ORIGINAL ARTICLE

Asymmetry in foot pressure distribution patterns during bend sprinting

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ABSTRACT

In curved track sprinting under high running speeds, such as in the short distance events of athletics, there are left-right differences in the exertion of force. However, the characteristics of the differences in foot pressure distribution related to force production during a curved track sprint have not yet been investigated. The purpose of this study was to clarify the asymmetry of foot pressure distribution during bend sprinting. Thirteen male university sprinters performed three maximum-effort 60 m sprints on a curved track with a radius of 37.9 m. Foot pressure was measured using a wireless insole pressure sensor system with 13 sensors per foot. The maximum foot pressure and the pressure of each sensor at the time of maximum foot pressure were calculated. No significant difference was observed between the left and right legs in terms of the maximum foot pressure. However, the pressure ratio at the sensor located near the fifth toe (Ch0) was significantly higher in the right leg than that in the left leg. By contrast, the pressure ratios at the sensors located around the first cuneiform (Ch8 and Ch10) were significantly higher in the left leg than in the right leg. These results suggest that during bend sprinting, mechanical loading is greater around the first toe in the right foot than in the left foot and around the medial midfoot in the left foot than in the right foot. These findings have implications for the performance enhancement and injury prevention of sprinters.
Keywords: Biomechanics, Sprint motion, Curvilinear, Foot pressure, Asymmetry.

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INTRODUCTION

In short-distance track events, the maximum sprinting speed observed in the middle phase of a race has been reported to have a significant impact on performance (Hanon & Gajer, 2009; Mackala, 2007). However, unlike the 100 m sprint, the 200 m and 400 m races require athletes to run on a curved track because of the design of standard athletics tracks. Furthermore, it has been reported that maximum sprinting speed often occurs in the curved section of a track (Ferro & Floria, 2013; Quinn, 2009). Thus, achieving high sprinting speeds on a curved track is one of the key challenges for improving performance in the 200 m and 400 m events.

To run on a curved track, in addition to generating force in the anteroposterior and vertical directions, as in straight-track running, athletes must also exert force in the lateral direction, namely, centripetal force. Theoretically, this force is expressed as "*body weight × velocity² / radius of curvature*," meaning that the required force varies depending on the running speed and lane position. A characteristic strategy for generating this force is to lean the body inward toward the centre of the curve. Previous research on sprinting mechanics on curved tracks has generally shown that sprinting speed is lower on curved tracks than on straight tracks (Chang and Kram, 2007; Churchill et al.,2015; Churchill et al.,2016; Stoner & Ben-sira, 1979). Additionally, studies have reported asymmetries in lower limb kinematics and kinetics during curved-track sprinting, as well as differences from straight-track running that vary between the left and right sides (Churchill et al.,2015; Churchill et al.,2016; Alt et al., 2015; Ishimura & Sakurai, 2016; Judson et al.,2019). However, research on the characteristics of running mechanics on curved tracks remains limited and no consistent findings have been established.

The kinematic and kinetic characteristics of running on a curved track have primarily been investigated using motion-analysis methods. However, while ground reaction forces, which play a crucial role in determining body movement, have been examined, no study has specifically analysed the distribution of these forces. During running, it has been reported that when the peak ground reaction force occurs, foot pressure distribution increases around the first metatarsophalangeal joint (Cavanagh, 1987). However, during curved-track running, because athletes lean their bodies inward toward the centre of the curve, it is presumed that the proportion of foot pressure distributed in the inward and outward directions of the track increases. However, the extent of the shift remains unclear. Furthermore, to examine the sprinting mechanics on curved tracks, it is necessary to conduct investigations under high-speed conditions, as suggested by the theoretical considerations mentioned earlier.

The purpose of this study was to clarify the asymmetry of foot pressure distribution during bend sprinting.

MATERIAL AND METHODS

Participants

Thirteen male university sprinters participated in this experiment (age: 19 ± 1 years, height: 1.75 ± 0.05 m, body mass: 69.1 ± 5.1 kg, World Athletics Score in their specialized event: 886 ± 93). The average IAAF score of the participants in this study corresponded to an estimated 100 m sprint time of 11.00 seconds. Prior to the experiment, the purpose, procedures, and potential risks were explained both in writing and verbally, and written informed consent was obtained from all the participants. This study was approved by the Ethics Committee of the Japan Institute of Sports Sciences.

Measures

The experimental trials consisted of three maximum-effort 60 m sprints on a curved track. The experiment was conducted at an indoor facility with an all-weather synthetic track surface. For the curved-track trials, a curve with a radius of 37.9 m - equivalent to lane 1 of a standard athletics track, was used. This setup was based on the findings of previous study (Greene, 1985), which indicated that smaller curve radii resulted in greater performance decline. The participants were allowed to rest adequately between trials at their discretion. Prior to the experiment, reflective markers were attached to the participants based on a Plug-in Gait model (Davis et al.,1991).

The foot pressure was measured using a wireless insole pressure sensor system (OpenGo; Moticon GmbH, Germany). As described in previous studies (Braun et al.,2015; Oerbekke et al.,2017; Stöggl et al.,2017; Nagahara & Morin,2018), the device used in this experiment contained 13 embedded sensors per foot, for a total of 26 sensors, and was fully wireless. Sensor placement is shown in Figure 1. The sampling frequency was set to 50 Hz. Prior to the measurement, the system was calibrated using measurement and analysis software (Moticon, Moticon Inc., Germany). The participants were seated with both legs suspended in air during calibration, and data collection was conducted during the trials. All participants wore the same type of shoe (AIR ZOOM PEGASUS; NIKE, USA). The preinstalled insoles were removed, and the insole pressure sensors were inserted. The shoelaces were tightened to ensure a secure fit and minimize foot movement inside the shoes during the trials.

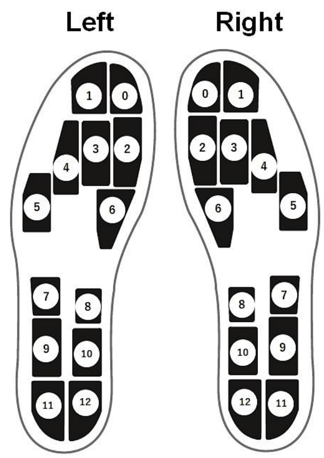


Figure 1. Location of each sensor buried in the measuring instrument. Adapted illustrations from Moticon Inc. manuals.

The measurement section was set approximately 45 m from the start, and data were collected. The printing motion was recorded using an optical 3D motion analysis system (Vicon-MX; Oxford Metrics Ltd., Oxford, UK) with a sampling frequency of 250 Hz. In the 3D measurement coordinate system, the Y-axis was defined as the anteroposterior direction, X-axis as the mediolateral direction, and Z-axis as the vertical direction. Additionally, a high-speed camera (LUMIX FZ300, Panasonic, Japan) was used to record the entire trial from start to end. Owing to software limitations, synchronizing the foot pressure sensor data with the motion data is challenging. Therefore, synchronization was performed using video footage recorded by the camera.

Procedures

Using the motion analysis software Vicon Nexus, the three-dimensional coordinates of the attached body markers were computed by appropriately processing the data in accordance with the Plug-in Gait protocol.

The whole-body centre of mass was calculated and was time-differentiated. The average resultant velocity in the X- and Y-axes over one running cycle was defined as the running speed. The trial with the highest running speed was selected for the foot pressure distribution analysis. For the foot pressure distribution analysis, the entire foot pressure dataset recorded using the aforementioned measurement and analysis software was transferred to a personal computer. Recorded video footage was used to count the number of steps, and the steps within the motion measurement section were identified. Based on the foot pressure data from the identified steps, the maximum foot pressure and the pressure ratio of each sensor at the time of maximum foot pressure were calculated.

Statistical analysis

A paired t-test was used to examine the differences between the left and right legs during curved-track sprinting. The significance level was set at less than 5%. The effect sizes were calculated using Cohen's d. Statistical analyses were performed using the IBM SPSS Statistics software (v. 22.0, SPSS Inc., Chicago, Illinois, USA).

RESULTS

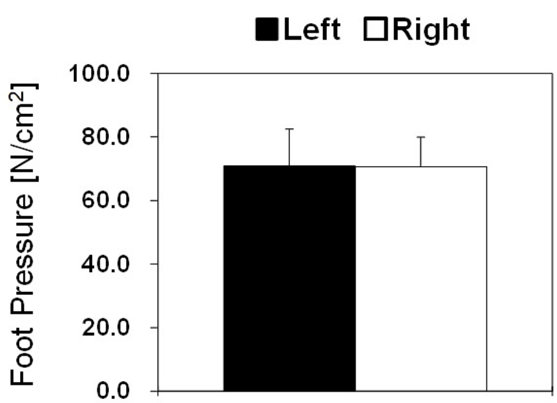
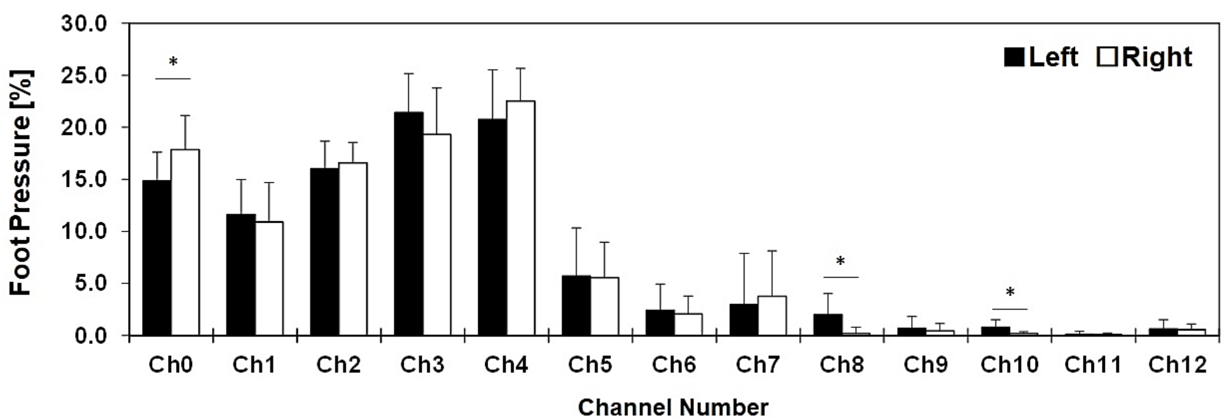


Figure 2. Maximum foot pressure during the left- and right-leg support phases. Black bars represent the left leg and white bars represent the right leg.



*Note. *: significant difference between left and right legs (p < .05).*

Figure 3. Differences in foot pressure ratio of each sensor between the left and right legs at the time of maximum foot pressure. Black bars represent the left leg and white bars represent the right leg.

Figure 2 shows the maximum foot pressure values for the left and right legs during the curved-track sprinting. No significant difference was observed between the legs in terms of maximum foot pressure (p = .30; d = 0.02). Figure 3 shows the pressure ratio of each sensor at the time of the maximum foot pressure.

The pressure ratio at Ch0 was significantly higher in the right leg than in the left leg (p = .03, d = 0.98). In contrast, the pressure ratios at Ch8 and Ch10 were significantly higher in the left leg than in the right leg (p = .01, d = 1.22; p = .02, d = 1.17, respectively).

DISCUSSION

This study aimed to clarify the asymmetry of foot pressure distribution during bend sprinting. The results revealed that while there was no difference in the maximum foot pressure between the left and right legs, the distribution ratio differed between them. The running speed in this study was 8.75 ± 0.15 m/s. This value is comparable to that reported in previous studies (Ishimura & Sakurai, 2016) on sprinting mechanics on curved tracks, indicating that the experimental setup for curved-track sprinting was appropriate.

At high running speeds, forefoot contact occurs during the stance phase, which reduces the ground contact time. In this study, 92.8 ± 7.7% of the contacts occurred within Ch0–6. Therefore, to improve performance, specifically to generate greater force, it is necessary to exert force in areas with a high load distribution. The results of this study showed that the pressure ratio at Ch0 was significantly higher in the right leg than that in the left leg. During curved-track sprinting, athletes lean their bodies inward toward the centre of the curve. This likely increases the loading toward the fifth toe on the left foot and toward the first toe on the right foot. The findings for Ch0 support this assumption. However, no significant difference between the legs was observed in the pressure ratio at Ch5. Judson et al. (2019) reported that throughout the entire stance phase during curved-track sprinting, the centre of pressure in the left foot was positioned laterally relative to the second metatarsal head, whereas in the right foot, it did not differ from straight-track running. In this study, only the pressure ratio at the time of maximum foot pressure—corresponding to the mid-stance phase—was analysed, and time-series analysis was not conducted. This may explain the discrepancy between findings. In other words, time-series changes in foot pressure distribution during curved-track sprinting may differ between the left and right legs.

The pressure ratios at Ch8 and Ch10 were significantly higher in the left leg than in the right leg. This result suggests that, in the left foot, greater mechanical loading occurs around the first cuneiform, a part of the midfoot, at the time of maximum foot pressure than in the right foot. The medial longitudinal arch plays a crucial role in shock absorption and energy transfer during weight bearing activities. Differences in arch height have been associated with variations in running-related injuries (Williams et al., 2001). Regarding lower-limb joint kinetics during curved-track sprinting, Judson et al. (2019) reported that the midfoot joint moment in the left foot was greater than that in the right foot. The findings of this study support previous research, suggesting that the left foot experiences greater loading on the medial longitudinal arch than the right foot, potentially increasing the risk of running injuries due to medial longitudinal arch dysfunction. No significant difference was observed in maximum foot pressure between the left and right legs during the stance phase. Previous studies on ground reaction forces during maximum-effort sprinting have also reported no significant difference in vertical ground reaction forces between legs (Churchill et al.,2016), supporting the results of this study.

To replicate high-speed conditions, wireless insole sensors were utilized in this study. However, it has been reported that the ground reaction forces estimated from the wireless insole pressure sensors used in this study tend to be lower than actual values (Stöggl et al.,2017). Additionally, measuring spatiotemporal variables and the vertical component of ground reaction forces during sprinting, which involves a short ground contact time, has been reported to be challenging (Nagahara & Morin,2018). Therefore, rather than using the absolute values of the measured pressure, this study examined the differences in the distribution between the left and right legs using pressure ratios. Future research should address limitations such as time resolution and number of sensors to further investigate time-series changes in foot pressure during curved-track sprinting.

CONCLUSION

The purpose of this study was to clarify the asymmetry of foot pressure distribution during bend sprinting. The results revealed that during curved-track sprinting, mechanical loading was greater around the first toe in the right foot than in the left foot, and around the first cuneiform, a part of the midfoot, in the left foot than in the right foot. For performance enhancement, using spike shoes with pins positioned in areas of high load distribution may have a positive effect. Additionally, for injury prevention, preventive measures such as using insoles to support the first cuneiform area of the left foot, which experiences high mechanical loading, may help reduce the risk of foot injuries.

AUTHOR CONTRIBUTIONS

Conceptualization: H.O., A.K., and T.Y.; methodology: H.O.; software: H.O.; validation: H.O., Y.C. and T.Y.; formal analysis: H.O.; investigation: H.O. and T.Y.; resources: H.O. and Y.C.; data curation: H.O., Y.C. and T.Y.; writing—original draft preparation: H.O.; writing—review & editing: H.O., A.K., Y.C. and T.Y.; visualization: H.O.; supervision: H.O. and T.Y.; project administration: H.O. and Y.C.; funding acquisition: H.O. All authors have read and agreed to the published version of the manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors.

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