Gait & Posture 62 (2018) 235–240

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length article

Foot posture is associated with plantar pressure during gait: A comparison of normal, planus and cavus feet

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ARTICLE INFO

Keywords:
Foot
Gait
Biomechanics
Foot posture
Plantar pressure

ABSTRACT

Background: Variations in foot posture, such as pes planus (low medial longitudinal arch) or pes cavus (high medial longitudinal arch) are associated with some lower limb injuries. However, the mechanism that links foot posture to injury is not clear. Research question The aim of this study was to compare plantar pressure between healthy individuals with normal, planus or cavus feet.

Methods: Ninety-two healthy volunteers (aged 18 to 45) were classified as either normal (n = 35), pes planus (n = 31) or pes cavus (n = 26) based on the Foot Posture Index, Arch Index and normalised navicular height truncated. Barefoot walking trials were conducted using an emed®-x400 plantar pressure system (Novel GmbH, Munich, Germany). An 11 region mask was used that included the medial heel, lateral heel, midfoot, 1st, 2nd, 3rd, 4th and 5th metatarsophalangeal joints, hallux, 2nd toe, and the 3rd, 4th and 5th toes. Peak pressure, pressure-time integral, maximum force, force-time integral and contact area were calculated for each region. One way analyses of variance and effect sizes were used to compare the three foot posture groups.

Results: Overall, the largest differences were between the planus and cavus foot groups in forefoot pressure and force. In particular, peak pressures at the 4th and 5th MTPJs in the planus foot group were lower compared to the normal and cavus foot groups, and displayed the largest effect sizes. Significance This study confirms that foot posture does influence plantar pressures, and that each foot posture classification displays unique plantar pressure characteristics.

1. Introduction

The alignment adopted by segments of the foot during weightbearing, commonly referred to as foot posture, can vary substantially between individuals and has been linked to injury. Two recent systematic reviews have found that foot postures such as pes planus (low medial longitudinal arch) or pes cavus (high medial longitudinal arch) are associated with increased risk of lower limb injury, including medial tibial stress syndrome and patellofemoral pain [1,2]. Nevertheless, to understand the mechanism of injury, a clear and comprehensive explanation of the variation in biomechanics between classifications is needed [2]. Such an explanation will provide insight into the interaction between foot posture and both intrinsic (i.e. body mass index) and extrinsic (i.e. footwear) risk factors [3].

A key tool in the analysis of foot and lower limb biomechanics is the measurement of the direction and magnitude of force applied to the plantar surface of the foot [4]. Our recent systematic review found some evidence of distinctive plantar pressure characteristics in planus and cavus feet [5]. Specifically, when normal and cavus feet were compared, planus feet displayed higher pressure, force and contact area values in the medial arch, central forefoot and hallux, while these variables were lower in the lateral and medial forefoot. In contrast, when compared to normal and planus feet, cavus feet displayed higher pressure in the heel and lateral forefoot and lower pressure, force and contact area in the midfoot and hallux.

Although some evidence of characteristic plantar pressure patterns among specific foot posture was identified in our systematic review, inconsistencies in gait analysis protocols and plantar pressure analysis techniques between included studies made it difficult to form definitive conclusions [5]. Furthermore, of the 10 included studies that compared

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https://doi.org/10.1016/j.gaitpost.2018.03.005
Received 12 October 2017; Received in revised form 1 March 2018; Accepted 3 March 2018
0966-6362/

plantar pressures between groups, only three compared all foot postures (normal, planus and cavus) [6–8]. Of the studies that included all foot postures, only one provided a comprehensive comparison of plantar pressure variables for the entire plantar foot [7]. This study also had a higher methodological quality score compared to other selected studies in the systematic review [5]. However, foot posture groups were assigned using angular measurements of foot alignment, such as the resting calcaneal stance position, which has been found to have poor reliability [9–11]. Thus, a limitation of this study is that the measure used to categorise foot posture is not considered gold-standard. Furthermore, such measures do not have adequate normative data, so clear and repeatable boundaries for foot posture classification have not been established [12,13]. In contrast, alternative measures, such as the Foot Posture Index (FPI) [14], the Arch Index (AI) [15] and normalised navicular height truncated (NNHt) [16], have acceptable reliability for clinical use [17,18] and have normative values that have been used in previous studies of foot posture [14,19].

Accordingly, the aim of this study was to compare plantar pressure and force variables between normal, planus and cavus foot posture groups using reliable foot posture measures that are supported with normative data.

2. Methods

2.1. Participants

Ninety-two participants (aged 18 to 45) from the general student and staff population of La Trobe University were recruited via a general call for volunteers. Volunteers were excluded from the study if they reported any current or recurring lower extremity injury or had been diagnosed with neurovascular disease or any biomechanical abnormality that may affect gait. The 6-item Foot Posture Index (FPI) [14], the Arch Index (AI) [15] and normalised navicular height truncated (NNHt) [16] were used to assign participants to either a normal, pes planus or pes cavus foot posture group. The FPI was the primary measure as it is a comprehensive method that uses multiple observations in all three cardinal planes, while the AI and NNHt were used as they are calculated from different categories of foot posture measurement (anthropometric and footprint) [20]. The AI was calculated using a static footprint obtained using Pressurestat® carbon paper (Footlogic Inc, South Salem, NY, USA) taken with the participant standing in relaxed bipedal stance. The footprint (excluded the toes) was divided into three equal areas and the AI was calculated as a ratio of area of the middle region to the area of the complete foot [15]. The NNHt was calculated by dividing navicular height by truncated foot length (length of foot between the posterior heel and most medial aspect of the 1st metatarsophalangeal joint) [16].

To qualify for the normal group, foot measurement values needed to be within one standard deviation of the mean of normative data for the FPI [14], and plus within one standard deviation of at least one of the AI or NNHt [21]. Participants were assigned to the pes planus or pes cavus groups if foot measurements were greater than or less than one standard deviation from the mean of normative data for the FPI and either the AI or NNHt (Supplementary file 1). Thirty-five participants (17 males, 18 females) were assigned to the normal group, 31 participants (16 males, 15 females) to the pes planus group, and 26 participants (12 males, 14 females) to the pes cavus group. There was one participant that displayed differing foot classifications between the FPI and both the NNHt and AI. In this instance, the contralateral foot was classified as normal according to the FPI and NNHt, so the participant was allocated to the normal group.

One foot of each participant was selected for testing. If only one foot of a participant satisfied selection criteria for a group, then this foot was tested. If both feet qualified, one foot was randomly selected for testing (using the random number generator function in Microsoft Excel®, Microsoft Corporation, Redmond, WA). Ethical approval was obtained from the La Trobe University Human Ethics Committee (ID number: HEC11-097) and all participants signed informed consent.

2.2. Experimental protocol

Dynamic barefoot plantar pressure data were collected using an EMED®-400 plantar pressure system (Novel GmbH, Munich, Germany), a 700 mm long by 403 mm wide platform incorporating 6080 capacitance transducer sensors (4 sensors/cm^2) sampling at a frequency of 100 Hz. The platform was embedded in the centre of a walkway and data were collected using the two-step initiation protocol, whereby participants were positioned two steps from the front edge of the platform and instructed to walk at their comfortable speed [22]. The two-step initiation protocol has good re-test reliability and was used to mitigate the influence that walking speed may have on plantar pressures [23].

A five-minute acclimatisation period was allowed for participants to become comfortable with the data collection procedure. Participants were asked not to look at the ground during walking trials, and in the event of targeting of the pressure plate, the trial was not analysed. Five successful trials were analysed for the tested foot.

2.3. Data processing and statistical analysis

Novel scientific medical software, version 23 was used to build individual ‘masks’ (11 mask standard division) to determine plantar pressures for 11 regions of the whole foot (Fig. 1). The regions were the lateral heel, medial heel, midfoot, 1st, 2nd, 3rd, 4th and 5th metatarsophalangeal joints (MTPJ), the hallux, 2nd toe, and the 3rd, 4th and 5th toes (combined). The following variables were extracted: peak pressure (kPa), maximum force (N), contact area (cm^2), pressure-time integral (kPa.s) and force-time integral (N.s) [5].

Total contact time, which is used as a proxy measure for walking velocity, was compared between all individuals [23]. This was to ensure that there were no differences in walking speed, which can influence plantar pressures [24]. The distribution of data was assessed for skewness, kurtosis and equality of variance (Levene’s test). If the assumption of normality for any variable was not met, data underwent transformation. To test for differences between groups, a one-way analysis of variance (ANOVA) was performed with significance level set at < 0.05. Post-hoc comparisons of the mean differences (MD) between groups with Bonferroni adjustments were applied to all ANOVAs. Confidence intervals (CI) and effect sizes (ES) using Cohen’s d were calculated for all significant mean differences [25]. The following interpretation of effect size was used: trivial: 0–0.2, small: 0.2–0.6, moderate 0.6–1.2, large: 1.2–2.0 [26]. All statistical tests were calculated using SPSS version 21 for Windows (IBM Corporation, NY).

3. Results

3.1. Participant characteristics

Participant characteristics, including anthropometric and foot posture variables are shown in Table 1. Participants in the planus group were significantly shorter compared to the normal and cavus group. Such a difference may influence walking speed, however, there was no significant difference in total contact time during stance phase. It is therefore unlikely that height influenced plantar pressure data, and as such, no adjustment was made for height.

3.2. Comparisons between foot posture groups

Comparisons between all three foot posture groups for peak plantar pressure, maximum force and contact area are presented separately, with significant differences, 95% confidence intervals and effect sizes shown in Tables 2–4. A graphical representation of differences in peak