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Technical and measurement report

An investigation of the reproducibility of a self-selected natural feet position when standing: Implications for the assessment of upright standing posture

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ABSTRACT

Background: Photogrammetry is often used to evaluate standing static postural alignment. Patients are often instructed to self-select a natural feet position but it's unclear whether this position can be consistently replicated across repeated assessments.
Objective: To determine whether people can replicate a self-selected natural feet position in upright standing across three sessions on different days.
Design: Between days test-retest reliability.
Setting: University laboratory.
Methods: Three variables – Base of Support (BoS), Foot Width (FW), Feet Opening Angle (FOA) – were measured from foot tracings of 150 participants (18–30 years) using established procedures. BoS data were assessed for systematic bias (Analysis of Variance), and absolute (Coefficient of Variation - CV%) and relative (Intraclass Correlation Coefficient - ICC) reliability.
Results: There was systematic bias in the BoS data across the three testing sessions. The CV% for the BoS data was 15.2%. The ICC (95% CI) for the BoS data was 0.84 (0.79–0.87). There were moderate-large correlations between the BoS and both FOA and FW respectively within each session.
Conclusion: If clinicians want to allow patients to use their self-selected natural feet position for repeated photogrammetric assessment of their static postural alignment it would be better to standardise the position of the feet, for example, by creating a tracing of a patient's self-selected natural feet position.

1. Introduction

There is a long tradition within the manual therapies of evaluating static postural alignment through photogrammetric approaches (Azadinia et al., 2022; Porto and Okazaki, 2017; Raine and Twomey, 1997; Singla et al., 2017). Linear distances and angular measures are routinely evaluated on neutral sagittal and coronal plane photogrammetric images of the spine using standardised anatomical landmarks (Porto and Okazaki, 2017; Silva et al., 2009; Singla and Veqar, 2017). Once a person's baseline postural alignment is established, a clinician will often want to compare these data to normative values and/or use the data as part of repeated photogrammetric assessments to evaluate the efficacy of interventions aimed at altering postural alignment (Cohen et al., 2017; Silva et al., 2009; Singla and Veqar, 2017).

If comparing data to normative values in the literature, a clinician should check if the data were collected using similar methodologies. If ongoing photogrammetric assessments are required to monitor progression, a clinician should use a standardised methodology so that if any change in postural alignment does occur, they can have confidence that this change was due, at least in part, to the intervention and not because the data were collected in a different way. One important aspect of a methodology for photogrammetric assessment of postural alignment that clinicians should consider is the position of the patient's feet when standing (Porto and Okazaki, 2017).

Postural stability in an upright standing position may be affected by body mass, the height of the body's centre of mass (CoM), and the size of

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Table 1
Participant characteristics displayed as mean (SD).

Parameter	Cohort ($n = 150$)	Male ($n = 61$)	Female ($n = 89$)
Age (years)	22.5 (3.6)	22.7 (3.6)	22.5 (3.6)
Height (m)	1.71 (0.09)	1.78 (0.07)	1.66 (0.06)
Mass (kg)	70.1 (14.4)	79.1 (14.0)	63.9 (11.1)

n = Number of Participants.

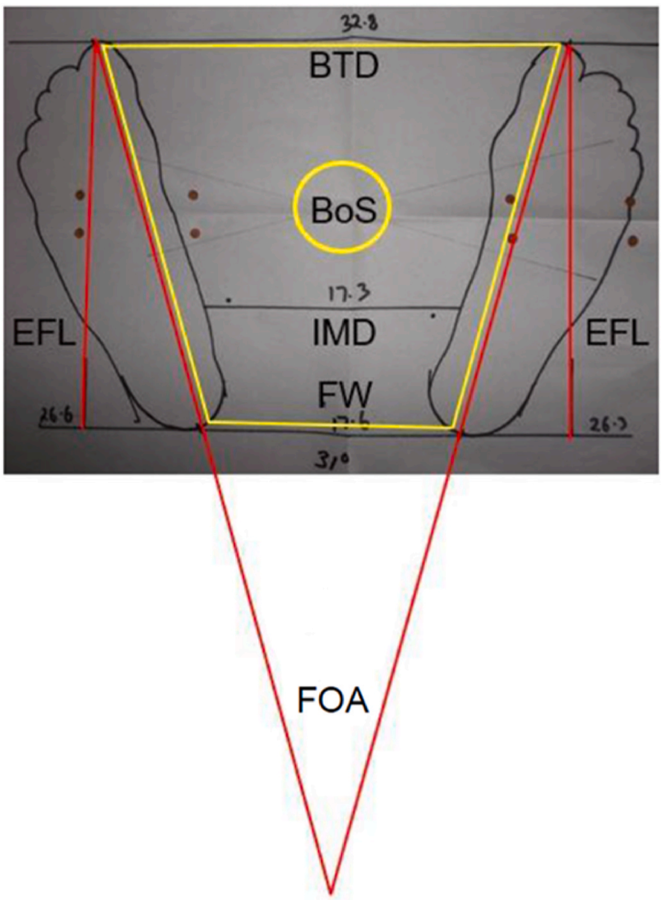

Fig. 1. Sample foot tracing with lines marked to illustrate how the three variables - FW: Foot Width, BoS: Base of Support, FOA: Feet Opening Angle - were measured. BTD: Big Toe Distance, EFL: Effective Foot Length, IMD: Inter-Malleolar distance (adapted from Chiari et al., 2002).

the body's base of support (BoS) (Hall, 2019). It is the position of a person's feet when standing that will determine the size of the BoS. A larger BoS provides greater stability because it is easier for a person to maintain their centre of mass within the boundary of a larger BoS (Hall, 2019). When in an upright standing position there is considerable inter-person variability in preferred feet position (McIlroy and Maki, 1997), consequently when assessing postural alignment through photogrammetry some studies choose to use a fixed distance between the participant's feet (e.g., de Oliveira Pezzan et al., 2011). Other studies prefer to allow people to assume their self-selected natural feet position (e.g., Raine and Twomey, 1994; Salahzadeh et al., 2014) because it is believed that this is more likely to ensure that people display their true postural alignment (Antoniolli et al., 2018).

Whilst there is some evidence that people can reliably reproduce their self-selected natural feet position within an assessment session (Kim et al., 2014), it is not known to what extent people change their natural feet position across different testing days (McIlroy and Maki, 1997). This is important for clinicians to know because they need to decide whether to permit patients to use their self-selected natural feet position during repeated photogrammetric assessment of their postural alignment. Therefore, the aim of this study is to determine the reliability of the size of the BoS derived from foot tracings of people standing with a self-selected natural feet position across three assessment sessions on different days.

2. Methods

2.1. Participants

A sample of 150 young adults were recruited from a university student population (Table 1). At the time of testing all participants were asymptomatic for any musculoskeletal and visceral problems. This was determined using a comprehensive series of standardised clinical and physical assessments as described by Daffin, Stuelcken, and Sayers (2019b). Approval for the study was obtained from an institutional Research Ethics Committee (S/14/607), and written informed consent was obtained from all eligible participants prior to the commencement of data collection in accordance with the human research ethics requirements.

2.2. Procedure

Participants attended three sessions over a period of approximately 3–4 weeks. In each session participants were required to test in bare feet. A standardized set of instructions was used. Initially participants were asked to march on the spot, raising their thighs to the horizontal five times on each side before walking forward onto a large sheet of paper that was placed on the ground in front of them. They were then asked to stop on the paper and stand in a comfortable and relaxed position with eyes looking straight ahead. A tracing of the position of the feet was then made by the lead researcher (LD).

This tracing was used to measure three variables – the Foot Width (FW), the Feet Opening Angle (FOA) (orientation angle), and the Base of Support (BoS) – using established procedures (Chiari et al., 2002; McIlroy and Maki, 1997). See Fig. 1. The FW was defined as the distance between the midlines of the two heels. The FOA was determined by constructing lines from the midpoint of the heel to the distal end of the great toe for each foot. These lines were extrapolated until they intersected. The angled formed between the two lines represented the FOA. Three measurements – the big toe distance (distance between the midpoints of the great toes - BTD), the inter-malleolar distance (the distance between the medial malleoli - IMD), and the effective foot length (the perpendicular distance from a line connecting the most posterior aspects of the heals of each foot to the midpoints of the great toes - EFL) – were used to calculate the BoS using the following equation:

$$BoS = \frac{(BTD + IMD)}{2} \times average\ EFL$$

2.3. Data analysis

Descriptive statistics were calculated and reported for the FW, FOA, and BoS across the three assessment sessions. A one-way repeated measures analysis of variance (ANOVA) was used to test for systematic bias in the BoS data. Post hoc repeated-measures ANOVA tests and pairwise comparisons (with Bonferroni adjustment) were subsequently undertaken in the event of a significant finding. If Mauchly's test indicated there was a violation in the assumption of sphericity and the Greenhouse-Geisser epsilon was below 0.75, then this epsilon was used to correct the analysis, whereas if the Greenhouse Geisser epsilon was above 0.75, the Huynh-Feldt epsilon was used (Atkinson, 2001). Given the relatively large sample size, an alpha level of 0.01 was used to determine statistical significance. Data for the BoS across the three assessment sessions are reported as mean ± 95% CI 'corrected' for

Table 2
The mean (SD) for each of the three variables measured from the foot tracings across the three assessment sessions.

	FOA (°)	FW (cm)	BoS (cm)
Session 1	9.5 (10.2)	19.4 (4.1)	503.8 (149.7)
Session 2	10.1 (11.4)	18.8 (3.8)	490.9 (138.7)
Session 3	9.4 (11.0)	18.4 (4.0)	476.0 (139.1)

FOA: Feet Opening Angle, FW: Foot Width, BoS: Base of Support.

between-subject variability (Loftus and Masson, 1994). Heteroscedasticity in the data was examined by plotting the absolute differences against the individual means and calculating the correlation (Atkinson and Nevill, 1998). There was modest heteroscedasticity present in the data so the Coefficient of Variation (CV%) was used as a measure of absolute reliability or 'agreement'. The CV% was calculated from log-transformed data (natural logarithm) (Batterham and George, 2000). Relative reliability was determined using the Intraclass Correlation Coefficient (ICC) which was calculated from the output of the one-way repeated measures ANOVA (Batterham and George, 2000). This corresponded to a two-way mixed effects model for absolute agreement. The 95% CI was also calculated. An ICC value of 0.5–0.75 indicated moderate reliability, a value of 0.75–0.9 indicated good reliability, and a value > 0.90 indicated excellent reliability (Koo and Li, 2016). The Pearson-product moment correlation coefficient (r) was used to investigate the relationship between the size of the BoS and both FW and FOA within each session. A Pearson-product moment correlation coefficient of 0.1–0.3 was considered small, 0.3–0.5 was considered moderate, 0.5–0.7 was considered large, and 0.7–0.9 was considered very large. All statistical analyses was perfomed using SPSS Version 27 (SPSS Inc., IBM, Chicago, Illinois).

3. Results

The mean ± SD for FW, FOA and BoS across the three assessment sessions are displayed in Table 2. Data for the BoS are presented graphically in Fig. 2 as mean ± 95% CI 'corrected' for between-subject variability. The one-way repeated measures ANOVA revealed a significant difference in the BoS data across the three assessment sessions ($F_{(2,285)} = 8.982$, $p < 0.001$). Pairwise comparisons further revealed that the BoS in session one was significantly different from session three (Fig. 2). The CV% for the BoS data was 15.2% and the ICC (95% CI) for the BoS data was 0.84 (0.79–0.87). There were large ($r = 0.718$–0.774) significant ($p < 0.001$) correlations between the size of the BoS and FW and moderate ($r = 0.563$–0.607) significant ($p < 0.001$) correlations between the size of the BoS and FOA within each session.

4. Discussion

The aim of this study was to determine the reliability of the size of the BoS derived from foot tracings of people standing with a self-selected natural feet position across three assessment sessions on different days. The analysis indicated some systematic bias in the BoS data with a trend for the size of the BoS to decrease across the three assessment sessions on different days (Fig. 2). Furthermore, the BoS in session three was significantly smaller than in session one. It is not clear why there was a trend for the size of the BoS to decrease across the three assessment sessions on different days, but it may represent some form of learning effect or familiarity with the testing procedures (Atkinson and Nevill, 1998; Batterham and George, 2000). It is also unclear whether this trend would continue over further assessment sessions or if it would stabilise. In general, a smaller BoS provides less postural stability because it is harder for a person to maintain their CoM within the boundary of a smaller BoS (Hall, 2019).

The ICC (95% CI) for the BoS data was 0.84 (0.79–0.87) indicating good reliability, but the relative reliability only tells us about the extent to which the participants maintained their rank order within the sample. There was considerable between participant variability in the size of the BoS, so a large ICC is possible even with poor trial to trail consistency (Weir, 2005). Therefore, the Coefficient of Variation (CV%) was used as a measure of absolute reliability or 'agreement'. The CV% for the BoS data was 15.2% indicating that 68% of the differences between assessments lie within 15.2% of the mean of the data. It is unclear whether such variation would elicit changes in photogrammetric measures of postural alignment. While there is some evidence to suggest it may not be sufficient (Antoniolli et al., 2018), it may be specific to what measurement is being taken and whether the measurement is in the sagittal or frontal plane. There was a large ($r = 0.718$–0.774) significant ($p < 0.001$) correlation between the size of the BoS and FW within each session so it is possible that measurements in the frontal plane may be more affected. Further work is required. In the meantime, if clinicians want to allow people to use their self-selected natural feet position for repeated photogrammetric assessments of their postural alignment it may be better to standardise the position of their feet by creating a

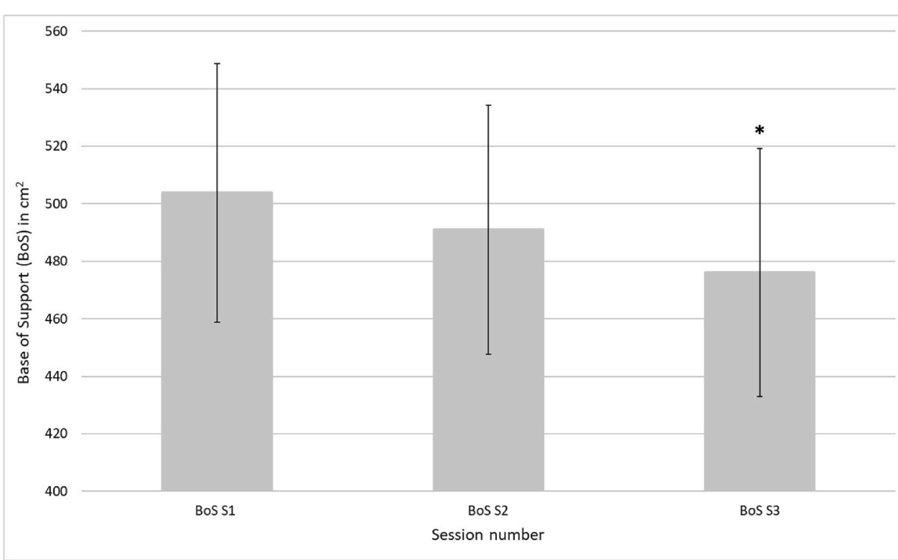

Fig. 2. Mean Base of Support (BoS) and 95% confidence intervals (corrected for between-subjects variability); * indicates significantly different from session 1 ($p < 0.001$). Please note that the scale on the vertical axis begins at 400 cm^2.

tracing of their self-selected natural feet position (Azadinia et al., 2022; Daffin, Stuelcken and Sayers, 2019a; Silva et al., 2011). This would remove feet position as a potential confounding variable by ensuring that the tracing can be used in subsequent assessments.

This methodological study had two limitations. Firstly, the sample consisted of young apparently healthy adults so care should be taken when generalizing these findings to other populations of different age and health status. Secondly, the methods used to measure the BoS required some simplifying assumptions and can therefore only be considered an estimate. In this regard, the way the BoS was measured in the current study (Fig. 1) is not consistent with how BoS is defined in the biomechanics literature – the entire area within the perimeter formed by outermost edges of a person's feet (Hall, 2019). The method used in the current study is, however, a published and accepted estimate (Chiari et al., 2002) that was consistently applied for each participant.

In conclusion, this study found that the BoS derived from foot tracings of people standing with a self-selected natural feet position varied across three assessment sessions on different days. Therefore, if clinicians want to allow patients to use their self-selected natural feet position for repeated photogrammetric assessment of their postural alignment it may be better to standardise the position of the feet, for example, by creating a tracing of a participant's self-selected natural feet position. This finding may also be important for clinicians who need to consider feet position when assessing posture stability using centre of pressure derived has measurements from a force platform (Chen et al., 2021).

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