On the design of rocker profile shoes
van Kouwenhove, Laurens

DOI:
10.33612/diss.198089349

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Document Version
Publisher's PDF, also known as Version of record

Publication date:
2022

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):

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Effects of rocker radii with two longitudinal bending stiffneses on plantar pressure distribution in the forefoot

I.Y. ten Wolde, L van Kouwenhove, R. Dekker, J.M. Hijmans & C. Greve

Outsole parameters of the shoe can be adapted to offload regions of pain or region of high pressures. Previous studies already showed reduced plantar pressures in the forefoot due to a proximally placed apex position and higher longitudinal bending stiffness (LBS). The aim of this study was to determine the effect of changes in rocker radii and high LBS on the plantar pressure profile during gait. 10 participants walked in seven shoe conditions of which one control shoe and six rocker shoes with small, medium and large rocker radii and low and high longitudinal bending stiffness. Pedar in-shoe plantar pressure measuring system was used to quantify plantar pressures while walking on a treadmill at self-selected walking speed. Peak plantar pressure, maximum mean pressure and force-time integral were analyzed with Generalized Estimated Equation (GEE) and Tukey post hoc correction ($\alpha = .05$). Significantly lower plantar pressures were found in the first toe, toes 2-5, distal and proximal forefoot in all rocker shoe conditions as compared to the control shoe. Plantar pressures in the first toe and toes 2-5 were significantly lower in the small radius compared to medium and large radii. For the distal forefoot both small and medium radii significantly reduced plantar pressure compared to large radii. Low LBS reduced plantar pressure at the first toe significantly compared to high LBS independent of the rocker radius. Plantar pressures in the distal forefoot and toes 2-5 were lower in high LBS compared to low LBS. Manipulation of the rocker radius and LBS can effectively reduce peak plantar pressures in the forefoot region during gait. In line with previous studies, we showed that depending on the exact target location for offloading, different combinations of rocker radius and LBS need to be adopted to maximize treatment effects.

Keywords: rocker shoes, forefoot plantar pressure, rocker radius, roll over shape
Chapter 4. Effects of rocker radii with two longitudinal bending stiffnesses on plantar pressure

Introduction
Adaptations to the outsole of the shoe are frequently performed to treat patients with foot pathologies such as people with loss of protective sensation due to diabetes, limited mobility of the metatarsophalangeal (MTP) joints or hallux valgus deformity [1,2]. Depending on the type of pathology, treatment goal (e.g., reduce plantar pressure) and the location of the injury, different outsole parameters can be adjusted [3,4]. For example, patients with metatarsalgia, at-risk regions for foot ulcers or sesamoid disorders can benefit from rocker shoes with a proximally placed apex position (figure 1)[2–4]. Placing the apex position proximal to the MTP reduces peak ankle plantarflexion moments and peak plantar pressures under the forefoot by facilitating early roll-over during the stance phase of gait [5,6]. Hence, placing the apex position proximal to the MTP region can prevent ulcers in at-risk regions and reduce pain in patients with forefoot pathologies [2,5,7–9].

Previously, the shape of the rocker distal from the apex position is described as the angle between the distal part of the shoe and the ground (rocker angle; figure 1)[3,5,8]. The rocker angle can be used to redistribute plantar pressures from the forefoot to more proximal foot regions. A steeper or larger rocker angle increases the time before the distal part of the sole touches the ground. Hence, larger rocker angles (15-20°) can redistribute peak plantar pressures and unload the MTP region during walking [5,10].

Nowadays, the shape of the forefoot rocker is described as a radius (rocker radius; figure 1)[11]. A smaller rocker radius induces a faster roll-over of the foot once the centre of pressure passed the apex position during walking and a faster roll-over motion reduces the time during which the forefoot region is exposed to high plantar pressures [5]. However, the effects of different rocker radii on pressure redistribution in the forefoot remains to be established.

The effect of changes in outsole parameters, such as apex position and rocker radius can be increased or decreased by adaptations of the outsole stiffness, also called longitudinal bending stiffness (LBS). Increasing the LBS prevents deformations of the outsole once the shoe is loaded with bodyweight and hence changes in the rocker radius. Outsoles with a low LBS may deform during the second rocker which minimize the effect in the rocker, while during the third rocker the radius decreases, both affecting plantar pressure distribution. For example, a recent study showed that when healthy adults walked in a rocker shoe with high LBS, as compared to low LBS with toe plantarflexion restriction, peak plantar pressures were redistributed from the first MTP joint to the first toe [7]. In this study the rocker radius was
kept constant [7]. Despite the knowledge on how individual outsole stiffness affects plantar pressure profiles it remains to be established how changes in LBS interact with varying rocker radii on plantar pressure profiles during gait. An often reported disadvantage of rocker shoes is the decreased stability [12] as the base of support is reduced with a proximal apex position. Therefore, targeted offloading by changes in rocker radius or LBS could play an important role to optimize the effectiveness of the rocker shoe without further decrease of the base of support.

The main aim of the current study was to establish how combined changes in the rocker radius and LBS affect the plantar pressure profile in especially the forefoot region when walking with rocker shoes. We systematically changed the forefoot rocker radius and LBS with custom-made rocker shoes and recorded the plantar pressure profile in healthy young adults during gait. Based on previous studies of Reints et al. [7] and Preece et al. [10] we hypothesized that peak plantar pressures in both the first toe and toes 2-5 will be reduced more in a shoe with a smaller radius and low LBS as compared to shoes with a larger rocker radius and high LBS. In contrast we expect peak plantar pressures beneath the MTP joints to be reduced more in a shoe with a smaller radius with high LBS compared to larger rocker radius and low LBS.

Methods

Study population
Healthy adults without any self-reported musculoskeletal complaints, older than 18 years and weighing less than 130 kg were eligible to participate in the study. Greve et al. [6] have shown that the effect of changes in LBS on gait biomechanics depends largely on the actual degree of outsole stiffness which can be achieved with the experimental manipulation. Because previous experiments showed that even carbon fibre insoles allow some degree of bending, we manufactured a custom-made shoe of PA12 (nylon). Since the fabricated shoe was only available in size 37 an additional inclusion criterium was shoe size 37. All participants signed informed consent before starting the experiment. The experimental protocol was approved by the Medical Ethical Committee (METc 2018.060). Participants were recruited in the period between October 2019 and February 2020.

Study and shoe design
After receiving information and signing informed consent, age, weight, and dominant leg of each participant were noted. The dominant leg was defined by asking the participant with which leg they would kick a ball [7]. Next, the location and range of motion of the ankle and MTP joint of each participant were measured in a standing position. The range of motion was measured using a hand-held goniometer [13]. Before start of the actual experiment, each participant walked on a treadmill for a maximum of two minutes for habituation and determination of self-selected walking speed. Two minutes of habituation has proven to be sufficient to stabilize gait on an instrumented treadmill [14]. The experimenter asked the participant every 30 seconds whether the walking speed was comfortable or should be increased or decreased with 0.05 km/h. The treadmill speed at the end of the habituation period was used during all experimental conditions. After habituation, the Pedar insole of the in-shoe plantar pressure measuring system (Novel; Munich, Germany) was fit into the shoe. Prior to each experimental condition zero-levelling was performed at the left and right shoe. Data was acquired at a sample frequency of 100 Hz. Between each condition at least one minute of rest was allowed to avoid fatigue.
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Each participant performed seven walking trials at the previously measured self-selected comfortable walking speed on a treadmill with the control shoe and three different rocker shoes with varying LBS (low (L) and high (H)) and radii (small: R16/62% shoe length, medium: R18.5/71% and large: R21/81%) (for example, L16). The rocker shoes were identical to the control shoe, except that the midsole was replaced by a 3D printed midsole covered with a thin rubber outsole with the three different rocker radii incorporated (figure 2) [11].

Figure 2: Experimental shoe (R21). Cable ties were used to increase LBS of the rocker sole (graphically visualized in blue). Cable ties were fitted in the holes and did not stick out the bottom nor affected sole geometry. Shoe soles had a thickness 35 mm and toe spring of 20 mm.

Longitudinal bending stiffness of the control, low LBS and high LBS were 6.7 Nm/rad, 24.1 Nm/rad and > 180 Nm/rad respectively. For high and low LBS, the same shoe was used per rocker radius. To adjust the high LBS cable ties were used, making toe motion impossible. In the low LBS the cable ties were cut which made toe dorsiflexion possible. Toe plantarflexion was restricted to maintain the rocker shape. Based on previous literature the apex position was set at 55% of shoe length (260 mm) with an apex angle of 90° [7,15]. The weight of the control shoe was 240 grams. The experimental shoe weights were 588 grams for R16, 556 grams for R18.5 and 558 grams for R21. For the high LBS shoes a thin layer of EVA (5 mm, 63 durometers, shore A) and thicker stiff sole (30 mm, Polyamide 12, 80 durometers, shore D) was used for the rocker profiles. Both the high and low LBS shoe had an inlay of 6 mm (25 durometers, shore A). Participants were blinded to the shoe design and the order of rocker radius conditions was randomized using customized MATLAB code (MATLAB, MathWorks R2019b). However, high LBS was always measured first followed by low LBS with the same rocker radius due to practical reasons (cutting cable ties). For every participant, the first twelve correctly measured steps of the dominant leg were selected per shoe condition and visually checked for eligibility immediately after the trial. Twelve steps per foot are recommended for valid and reliable in-shoe plantar pressure data measured with the Pedar system [16]. If there were less than twelve correctly measured steps, the measurement for that shoe condition was repeated. Foot progression angle was measured with an optic motion analysis system (Vicon, Bonita) to describe the population.

Data analysis

Because we expected to achieve the largest effect in plantar pressure redistribution in the proximal-distal direction of the forefoot we modified the traditional masks [7,8,10] and masks of Forghany et al. [17]. The Pedar insole was divided into six masks: the first toe (1), toes 2-5 (2), distal forefoot (3), proximal forefoot (4), midfoot (5) and heel (6) for measurement of the proximal-distal shift of peak pressure (PP), maximum mean pressure (MMP) and force-time integral (FTI) (figure 3) [7,15]. Customized MATLAB scripts were used to process the data of the dominant leg and to determine the highest measured pressure within each mask per step (PP) and timing of PP as percentage of stance phase (%SP). Also, MMP was determined
by calculating the mean pressure of one step within each mask after which the maximum mean pressure within the mask per step was selected. FTI was determined by multiplying all pressures within one mask for each step with the sensor area. The sum of forces from the sensor within one mask were then divided by the frequency within each mask [7]. The reported values of PP, MMP, and FTI are the mean values of twelve steps, in line with data processing of previous research [16].

**Statistical analysis**

For statistical analysis R studio (version 4.0.4) was used. All parameters were checked for normality and outliers. The mean and standard deviation were calculated to describe the study population and outcomes of the plantar pressure measurements. A generalized estimating equations (GEE) was conducted using an exchangeable working correlation matrix with the shoe condition and masks as within-subjects and PP, MMP and FTI as dependent variables [7,18,19]. Pairwise comparisons were conducted using Tukey’s correction. For both GEE as Tukey’s post-hoc test the level of significance was set at p<0.05.

**Results**

**Study population**

The research population consisted of ten healthy young women with a mean age of 20.8 years (± 2.5), height of 164.4 cm (± 3.3) and body weight of 67.5 kg (± 11.1). Manual assessments of joint range of motion revealed normal joint mobility at the ankle and first MTP joint (8.0° (± 2.6) ankle dorsiflexion and 56.0° (± 10.8) MTP dorsiflexion). The mean comfortable walking speed was 1.2 m/s (± 0.2). Mean foot progression angle ranged from 1.9° (±3.2) in the control shoe to 4.3 ° (±3.8) abduction in the L18.5 condition.

**Main effects of changes in outsole parameters on plantar pressure**

The GEE showed a significant main effect for PP (p<.001), MMP (p<.001) and FTI (p<.001) between all shoe conditions including the control shoe (figure 4; table 1). PP, MMP and FTI decreased significantly (p<.05) in all experimental shoe conditions compared to the control shoe in the first toe, toes 2-5 and proximal to MTP, except PP in H21 for the first toe and FTI in the first toe and toes 2-5. In the midfoot, PP was significantly higher (p<.05) in the experimental conditions compared to the control condition. PP, MMP and FTI were significantly higher (p<.05) in the heel region when walking with rocker shoes as compared to the control shoe (figure 4). Absolute values, level of significance and pairwise comparisons

**Figure 3:** Masks of Pedar and Forghany combined and reorganized into six masks. 1: first toe, 2: toes 2-5, 3: distal forefoot, 4: proximal forefoot, 5: midfoot, 6: heel.
are presented in table 1. For pairwise comparisons per mask (figure 5 & 6) only significant results are presented. Also timing of PP was assessed. PP pressure in the control shoe occurred at the first toe at 85.3 %SP (±3.2); at toes 2-5 at 84.8 %SP (±4.1), at distal forefoot at 78.3%SP (±4.0), proximal forefoot 52.5%SP (±13.5), at midfoot at 35.9 %SP (±7.0), and at the heel at 16.5%SP (±2.6).

**Figure 4:** Main effects (experimental conditions compared to control shoe). Green is decreased plantar pressure and orange is increased. Left: peak pressure, middle: maximum mean pressure, right: force-time integral.

**Effect of outsole manipulations on plantar pressures per mask**

**First toe and toes 2-5**

PP and MMP significantly (p<.05) differed between all shoe conditions in the first toe and toes 2-5, in which PP and MMP were lowest in R16 as compared to the control and other experimental conditions. Higher LBS increased PP and MMP in the first toe and decreased PP in toes 2-5 significantly. No significant difference in MMP of toes 2-5 was found when comparing the effect of high and low LBS between R16 and R18.5, while MMP was lower in L21 compared to H21.

**Distal and proximal forefoot**

PP at the distal forefoot in R16 and R18.5 were significantly lower as compared to R21 and the control shoe (p<.05). PP was significantly lower at the distal forefoot when walking with high as compared to low LBS (p<.05). MMP in the distal forefoot remained unaffected by changes in the shoe conditions. FTI significantly decreased in the R16 and R18.5 conditions when walking with low LBS (L16 and L18.5) as compared to high LBS (H16 and H18.5) (p<.05). No significant differences were found between shoe conditions in the proximal forefoot.
Table 1: In this table significant* decreases (green) and increases (red) of PP, MMP and FTI are presented.

<table>
<thead>
<tr>
<th></th>
<th>Compared to the control shoe</th>
<th></th>
<th>Radii3</th>
<th>LBS4</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L16</td>
<td>H16</td>
<td>L18.5</td>
<td>H18.5</td>
</tr>
<tr>
<td>Peak pressure (kPa)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>First toe</td>
<td>171.85</td>
<td>187.81</td>
<td>195.61</td>
<td>199.78</td>
</tr>
<tr>
<td>Toes 2-5</td>
<td>115.08</td>
<td>105.65</td>
<td>117.71</td>
<td>129.71</td>
</tr>
<tr>
<td>Distal forefoot</td>
<td>193.31</td>
<td>188.51</td>
<td>189.81</td>
<td>200.73</td>
</tr>
<tr>
<td>Proximal forefoot</td>
<td>55.94</td>
<td>56.97</td>
<td>57.34</td>
<td>58.76</td>
</tr>
<tr>
<td>Midfoot</td>
<td>87.52</td>
<td>73.64</td>
<td>96.81</td>
<td>86.67</td>
</tr>
<tr>
<td>Heel</td>
<td>234.52</td>
<td>241.45</td>
<td>226.99</td>
<td>224.44</td>
</tr>
</tbody>
</table>

| Maximum mean pressure (kPa) |      |      |       |       |      |      |         |       |      |       |      |      |       |      |      |       |      |
| First toe        | 133.93 | 144.29 | 150.00 | 152.87 | 161.92 | 170.45 | 175.36 | 175.36 | 133.93 | 152.87 | 161.92 | 170.45 | <.001  | -8.58 | -26.15 | -17.57 | -10.35 |
| Toes 2-5         | 57.16  | 57.46  | 61.86  | 62.14  | 63.03  | 69.06  | 75.49  | 75.49  | 57.16  | 57.46  | 61.86  | 62.14  | <.001  | -4.88 | -11.60 | -6.92  | -0.30  |
| Distal forefoot  | 101.39 | 104.56 | 100.06 | 102.84 | 107.83 | 105.35 | 123.30 | 123.30 | 101.39 | 104.56 | 100.06 | 102.84 | <.001  | 1.72  | -0.79  | -2.51  | -3.17  |
| Proximal forefoot| 16.47  | 18.39  | 17.17  | 18.03  | 17.83  | 20.18  | 36.09  | 36.09  | 16.47  | 18.39  | 17.17  | 18.03  | <.001  | 0.36  | -1.79  | -2.15  | -1.91  |
| Midfoot          | 27.03  | 21.47  | 31.36  | 28.39  | 27.55  | 25.82  | 29.00  | 29.00  | 27.03  | 21.47  | 31.36  | 28.39  | <.001  | -6.91 | -4.34  | 2.57   | 5.55   |
| Heel             | 136.31 | 140.02 | 133.13 | 136.38 | 134.62 | 136.89 | 123.98 | 123.98 | 136.31 | 140.02 | 133.13 | 136.38 | <.001  | 3.64  | 3.13   | -0.51  | -3.71  |

| Force-time integral (N s) |      |      |       |       |      |      |         |       |      |       |      |      |       |      |      |       |      |
| First toe        | 26.49  | 29.22  | 29.32  | 30.45  | 32.48  | 30.72  | 32.72  | 32.72  | 26.49  | 29.22  | 29.32  | 30.45  | <.001  | -1.83 | -3.25  | -1.42  | -2.73  |
| Toes 2-5         | 29.41  | 30.45  | 31.65  | 32.49  | 32.74  | 35.43  | 32.12  | 32.12  | 29.41  | 30.45  | 31.65  | 32.49  | <.001  | -2.95 | -5.89  | -2.94  | -0.14  |
| Proximal forefoot| 9.21   | 10.79  | 10.79  | 10.66  | 11.76  | 12.39  | 24.55  | 24.55  | 9.21   | 10.79  | 10.79  | 10.66  | <.001  | 0.13  | -1.60  | -1.73  | -1.58  |
| Midfoot          | 22.95  | 17.53  | 27.57  | 24.90  | 22.68  | 20.36  | 20.56  | 20.56  | 22.95  | 17.53  | 27.57  | 24.90  | <.001  | -7.37 | -2.83  | 4.54   | 5.41   |
| Heel             | 160.45 | 159.92 | 153.47 | 150.55 | 147.98 | 145.11 | 121.23 | 121.23 | 160.45 | 159.92 | 153.47 | 150.55 | <.001  | 4.36  | 14.80  | 10.44  | 0.53   |

1 The coloured blocks represent a significant difference if p<.05 in which light green blocks are decreases in plantar pressure and red blocks are increases.
2 Comparisons between experimental conditions compared to control shoe. Significant differences are presented in bold.
3 Comparisons between radii measured between high LBS only because of the possibility of dorsiflexion motion in the low LBS (7).
4 Comparisons between low (L) and high (H) longitudinal bending stiffness (LBS).
Figure 5: Pairwise comparisons between radius 16, 18.5 and 21 cm. First row differences in radii and second row in flexibility. For the first row and column green means lower peak pressure is present in R16 for the first toe, toe 2-5 (region 1 and 2) and midfoot (region 5) compared to R18.5.
Figure 6: Percentual changes of PP, MMP and FTI compared to the control shoe (zero line). Significant changes are marked with an asterisk.
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Midfoot
As compared to the control shoe, increase in PP was significantly less in R16 as compared to R18.5 and R21 shoe condition (p<.05). The increase of PP was significantly less in high LBS as compared to the low LBS (p<.05). No significant differences in MMP and FTI were reported between the experimental conditions.

Heel
PP was significantly lower in R18.5 as compared to R16 and R21 in the heel region (p<.05). In all experimental conditions PP was lower in low LBS as compared to high LBS. MMP remained unaffected by changes in rocker radius and LBS. FTI was significantly lower in R21 compared to R16 and R18.5 (p<.05). LBS had no effect on FTI.

Discussion
The main aim of the current study was to establish how combined changes in forefoot rocker radius and LBS affect the plantar pressure profile in the forefoot region of healthy young adults during gait. As hypothesized, plantar pressures in the first toe and toes 2-5 were lower in the small radius (R16; 62% of shoe length) as compared to larger (R18.5 and R21) radii independent of the LBS. At the distal forefoot, both the small and medium radii (R18.5; 71% of shoe length) resulted in significantly larger reductions of peak plantar pressure as compared to the large radius (R21; 81% of shoe length).

In line with previous studies investigating the effect of changes in outsole parameters on plantar pressure profile our results showed that depending on the exact target location for offloading, different combinations in outsole parameters (e.g. rocker radius and LBS) need to be chosen to maximize treatment effects [7,8,10]. While PP under the first toe reduced most in rocker shoes with a small radius and low LBS, PP in toes 2-5 and the distal forefoot decrease most in rocker shoes with a small radius but high LBS. Similarly, PP under the heel is significantly lower when walking with low LBS independent of the radius while PP under the midfoot reduces when walking with high LBS. Plantar pressure reduction in the proximal forefoot was comparable between rocker conditions.

The size of radii is based on shoe length and should therefore be used in terms of percentage of shoe length instead of absolute values. A radius of 62% shoe length (R16) reduced PP under the first toe below the advised threshold (for people with diabetic neuropathy) of 200 kPa [20]. Radii greater than 71% shoe length (R18.5) were inadequate in reducing PP below the advised threshold. Combining our findings with previous studies we recommend clinicians to use an apex position between 50 and 60% of shoe length combined with radii below 62% of shoe length (R21), low LBS and an apex angle above 90° to offload first toe and prevent ulceration at that specific location [5,7,8,10]. It is important to note however, that a fixed apex position at 55% of shoe length was used during the experiment. Previous findings suggest that PP might even be reduced more in forefoot regions at-risk of diabetic ulcers when the apex position is placed more distally, beyond 55% [10]. The exact effect of changes in apex position combined with changes in rocker radius remains to be established and will be part of future experiments.

While the forefoot region can be offloaded through adaptations in radius and LBS, PP in more proximal foot regions increases when walking with high LBS and small radius rocker shoes.
This redistribution of PP to the mid- and hindfoot regions is not trivial since it might increase the risk of other foot pathologies such as plantar fasciitis [21]. There is a complex relationship between forefoot pressure and pain. While prolonged excessive plantar pressure can cause pain and for example erosion in rheumatoid arthritis [22], pain itself is often avoided through gait adaptations; often referred to as antalgic gait [23]. Choosing rocker parameters in such a way that pressure is reduced at painful areas and areas at risk for pain can play a role in both the prevention of pain and the management of existing pain.

Especially in diabetic patients changes in outsole parameters need to be chosen carefully since they are especially vulnerable to increases in PP and more vulnerable to other foot pathologies (e.g., plantar fasciitis) [21,24]. Clinicians might therefore consider to add soft heel-pads when prescribing shoe adaptations with small radii and high LBS in patients with diabetes and overuse injuries at the heel [25]. IWGDF Guidelines on the prevention and management of diabetic foot disease [26] advice a reduction in peak pressure to <200kPa or with ≥30 % to reduce the chance of developing ulcers, but only in the case of increased baseline pressures. In our study we showed that with the optimal radius and LBS setting, reductions of 12-36% in PP were found in the forefoot regions and in all optimal settings PP was <200 kPa on average. This means that on group level the rocker effect could be considered sufficient. However, to prevent ulcers, individual pressure measurements after application of shoe modification must be taken to ensure sufficient reductions in PP. If PP remains over 200kPa or reductions are <30%, additional measures like the application of an insole are needed.

Next to changes in apex position, rocker radius and LBS, another important outsole parameter to reduce peak plantar pressures is the apex angle (figure 1). Previous studies showed that increasing the apex angle beyond 95⁰ in rocker shoes reduces PP at the medial forefoot while decreasing the apex angle below 95⁰ reduces PP beneath the lateral forefoot [8,10]. Future studies will show the exact interaction between changes in apex angle, varying LBS and rocker radii on PP during gait.

Next to clinical suggestions we want to propose some methodological recommendations for future scientific studies. We suggest that scientists should choose the masks in such a way that they match the main interest of the study or hypothesized treatment effect. For example, we modified the standard medio-lateral masks to proximal (mask 4) and distal (mask 3) forefoot masks because we hypothesized that our adaptations in outsole parameters mainly affect the anterior-posterior distribution of plantar pressure. However, when the main interest or expected treatment effect is in the medio-lateral PP distribution, we recommend using the standard approach.

A potential limitation of our study is that we included only young, healthy female individuals. Previous studies showed that the effect of changes in outsole parameters on PP is similar between healthy adults and low risk patients with diabetes without foot deformity or serious neuropathy [8]. However, foot deformities and limited joint mobility are causes of high plantar pressures and therefore a risk factor for development of ulcers in diabetic patients [27]. We recommend reproducing our experiment in patients with forefoot pathologies to strengthen the clinical relevance of our findings. Another limitation of this study was that comfort was not systematically measured. Although no discomfort was reported, in future studies in
patient populations comfort must be measured systematically as it is a factor for actual use of therapeutic footwear [28].

Conclusion
For maximizing treatment effects different combinations of rocker profile parameters are preferred based on the exact target region that needs offloading. Although this research is based on a small sample of healthy females, some preliminary recommendations can be made. A proximally placed apex position and a small radius reduces plantar pressures at the first toe and toes 2-5. A low LBS shoe is preferred for pressure reductions at the first toe, whereas a high LBS shoe is preferred for plantar pressure reduction at toes 2-5. To decrease plantar pressures at the distal forefoot, rocker radii smaller than 72% shoe length and high LBS should be used. For targeted offloading of painful plantar areas or areas at risk for ulceration (PP > 200kPa), application of specific design parameters, including rocker radius and longitudinal bending stiffness, is of eminent importance to optimize the treatment effects of rocker shoes. Indication of areas at risk for ulceration (PP > 200 kPa) can only be achieved with an adequate in-shoe plantar pressure measurement. Further studies are needed to assess the influence of varying rocker radii combined with more distally or proximally placed apex positions on plantar pressure distributions in patients with foot pathologies or loss of protective sensation.

Declaration of interest
The authors have no conflict of interest in this study.
References


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