

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