Influence of wedge stiffness on biomechanics during heel-strike transient phase

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1. Introduction

When human beings walk or run, the plantar regions of the feet are subjected to considerable forces at each step during the ground-contact phase (Cavanagh & Lafortune 1980). In many instances, the heel is the first portion of the foot to strike the ground. The contact of the heel with the ground results in ground reaction forces known as heel-strike transient (HST, Collins & Whittle 1989), HST was previously considered as an artefact until 1985, and it was identified mainly by the low cut-off frequencies of the force plate conditioners used at that time (Schneider & Chao 1983; Gill 1996). Heel-pad stiffness has drawn considerable research attention, and the impact was found to be directly transmitted through the heel while the heel pad passively attenuates the shock (Oakley & Pratt 1983). Low-stiffness foams can further reduce acceleration during (HST, Collins & Whittle 1989), but they make the shoe feel too soft and spongy. During barefoot walking, the heel pad is responsible for minimising the force during heel strike by increasing the contact duration, hence reducing peak deceleration (Schneider & Chao 1983; Kirtley 2006).

A good stability index during heel strike is the displacement of the centre of mass CG. Some authors investigated the displacement of CG under different walking conditions. You et al. (2001) reported that the displacement and velocity of CG decrease under slippery perturbations. Other authors have investigated the effect of plantar support stiffness on stability and posture (Christovão et al. 2013) during walking; however, the relationship between stiffness and CG kinematics remains unclear.

2. Methods

Ten healthy young male volunteers (age: 23.8 ± 44 years, height: 175.5 ± 7.1 cm, mass: 70.9 ± 8.7 kg), free from injury for at least 12 months prior to participation, took part in this study. All volunteers provided written informed consent prior to participation, and were asked to wear successively three pairs of heel lifts (Table 1). The following procedure was repeated in a random order for each of the three test configurations: after 2 min of unrecorded trials for training purposes, the subjects were asked to walk on a walkway at an imposed frequency of 100 steps/min using a metronome. To ensure good reproducibility of results and time saving accordingly, a podobaroscopy platform (Novel, GMBH) was placed on top of a force platform (AMTI, Watertown, MA) with high frequency (2 kHz), both forming the so-called platform for the rest of the article. Each volunteer was asked to position itself freely on the platform and stabilize his posture, taking time to feel comfortable. Three successful trials for each of the three test conditions (see Table 1) were then completed. The trials were considered as successful when the right foot would be completely set on the force platform and no visible indication appeared that the volunteer altered the wedge gait characteristics while walking over the platform. The duration of the HST phase was assumed in our study to end at the middle of the double-stance (i.e. ~5% of the gait cycle).

Analysis of variance was used to identify the significant differences among the groups and Student T test were used to identify significant differences between groups ($\alpha < 0.05$) using STATISTICA (Stat Soft, Tulsa, OK) to assess the possible effects of stiffness on the static plantar support. It also identified the position of the CG and evaluated the influence of midsole stiffness on the ground forces during walking under both preferred and imposed frequency conditions. The means of three valid trials of each subject for each plantar support were used in the statistical analysis.

3. Results and discussion

The recorded reaction peak forces and corresponding times are listed in Table 2.
Compared with the hard wedge, the vertical peak force ($F_z$) as found to be significantly ($p<0.05$) different and lower when the subjects wore the soft wedge. The corresponding time $T_{Fz}$ was found to be significantly different between the soft and hard wedges and between the medium and hard wedges. The ground reaction forces were found to be affected by the stiffness of the wedges at the time of impact. Specifically, compared with that in the hard wedge (Figure 1). The difference between the relative maximum amplitude of the peak force was 32%, observed for the AP force. This result corresponds to better shock absorption when the heel strikes the ground, which is consistent with the previous results from the literature (Lafortune et al. 1996; Addison 2015).

Figure 2 shows that CG shifted to the lateral board and forward by approximately 3 cm during IW compared with that during PW. The maximum shift was noted for the soft wedge, particularly at PW. This result agrees with the findings of Staszkiewicz et al. (2010). During natural locomotion, an increasing trend of CG displacement appears as the walking speed increases.

### 4. Conclusions

The medium and soft wedges significantly affected the ground peak force, particularly during IW, whereas the hard wedge affected the percussion. The CG shifted forward during PW, especially when the soft wedge was used. The medium wedge was more stable and provided better ergonomics.

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