Effects of foot orthosis on ground reaction forces and perception during short sprints in flat-footed athletes

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Abstract

Prefabricated foot orthosis (FO) is commonly worn for flat foot management. This study aimed to investigate the kinetic and perceptual effects of wearing prefabricated FO among flat-footed athletes during bouts of sprints. Twenty male sprint-based sports athletes who had flat foot bilaterally ran at three test speeds (5, 6, 7 m/s) under two conditions: prefabricated FO and sham FO. Ground reaction force (GRF) variables and subjective perceptions were recorded. Kinetic variability of GRF variables were computed to indicate step-to-step variance. Biomechanically, wearing prefabricated FOs increased vertical impact force (p = .005), loading rate (p = .001), and kinetic variability of peak propulsive force (p = .038) and loading rate (p = .019) during sprinting speeds across 5 to 7 m/s. Subjectively, prefabricated FO provided better arch support (p = .001) but resulted in reduced forefoot cushioning (p = .001), heel cushioning (p = .002), and overall comfort (p = .008).

Keywords

Prefabricated; Gait; Kinetic; Variability; Loading rate; Comfort

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Introduction

Flat foot is identified as a foot with a lowered longitudinal medial arch. The reduction of a medial arch is linked to overpronation of the rearfoot during locomotive foot strikes at early stance phase (Aenumulapalli, Kulkarni, & Gandotra, 2017; Cunningham, 2008). Foot orthosis (FO), among other flat-foot management modalities such as taping (Siu, Shih, & Lin, in press), is commonly administered to provide arch support and to reduce rearfoot overpronation (Aboutorabi, Saeedi, Kamali, Farahmand, Eshraghi, & Dolagh, 2014; Cunningham, 2008). A recent review summarised that FO was effective in preventing overall musculoskeletal injuries and stress fractures across a wide range of activities from military exercises to sports competitions (Bonanno, Landorf, Munteanu, Murley, & Menz, 2017). There are essentially two types of FO used to treat flat foot: prefabricated FOs are ready made non-moulded orthosis, and custom-made FOs are moulded to an individual's foot shape. Both prefabricated and custom-made FOs have been shown as effective in supporting the flat foot (Payehdar, Saeedi, Ahmadi, Kamali, Mohammadi, & Abdollah, 2016). Since prefabricated FOs are generally affordable and readily accessible, it is often the preferred option.

Biomechanically, overpronation at the early stance phase of running delayed peak vertical ground reaction force (GRF) (Williams, McClay, Hamill, 2001). The use of a medially posted FO was found to reduce overpronation but increased vertical impact peak and maximum loading rate (Mündermann et al., 2003). This may seem as if the use of FO has a negative influence on athletes as higher GRF magnitudes were identified as key biomechanical indicators in running-related injury risk among recreational athletes (Napier, MacLean, Maurer Taunton, & Hunt, 2018). It should be noted, however, that all previous studies on the effects of FO on running biomechanics used slow to moderate running speeds below 4 m/s (Mills K, Blanch, Chapman, McPoil, & Vicenzino, 2010; Murley, Landorf, Menz, & Bird, 2009). Athletes participating in sprint-based sports are often required to perform short bouts of sprints at faster speeds. For example, an average basketball player performs a sprint in every 39 seconds, a total of 55 sprint bouts per game (Ben Abdelkrim, El Fazaa, El Ati, & Tabka, 2007) at speeds approximately from 4.77 m/s to 6.5 m/s (Scanlan, Tucker, & Dalbo, 2014). Findings on the effectiveness of FO use from studies using slower speeds may not be applicable to sprint-based athletes, as running at faster speeds led to higher magnitudes in GRF (Keller, Weisberger, Ray, Hasan, Shiavi, & Spengle, 1996). Currently, there are no studies examining the effects of prefabricated FO use on GRF magnitudes during running beyond the speed of 4 m/s.

When examining the magnitudes of GRF, it is also useful to consider the step-to-step variance of the force variables. One study found that the use of custom-made FO increased kinematic variability in tibia and calcaneus coordination at early stance phase during jogging at 3 m/s amongst injured runners (MacLean, van Emmerik, & Hamill, 2010). When gait variability is low, the same soft tissues in the lower limb may be continuously stressed by repeated movements. As localised stress is a risk factor to overuse injuries, having higher gait variability could thereby distribute the stress more evenly to reduce the incidence of overuse injuries (Hamill, Palmer, & van Emmerik, 2012). Thus, it is worth exploring the effect of prefabriced FO use on kinetic variability during running at fast speeds.

Practically, it is unlikely that athletes would perform optimally in uncomfortable sport attire or gears. In previous studies, participants have reported increased comfort perception when walking and running with prefabricated and custom-made FOs (Lucas-Cuevas, Pérez-Soriano, Priego-Quesada, & Llana-Belloch, 2014; Hatfield et al., 2016). Specifically to running, FO comfort perception was linked to the degree of arch support (Lucas-Cuevas et al., 2014). To allow a more comprehensive understanding on how FOs affect sprint-based athletes, it is therefore important to include comfort perception measurements alongside with biomechanial variables.

This present study aimed to investigate the effects of prefabricated FO use on kinetic and perceptual variables in flat-footed athletes during short bouts of sprints at 5, 6, and 7 m/s. It was hypothesised that prefabricated FO use would increase GRF magnitudes and kinetic variability while improving subjective perception ratings among flat-footed athletes.

Methods

Design

This study adopted a randomised crossover design. Within-participant comparisons were made for two conditions: prefabricated FO (experimental) versus sham FO (control). The sprinting speeds were set beyond 4 m/s, specifically at 5, 6, and 7 m/s. This study was approved by XXX (blind for review) Institutional Review Board (IRB-XXX blind for review).

Participants

An a-priori power analysis showed that at least 15 participants (α = .05, effect size = .80 large, power = .80) were required. To account for potential dropouts and unexpected technical errors, 20 flat-footed male athletes (26.1 ± 3.1 years, 1.7 ± .05 m, 73.1 ± 9 kg) were recruited from local universities, military camps, and fitness gyms. All participants provided written informed consent prior to data collection. To be included in the study, participants had to be 18-35 years old, male, have bilateral flat foot that fit shoe sizes UK 9 – 11, and have actively participated in sprint-based sports (> 2 times per week for the past 3 months). Participates were excluded if they had any pain, health conditions which required long-term prescribed medication, or serious injuries to the back or lower limb within the past 6 months. To confirm flat foot type, participants must meet at least two out of three test criterions for both feet (Ho, Kong, Chong, & Lam, 2019). The three tests are Arch Index (≥ 0.26), navicular drop test (≥ 10 mm), and resting calcaneal stance position angle (≥ 4° valgus) (Razeghi & Batt, 2002). For the Arch Index assessment, dynamic plantar pressure was captured by using the emed® platform (Novel GmbH, Germany) using a 2-step approach (Tong & Kong, 2013). Both the navicular drop test and resting calcaneal stance position angle were conducted manually (Lee, Kim, Kim, & Hong, 2017; Mueller, Host, & Norton, 1993).

Foot orthosis properties

Prefabricated FOs (Firm Orthotic Insole, Salford Insole, UK) and sham FOs without arch support (Li-Ning Company Limited, China) were used in this study (Figure 1). This brand of prefabricated FO was chosen as it has been found to reduce pronation of the foot effectively (Liu et al., 2012). The sham FO was the flat insole that came with the running shoes (Li-Ning, Beijing, China) provided to the participants. Three sizes (UK 9, 10, 11) of shoes and FOs were available to fit the foot size of the participants. The prefabricated FO provided medial arch support and were more rigid than the sham FO. The hardness of the prefabricated and sham FOs was measured by a type C shore durometer, 1600 Asker SP-698 (Rex Durometers, Rex Gauge Co., Buffalo Grove IL, USA). Five measurements were taken at each of the five dots from each of the foot regions and averaged to indicate the regional hardness of the FOs (Figure 1b). To reduce information bias, the brand logo of both prefabricated and sham FOs was covered by tape. Participants were told that

FO inserts were used in both prefabricated and sham conditions. No other information was disclosed.

*** Figure 1 goes here ***

Protocol

Participants were required to attend two sessions consisting of familiarisation and main test trials. The familiarisation session was to allow the participants to familiarize running on the instrumented treadmill (Bertec Corp., Columbus, OH) for actual testing. Participants jogged for 2 minutes at a speed of 2.5 m/s. After which, the speed was progressively increased to 5 m/s, 6 m/s, and 7 m/s. Each trial speed was sustained for 5 seconds to allow steady GRF data to be collected during the last 3 seconds. The speed was increased at a rate of 0.4 m/s^2, mirroring the acceleration of the actual test. A 3-min rest interval was included between trials.

The second session took place after at least 24 hours from the end of the familiarisation session to minimise the effect of exercise fatigue. Biomechanical test procedures were conducted in the same manner as the first session while perceptual tests were administered after. The participants were provided with a pair of standardised, new socks and a pair of experimental shoes matched to their foot sizes. After a warm-up period, participants were then required to run on the instrumented treadmill under two conditions: 1) prefabricated FO (experimental) and 2) sham FO (control). The orders of FO conditions and running speeds were randomised among the participants. A 3-min rest interval was included between trials.

Participants ran at each speed for 5 seconds for FO condition. Three-dimensional GRF data of the final 3 seconds of each trial were recorded at 1000 Hz. Immediately after completing all 3 test speeds in each FO condition, perceptual measurements of forefoot cushioning, heel cushioning, arch support, and overall comfort were rated on a 15-cm visual analogue scale (VAS). For each perception variable, a single vertical line was indicated on the scale by the participant.

Data processing

A fourth order digital Butterworth low-pass filter was used to filter GRF data at 110 Hz determined by residual analysis. A customised MATLAB programme (The MathWorks Inc., Natick, MA) was used to identify each contact phase from touchdown to toe-off based on a threshold of 40 N in the vertical GRF (Girard, Brocherie, Morin, & Millet, 2017). Key vertical and antero-posterior GRF variables were extracted, including stance time, peak braking force, peak propulsive force, time to peak braking force, time to peak propulsive force, peak vertical impact force, peak vertical active forces, and vertical mean loading rate (measured from 20% to 80% of time to peak vertical impact force). Kinetic variability was calculated to indicate step-to-step variance using the standard deviation (SD) of 8 running steps for the GRF variables. Raw VAS data were evaluated with a 15-cm ruler and digitally recorded to the nearest 1 mm.

Statistical analysis

All statistical analyses of the data were performed using IBM SPSS Statistics for Windows, Version 24 (IBM Corp., Armonk, NY, USA). For each GRF and kinetic variability variable, a two-way (speed × orthosis) Analysis of Variance with repeated measures was performed with Bonferroni adjusted *post-hoc* comparisons. For the VAS data, paired sample *t*-tests were performed on perceptual variables. The respective effect size for partial Eta-squared (η^2_p) and Cohen's d (d) were calculated and interpreted as small ($0.01 < \eta^2_p < 0.06$; $0.2 < d < 0.5$), medium ($0.06 \leq \eta^2_p < 0.14$; $0.5 \leq d < 0.8$) or large ($\eta^2_p \geq 0.14$; $d \geq 0.8$). The level of significance was set at

$p < .05$. Mean differences and 95% confidence interval were also calculated between the FO conditions.

Results

Across all running speeds, rearfoot strikes were predominantly adopted as indicated by double-peaked vertical GRF curves (Figure 2). On occasions where non-rearfoot strikes were seen (single peaked vertical GRF curve), peak vertical impact force and vertical loading rate could not be determined and the data were excluded in the analyses of these two vertical GRF variables (n = 17 at 5 m/s, n = 18 at 6 m/s, n = 17 at 7 m/s).

*** Figure 2 goes here ***

There was a statistically significant main effect of speed for most GRF variables (Table 1) and some kinetic variability variables (Table 2) but no significant interaction between speed and orthosis conditions. For VAS variables, wearing prefabricated FO significantly increased arch support perception but decreased ratings in all other perceptual variables (Table 3).

***Tables 1, 2, and 3 go here ***

Discussion

This study examined the effects of prefabricated FO use on biomechanical and perceptual variables in flat-footed athletes during short sprints. When running at 5 m/s to 7 m/s, wearing prefabricated FO led to increased vertical impact force and vertical loading rate, and higher step-to-step kinetic variability in peak propulsive force and vertical loading rate. Subjectively, participants perceived better arch support but poorer cushioning and overall comfort when wearing prefabricated FO.

Ground reaction force variables

The findings of higher vertical impact force and vertical loading rate in prefabricated FO compared with the sham condition support the first hypothesis that wearing prefabricated FOs would increase GRF magnitudes. These results are in line with an earlier study by Mündermann et al. (2003) which examined FO use at a slower running speed of 4 m/s. The authors reported increased vertical impact peak and maximum loading rate when the orthosis was posted at the medial region. It would seem that the prefabricated FO caused vertical loading rate to increase by reducing overpronation in the low-arch foot (Aboutorabi et al., 2014; Liu et al., 2012; Williams, Davis, Scholz, Hamill, & Buchanan, 2004).

In the present study, the magnitude of GRF variables were higher with increased running speeds and this observation is consistent with the literature (Murley et al., 2009). It is known that different rigidness and cushioning materials used in fabricating FO can influence kinetic outcomes (Majumdar et al., 2013). One study showed that shoe-ground interface as manipulated by shoe midsole hardness could influence peak vertical impact forces during running (Baltich, Maurer, Nigg, 2015). Based on the mechanical properties, the prefabricated FO is harder, heavier, and had greater arch height than the sham FO (Figure 1). The changes in GRF magnitudes may be caused by the different material hardness and/or geometry of the insoles. In the general population, FOs use have been found to reduce running injury risks by controlling excessive foot motion towards the gait pattern of a normal arched foot (Bonanno et al., 2017; Payehdar et al., 2016). While the longitudinal impact of prefabricated FO use on injury risks for athletes is uncertain, findings from the present study confirm that wearing prefabricated FO cannot attenuate impact forces during sprinting activities among flat-footed athletes.

Kinetic variability

Across the three tested speeds, the kinetic variability of peak propulsive force and vertical loading rate increased under the prefabricated FO condition (Table 2). This finding supports the second hypothesis that prefabricated FO could lead to higher kinetic variability. In the literature, kinematic variability of the lower limbs during running had been linked to injury occurrences (Hamill et al., 2012; Donoghue, Harrison, Coffey, & Hayes, 2008). The underlying mechanism is that lower variability may be indicative of localised mechanical stress on a body and higher variability may help distribute the load and hence reduce overuse injury (Hamill et al., 2012). In the present study, the use of prefabricated FO increased kinetic variability during sprints, specifically upon initial impact and during propulsion. The higher kinetic variability with FO use may reflect higher variability in lower limb joint coordination (MacLean, van Emmerik, & Hamill, 2010). It is acknowledged that the relationship between kinetic and kinematic variabilities needs to be further established and hence caution should be taken when interpreting kinetic variability in relation to injury risk.

In this study, all the participants wore the experiment and sham FOs only for one session before data were collected. Since the introduction of an arch support into the footwear caused some degrees of discomfort (Table 3), it is postulated that the participants explored different running strategies and ran at greater degrees of freedom to minimize discomfort (MacLean et al., 2010). The adaptation strategies may have influenced the joint co-ordination and hence kinetic variability. Future studies may consider including a longer ‘break-in’ and adaptation time for the participants to get used to the new FO and shoes before trials commenced. This will ascertain if the elevated gait variability would be sustained over time, or if they would subside due to gradual adaptation.

Perception

The third hypothesis that prefabricated FO would improve subjective perception ratings was not supported, as the participants only reported better arch support but poorer ratings in all other perceptual variables when wearing the prefabricated FO. The poorer perceptions in cushioning and overall comfort are in line with a previous study reporting decreased comfort associated with adding medial posting to custom-made FO in runners (Mündermann et al., 2003). In contrast, another study found increased comfort perception for other types of FOs (Lucas-Cuevas et al., 2014). The mixed findings may be influenced by the different GRF magnitudes associated with running speeds. When sprinting at 5 to 7 m/s, participants in the current study perceived better arch support but poorer cushioning and overall comfort. The harder material of prefabricated FO (Figure 1) may have lowered the wearer's perceived cushioning in the heel and forefoot regions. The large variation in thickness across the length of prefabricated FO (arch 29 mm and heel 3.0 mm) may have lowered comfort perception. It has been reported that FOs with lower wedge angle (medial arch region) relative to heel height (rearfoot region) can increase wearing comfort (Witana, Goonetilleke, Au, Xiong, & Lu, 2009). Future research could examine different material hardness and thickness variances of FOs to establish a relationship between the functional demands and perceptual ratings for sports activities. It should be noted that the current study did not detail the participants' prior experience in using FOs. Based on personal communication, most participants did not wear prefabricated or customised FOs regularly. For some participants, it was even their first time wearing any FOs despite being bilaterally flat-footed. Given that user experience is important for perception test, the next step forward should be to consider prior FO use histories and to conduct longitudinal studies.

Limitations

There are a few limitations to the present study. Firstly, only one brand of prefabricated FO was tested. Since different mechanical properties of FOs can have various effects on forces and perception (Mündermann et al., 2003), results from the present study may not be applicable to other types of FOs. Secondly, the current study considered the prefabricated FO as a 'factory made' final product which differed from the sham FO in multiple aspects. While this approach of adopting a ready-made product provides relevant and practically meaningful information to the end-users, it is acknowledged that this study design cannot identify whether the alterations in GRFs between prefabricated and sham FOs are caused by the different material hardness, mass, arch height, or thickness in forefoot/rearfoot areas. Thirdly, all sprint-based athletes were not differentiated among their sports (e.g. 100-m sprint, soccer) and have varied playing level/experience. Recent evidence suggested that foot posture can be influenced by the type of sports training (Lopezosa-Reca, Gijon-Nogueron, Garcia-Paya, & Ortega-Avila, 2018). It would be of interest to investigate if the response to FO use differs among athletes participating in various sports. Finally, only GRF magnitudes and variabilities were examined in the present study. Future studies can consider a more comprehensive evaluation including measurements of kinematics and muscular activity.

Conclusions

Among flat-footed male athletes, prefabricated FO was found to increase the vertical loading and step-to-step kinetic variability at sprint speeds of 5 to 7 m/s when compared with a sham insole. These changes in biomechanics may be caused by the different material hardness and/or geometry such as thickness and arch height of the insoles. Clinicians, coaches, and athletes should be aware that wearing prefabricated FO with similar physical properties as the FO used in the present study may not help with force attenuation during sprinting activities, particularly upon initial impact. Subjectively, athletes wearing prefabricated FO reported improved arch support but poorer perceived cushioning and overall comfort when performing short sprints at moderate to fast speeds.

Conflicts of interest statement:

The authors declare that they have no competing interests.

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List of Figures

Figure 1. (a) Experimental running shoes, prefabricated and sham foot orthoses. (b) An example of locations of hardness measurement for UK size 9-foot orthosis. (c) Hardness and dimensions of the prefabricated and sham foot orthosis (FO) conditions.

Figure 2. Vertical and anteroposterior ground reaction force (GRF)-time profiles of rearfoot strikers running at 5 m/s (n = 17), 6 m/s (n = 18), and 7 m/s (n = 17) in prefabricated and sham foot orthosis (FO) conditions. Error bars in the figures are the standard deviations of the GRF-time profiles.

List of Tables

Table 1 Magnitudes of ground reaction force variables under foot orthosis (FO) conditions during short sprints.

Table 2 Variability (SD) of ground reaction force variables under foot orthosis (FO) conditions during short sprints.

Table 3 Subjective comfort perception in prefabricated and sham foot orthosis (FO) conditions.

Table 1 Magnitudes of ground reaction force variables under foot orthosis (FO) conditions during short sprints.

Variables	Speed	Prefabricated FO	Sham FO	Diff [95% CI]	ANOVA Orthosis P	ANOVA Orthosis η^2_p	ANOVA Speed P	ANOVA Speed η^2_p	ANOVA Interaction P	ANOVA Interaction η^2_p	*Post-hoc*
Stance time [ms]	5 m/s	181 (21)	183 (25)	-1.53 [-5.99, 2.93]	.958	<.001	**<.001***	.872	.522	.030	5 > 7
	6 m/s	161 (22)	161 (17)	.94 [-5.67, 7.54]							6 > 7
	7 m/s	137 (14)	136 (15)	.29 [-2.91, 3.49]							5 > 6
Peak braking force [BW x 10^{-2}]	5 m/s	-62.70 (21.65)	-63.52 (17.23)	.82 [-3.77, 5.41]	.795	.004	**<.001***	.652	.911	.004	5 > 7
	6 m/s	-71.88 (16.35)	-72.69 (18.39)	.82 [-3.38, 5.01]							6 > 7
	7 m/s	-84.16 (23.02)	-84.02 (24.53)	-.14 [-6.20, 5.93]							5 > 6
Time to peak braking force [ms]	5 m/s	46 (15)	46 (17)	.01 [-4.04, 4.05]	.758	.005	**<.001***	.712	.612	.021	5 > 7
	6 m/s	40 (16)	38 (15)	2.12 [-4.88, 9.12]							6 > 7
	7 m/s	30 (15)	30 (15)	-.41 [-4.79, 3.96]							5 > 6
Peak propulsive force [BW x 10^{-2}]	5 m/s	51.69 (7.70)	51.60 (6.79)	.08 [-1.68, 1.85]	.692	.008	**<.001***	.676	.729	.017	5 < 7
	6 m/s	56.37 (7.83)	56.43 (8.42)	-.06 [-1.28, 1.16]							6 < 7
	7 m/s	63.84 (10.88)	64.75 (10.16)	-.92 [-4.17, 2.34]							5 < 6
Time to peak propulsive force [ms]	5 m/s	142 (23)	140 (22)	1.69 [-4.76, 8.15]	.621	.013	**<.001***	.826	.198	.084	5 > 7
	6 m/s	123 (22)	125 (18)	-1.33 [-7.54, 4.88]							6 > 7
	7 m/s	100 (18)	104 (15)	- 3.88 [-9.37, 1.62]							5 > 6
Peak vertical impact force [BW]	5 m/s	2.56 (.46)	2.48 (.44)	.08 [-.04, .19]	**.005***	.437	**<.001***	.765	.121	.140	5 < 7
	6 m/s	2.99 (.40)	2.83 (.35)	.16 [-.01, .31]							6 < 7
	7 m/s	3.26 (.38)	3.02 (.26)	.24 [.09, .40]							5 < 6
Peak vertical active force [BW]	5 m/s	2.78 (.33)	2.81 (.28)	-.03 [-.12, .05]	.611	.014	.503	.029	.292	.063	
	6 m/s	2.80 (.48)	2.85 (.37)	-.04 [-.15, .06]							
	7 m/s	2.85 (.47)	2.82 (.47)	.03 [-.05, .11]							
Loading rate [BW/s]	5 m/s	95.75 (30.47)	78.22 (22.37)	17.53 [5.28, 29.78]	**<.001***	.750	**<.001***	.533	.721	.023	5 < 7
	6 m/s	127.42 (55.82)	97.41 (37.08)	30.00 [13.23, 46.78]							6 < 7
	7 m/s	167.04 (77.79)	132.50 (48.89)	34.54 [10.32, 58.75]							5 < 6

Notes: Diff = mean difference (prefabricated - sham); CI = confidence intervals; η^2_p = partial eta squared. Significant *P*-values ($p < .05$) are shown with *. Effect size was interpreted as small ($0.01 < \eta^2_p < 0.06$), medium ($0.06 \leq \eta^2_p < 0.14$) or large ($\eta^2_p \geq 0.14$).

Table 2 Variability (SD) of ground reaction force variables under foot orthosis (FO) conditions during short sprints.

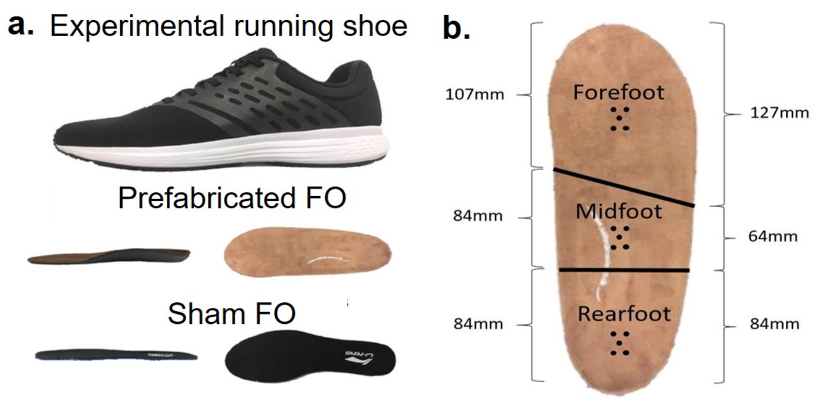
Variables	Speed	Prefabricated FO	Sham FO	Diff [95% CI]	ANOVA: Orthosis P	ANOVA: Orthosis η^2_p	ANOVA: Speed P	ANOVA: Speed η^2_p	ANOVA: Interaction P	ANOVA: Interaction η^2_p	*Post-hoc*
Stance time SD [ms]	5 m/s	6 (2)	5 (2)	.35 [-.92, 1.62]	.255	.068	.147	.107	.405	.038	
	6 m/s	13 (27)	7 (3)	6.00 [-6.82, 18.82]							
	7 m/s	7 (3)	6 (3)	1.11 [-.71, 2.93]							
Peak braking force SD [BW x 10^{-2}]	5 m/s	8.97 (3.57)	9.59 (5.00)	-.62 [-2.43, 1.19]	.905	<.001	**<.001***	.500	.765	.014	5 < 7
	6 m/s	12.13 (4.58)	11.55 (3.47)	.58 [-2.27, 3.44]							6 < 7
	7 m/s	14.16 (4.84)	14.38 (5.12)	-.22 [-2.86, 2.43]							5 < 6
Time to peak braking force SD [ms]	5m/s	12 (4)	12 (5)	.34 [-1.40, 2.08]	.244	.071	.192	.086	.225	.077	
	6 m/s	19 (26)	10 (5)	8.05 [-5.13, 21.24]							
	7 m/s	10 (7)	10 (6)	.17 [-2.98, 3.32]							
Peak propulsive force SD [BW x 10^{-2}]	5 m/s	6.84 (3.66)	6.09 (2.84)	.75 [-.95, 2.45]	**.038***	**.**208	**<.001***	.340	.721	.017	5 < 7
	6 m/s	8.44 (3.29)	7.40 (3.03)	1.03 [-.17, 2.23]							
	7 m/s	10.39 (2.99)	8.88 (3.54)	1.52 [-.16, 3.19]							
Time to peak propulsive force SD [ms]	5 m/s	8 (4)	12 (12)	-3.89 [-9.82, 2.03]	.345	.047	.127	.103	.208	.082	
	6 m/s	19 (28)	11 (11)	7.78 [-5.30, 20.85]							
	7 m/s	15 (12)	13 (11)	1.67 [-2.60, 5.94]							
Peak vertical impact force SD [BW]	5 m/s	22 (.08)	.20 (.10)	.01 [-.06, .08]	.053	.241	**<.001***	.544	.494	.049	5 < 7
	6 m/s	.27 (.14)	.23 (.09)	.05 [-.03, .12]							6 < 7
	7 m/s	.37 (.17)	.31 (.11)	.06 [-.02, .14]							
Peak vertical active force SD [BW]	5 m/s	.13 (.08)	.12 (.05)	.01 [-.04, .06]	.114	.126	**<.001***	.407	.647	.023	5 < 7
	6 m/s	.15 (.07)	.12 (.04)	.04 [.00, .07]							6 < 7
	7 m/s	.19 (.09)	.16 (.07)	.03 [-.02, .07]							
Loading rate SD [BW/s]	5 m/s	19.65 (13.07)	14.41 (9.44)	5.25 [-1.78, 12.28]	**.019***	.334	**<.001***	.733	.789	.010	5 < 7
	6 m/s	34.42 (20.16)	24.80 (16.43)	9.62 [.53, 18.70]							6 < 7
	7 m/s	60.27 (25.89)	50.74 (22.99)	9.53 [-2.43, 21.50]							5 < 6

Notes: Diff = mean difference (prefabricated - sham); CI = confidence intervals; η^2_p = partial eta squared. Significant *P*-values ($p < .05$) are shown with *. Effect size was interpreted as small ($0.01 < \eta^2_p < 0.06$), medium ($0.06 \leq \eta^2_p < 0.14$) or large ($\eta^2_p \geq 0.14$).

Table 3 Subjective comfort perception in prefabricated and sham foot orthosis (FO) conditions.

Variables	Prefabricated FO	Sham FO	Diff [95% CI]	*P*-value	Cohen's *d*
Forefoot cushioning [cm]	6.17 (2.88)	11.56 (2.00)	-5.39 [-6.96, -3.82]	**.001***	1.61
Heel cushioning [cm]	7.61 (2.96)	10.37 (3.08)	-2.75 [-4.35, -1.16]	**.002***	0.81
Arch support [cm]	11.04 (2.14)	6.26 (3.84)	4.78 [2.92, 6.64]	**.001***	1.20
Overall comfort [cm]	9.17 (2.77)	10.97 (2.52)	-1.80 [-3.05, -.54]	**.007***	0.67

Diff = mean difference (prefabricated - sham), CI = confidence intervals. *Significance ($p < .05$) determined from paired sample *t*-tests. Effect size was interpreted as small ($0.2 < d < 0.5$), medium ($0.5 \leq d < 0.8$) or large ($d \geq 0.8$).



c. Hardness and dimensions of prefabricated and sham FOs

	Prefabricated FO	Sham FO
Mass [g]	45.0	23.5
Arch height [mm]	29	5
Forefoot thickness [mm]	3.4	5
Rearfoot thickness [mm]	3.0	5.2
Hardness [Shore C durometer points]		
Forefoot	70.0	50.1
Midfoot	65.2	50.1
Rearfoot	66.5	50.1

Figure 1

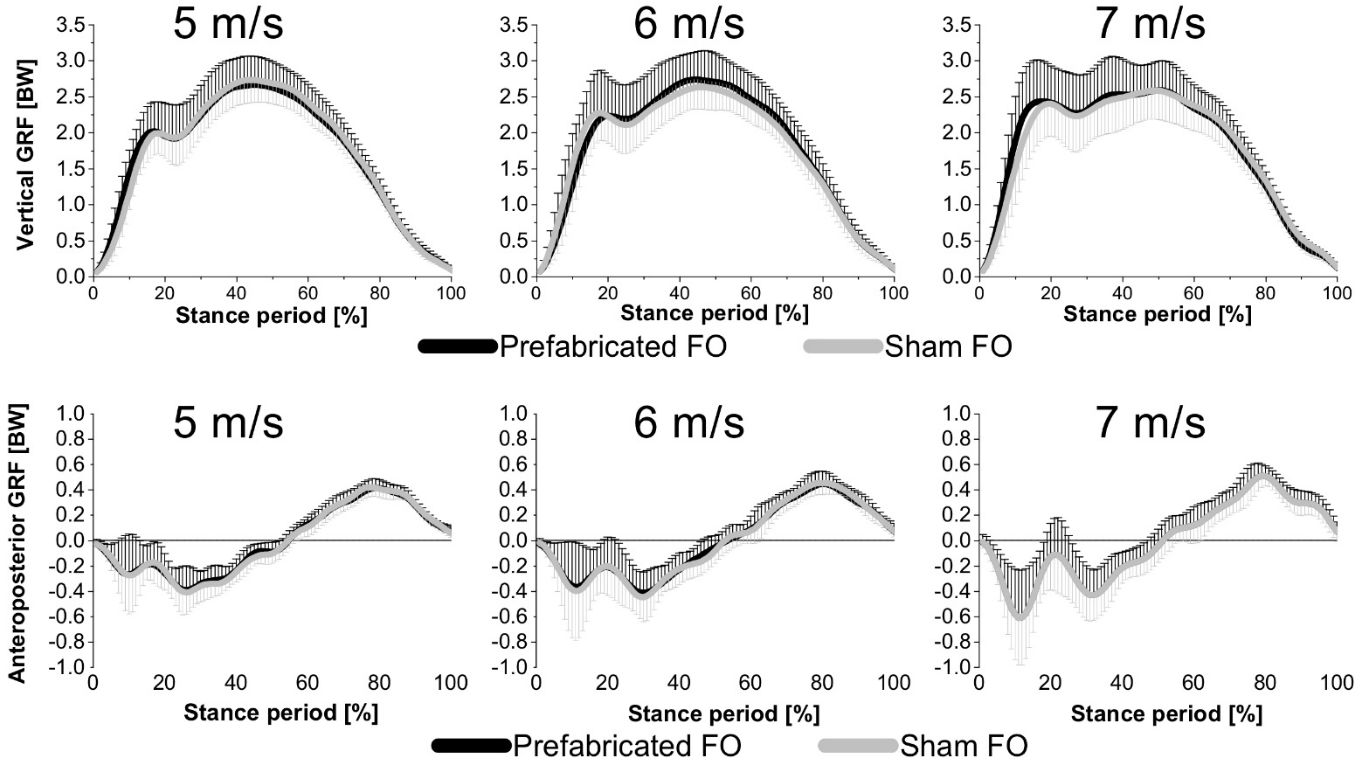

5 m/s
6 m/s
7 m/s
Vertical GRF [BW]
Stance period [%]
Prefabricated FO
Sham FO
Anteroposterior GRF [BW]

Figure 2