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Shod wear and foot alignment in clinical gait analysis

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Highlights

- Established the accuracy of foot alignment methods during shod analysis
- Showed that visual alignment may be accurate
- Showed that a dorsiflexion bias exists with current software alignment
- Proposed an adjusted foot alignment method without dorsiflexion bias

Abstract

Sagittal plane alignment of the foot presents challenges when the subject wears shoes during gait analysis. Typically, visual alignment is performed by positioning two markers, the heel and toe markers, aligned with the foot within the shoe. Alternatively, software alignment is possible when the sole of the shoe lies parallel to the ground, and the change in the shoe's sole thickness is measured and entered as a parameter. The aim of this technical note was to evaluate the accuracy of visual and software foot alignment during shod gait analysis. We calculated the static standing ankle angles of 8 participants *(mean age: 8.7 years, SD: 2.9 years)* wearing bilateral solid ankle foot orthoses (BSAFOs) with and without shoes using the visual and software alignment methods. All participants were able to stand with flat feet in both static trials and the ankle angles obtained in BSAFOs without shoes was considered the reference. We showed that the current implementation of software alignment introduces a bias towards more ankle dorsiflexion, mean = 3°, SD = 3.4°, $p = 0.006$, and proposed an adjusted software alignment method. We found no statistical differences using visual alignment and adjusted software alignment between the shoe and shoeless conditions, $p = 0.19$ for both. Visual alignment or adjusted software alignment are advised to represent foot alignment accurately.

Introduction

Ankle angle is often a key variable in clinical gait analysis. Dorsiflexion and plantar flexion is calculated as the angular rotation of the foot around the lateral axis of tibia [1]. Therefore, the ankle angle is affected by foot alignment in the sagittal plane. The conventional gait model describes the foot as a rod defined by a marker at the heel and dorsal surface of the foot [2, 3]. The assessors visually align these markers to the sole of the foot in the sagittal plane and parallel to the long axis of the foot in the coronal plane [3]. The aid of a striped transparent Perspex board may be used (figure 1, A). However, visual alignment is a subjective and time consuming process as assessors often lay prone on the floor at foot height to minimise parallax error.

Software alignment is an alternative method when the patient can stand barefoot with flat feet, i.e. with the sole of the foot parallel to the ground. Software alignment adjusts the height of the heel marker to match the height of the forefoot marker above the ground [4]. This eliminates the need for sagittal plane alignment and only leaves coronal plane alignment during marker placement. In shod gait analysis, sagittal foot alignment within the shoe is more complex and shod studies may constrain shoe wear to a particular model or have cut outs to improve consistency and accuracy of marker placement [5, 6]. In a clinical setting, this approach is impractical and visual alignment is used.

Software alignment in shod analysis may still be possible if the patient can stand with their shoes flat on the ground and the change in shoe sole thickness across the length of the shoe is measured and entered as a parameter, sole delta (Plug-in-Gait, VICON, [4]). Measurement of sole delta is taken at the two major points of contact of the foot within the shoe (figure 1, B), estimated to be at the metatarsal heads and the centre of the heel [7, 8]. However, this may introduce a small dorsiflexion bias since sole delta is applied to the heel marker rather than at the centre of the heel (figure 1, C). Adjusting sole delta (s_{adj}) to remove the bias requires a measure of the distance between the centre of the heel and the heel marker (d_{heel}). Alternatively, the projection of the ankle joint centre on the sole of the foot may be used as a proxy for the position of the rear contact point.

The aim of this technical note was to quantify the magnitude of the bias and to evaluate the accuracy of the visual and software foot alignment methods during shod analysis. We also proposed and evaluated an adjusted software alignment method.

[approximate position of figure 1]

Materials and Method

Sole delta (s) is the height difference at the rear and front of the shoe (figure 1, B). The adjusted sole delta (s_{adj}) value is calculated for greater foot alignment accuracy using the principle of similar triangles (figure 1, C):

$$s_{adj} = \frac{s \times d_{foot}}{d_{foot} - d_{heel}}$$

Where d_{foot} is the distance between the heel and toe markers projected on the floor and d_{heel} is the distance between the heel marker and rear contact point projected on the floor. The location of the rear contact point is a visual estimation. The dorsiflexion bias (α_{error}) is calculated as $\alpha_{error} = \alpha_{adj} - \alpha_{meas} = tan^{-1}\left(\frac{s_{adj}}{d_{foot}-d_{heel}}\right) - tan^{-1}\left(\frac{s}{d_{foot}}\right)$.

We evaluated the accuracy of visual and software alignment methods on children attending a clinical gait analysis appointment. We also evaluated the accuracy of an adjusted software alignment method where the rear contact point was assumed to be at the ankle joint centre. In this instance, d_{heel} is the distance between the heel marker and the ankle joint centre projected on the floor in the direction of the foot.

Children with bilateral solid AFOs without a wedge (BSAFO) and requiring a barefoot and BSAFO gait analysis were eligible to participate in the study. Static standing calibration was performed for two conditions: wearing BSAFO and shoes (shoe), and wearing BSAFO without shoes (shoeless). Markers were positioned on the subject according to Plug-in Gait requirements [4]. Specifically, foot markers were visually aligned in the coronal and sagittal planes and placed on the AFO and foot (shoeless condition), or on the shoe (shoe condition). Sole delta was measured according to figure 1, B.

Static trials were acquired using a 10-camera Vicon® system sampling at 100 Hz, processed in Vicon® Nexus 1.8.5 and modelled with Plug-In Gait using the visual, software and adjusted software alignment methods. Twenty frames with minimal movement were selected and average ankle dorsiflexion angles for the shoe and shoeless conditions were calculated.

The difference in static dorsiflexion angles between the two conditions: shoe – shoeless were calculated for the visual, software and adjusted software alignment methods. Since the subjects wore solid AFOs in the two static trials, we would expect a difference of 0°. A student t-test was performed to test for significant differences from 0°, of the visual, software and adjusted software alignment methods in Minitab® 17.2.1 (Minitab Inc, USA).

Results

The expected error for a given individual was graphed by holding d_{foot} constant and plotting the bias over a range of rear contact point (d_{heel}) and sole delta (s) values. Figure 2 provides an example of the expected error for average 6 year old (A) and adult (B) females.

[approximate position of figure 2]

Figure 2 highlights that three factors exaggerate dorsiflexion angles: increased distance between the heel marker and the rear contact point, increased sole delta, and decreased foot length. As a result, careful analysis is recommended for large sole delta on small feet.

[approximate position of figure 3]

Eight participants *(mean age: 8.7 years, SD: 2.9 years)* were included in the study. Three physiotherapists each assessed two or three participants. The results on ankle angle differences were normally distributed and the statistical analysis (figure 3) showed no statistical differences between the shoe and shoeless conditions for the visual alignment method, $p = 0.19$, or the adjusted software alignment method, $p = 0.19$. However, software alignment resulted in significant increased dorsiflexion between the shoe and shoeless conditions, mean = 3°, SD = 3.4°, $p = 0.006$.

Discussion and conclusion

Our aim was to evaluate the accuracy of sagittal plane alignment during shod gait analysis. Our results show that visual and adjusted software alignments did not introduce a significant bias in ankle dorsiflexion angle, however standard software alignment did.

Our study assumed that ankle dorsiflexion angle was identical between the shoe and shoeless conditions. To verify this, we calculated AFO deformation during stance phase in gait using the model described in Ridgewell et al. [11]. Minimal additional deformation of the AFOs was found (mean increased deformation: 2°, SD: 2.8°). A limitation is that we collected data on a relatively small range of sole delta values (mean sole delta (*s*): 9.8 mm, SD: 7.58 mm). Larger sole delta values increase the distance between the projection of the ankle joint centre and the heel marker, d_{heel}.

Visual alignment and adjusted software alignment provided equally accurate results. The adjusted software alignment was reported to be physically easier during marker placement, more time efficient and is independent of experience. We chose to use the adjusted software alignment method in shod gait analysis.

Each author certifies that he or she has no commercial associations that might pose a conflict of interest in connection with the article.

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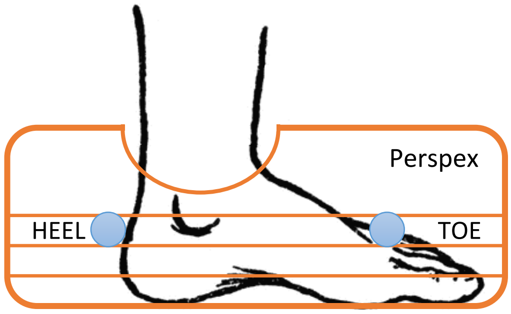
12.

Figures (three figures)

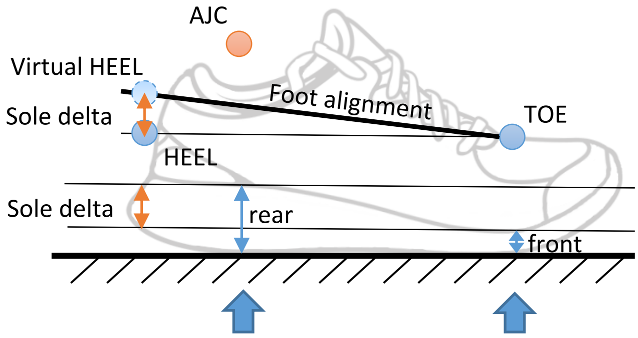
Figure 1

(A) Example of a Perspex board with a series of parallel lines to aid marker positioning during visual alignment. (B) The thick blue arrows under the shoe indicate the two points of sole height measurement at the heel (rear) and metatarsal heads (front) used to calculate sole delta. Sole delta is added to a pre-levelled HEEL marker to model sagittal foot alignment within the shoe. (C) Visual representation of the variables used to calculate the bias $\alpha_{meas} - \alpha_{adj}$. d_{foot} is the distance on the floor between the HEEL and TOE markers. d_{heel} is the distance on the floor between the HEEL marker and the rear measurement point. α_{meas} is the pitch of the foot calculated when sole delta is applied to the HEEL marker (s). α_{adj} is the pitch of the foot when sole delta is applied to the rear measurement point and corresponds to the adjusted sole delta s_{adj} at the HEEL marker.

A


Perspex
HEEL
TOE

B


AJC
Virtual HEEL
Foot alignment
Sole delta
TOE
HEEL
Sole delta
rear
front

C

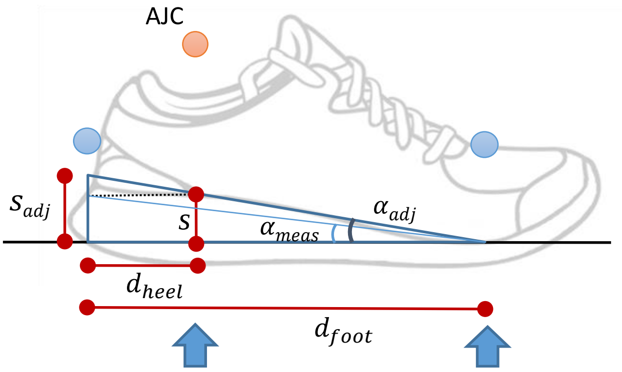
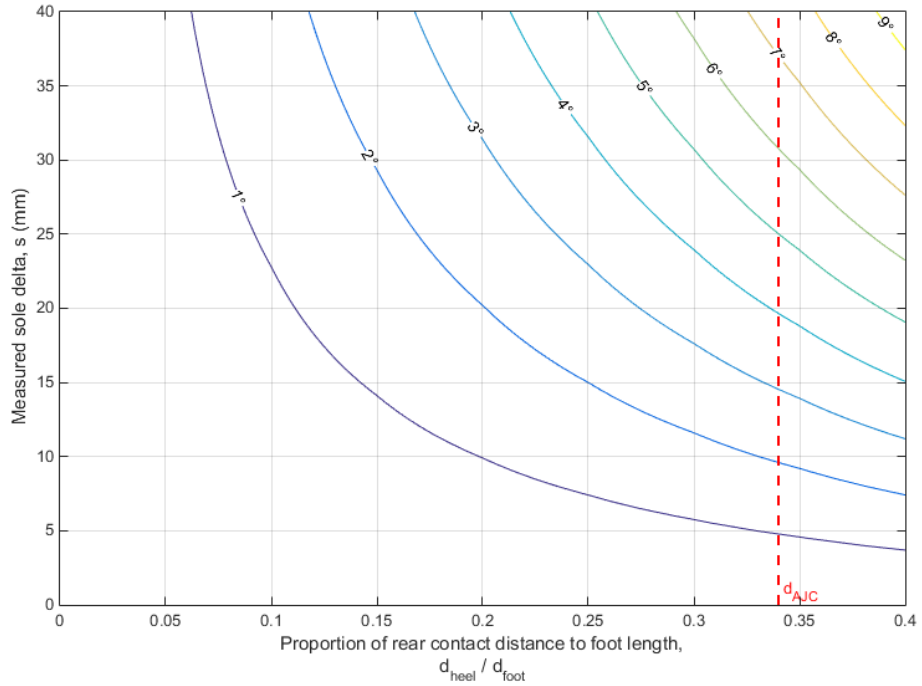

AJC
s_{adj}
s
α_{adj}
α_{meas}
d_{heel}
d_{foot}

Figure 2

Contour plots of the dorsiflexion error in degrees with respect to sole delta (s) and the ratio between the rear contact point to heel marker distance (d_{heel}) and foot length (d_{foot}). The vertical red dotted line (d_{AJC}/d_{foot}) indicates the mean location of the ankle joint centre in the cohort studied (*mean: 0.34, SD: 0.03*).

(A) Graph based on d_{foot} = 141 mm for an average 6 year old female child [9]. (B) Graph based on d_{foot} = 177 mm for an adult female [10].

A



B

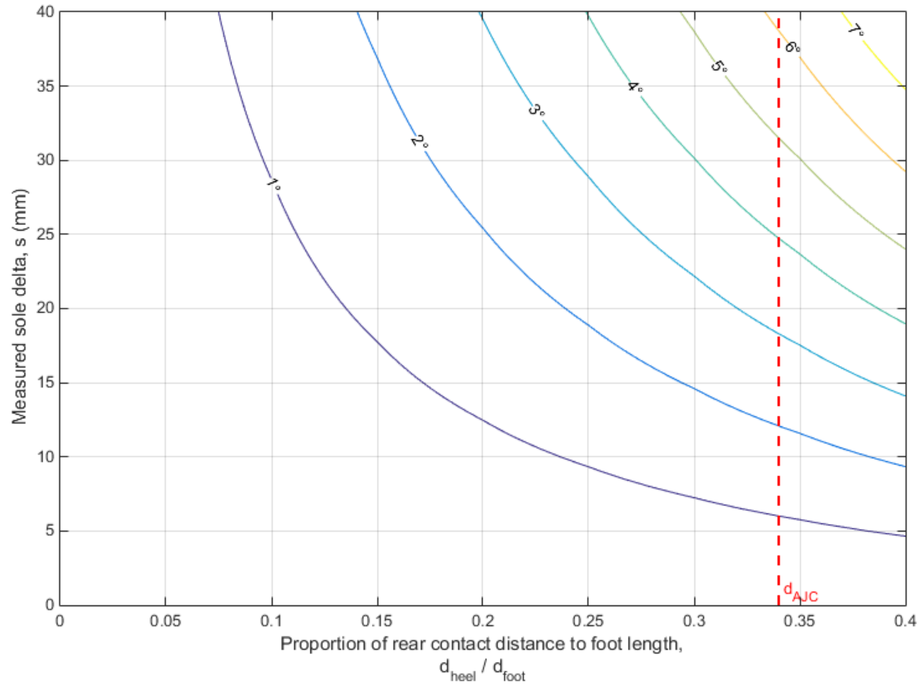


Figure 3

Boxplot of the difference between the ankle dorsiflexion angles with solid AFOs in and out of the shoes. Visual (mean: 1°, SD: 3.9°) and adjusted software alignment (mean: 1°, SD: 3.8°) were not different form 0° (p = 0.19 for both) but current software alignment was significantly different from 0° (mean: 3°, SD: 3.4°, p = 0.006).