



Full length article

Kinematic differences between neutral and flat feet with and without symptoms as measured by the Oxford foot model

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ABSTRACT

Background: Flatfoot is a common presentation in children. It is usually asymptomatic, though a small number of children experience pain. Foot function during flatfoot walking is rarely considered, yet as an activity that places significant demands on the feet, this could explain the differences in terms of symptoms.

Research question: This paper investigates walking patterns in neutral and flat feet, with and without symptoms, to determine which kinematic parameters are associated with symptomatic flat feet.

Methods: This is a retrospective study in which one hundred and six children between five and 18 years old were assessed by a physiotherapist for foot posture. Each foot was classified into one of four groups, giving 98 asymptomatic neutral, 47 asymptomatic mild flat, 29 asymptomatic flat, and 38 symptomatic flat feet with complete data for analysis. Using Plug-In-Gait and Oxford-Foot-Model markers, walking kinematics were measured, along with ground reaction forces. Median values of 14 lower limb joint angles were calculated at foot strike, midstance, and foot off. Each foot was treated as an independent sample. ANOVA and ANCOVA (with the speed-related variable relative stride length as the covariate) and post-hoc tests were used to assess whether angles differed between groups.

Results: The symptomatic flat feet showed significant differences from asymptomatic groups (most commonly the neutral feet) in terms of hip flexion, knee flexion and varus, hindfoot inversion-eversion, and forefoot abduction-adduction. Increased forefoot abduction occurred throughout stance phase in symptomatic flatfooted participants compared to all asymptomatic groups.

Significance: The results suggest that foot motion in the transverse plane is closely associated with the presence of symptoms in flat feet and that this is accompanied by changes in the kinematics of the ankle, knee, and hip.

1. Introduction

Idiopathic flexible flatfoot may present as symptomatic or asymptomatic in children; however, it is not clear from current understanding why this is the case. Although standing posture is often used to assess these feet, examining foot motion during dynamic activities such as walking that place greater demands on the feet may be more relevant.

Previous studies that used multi-segment models to investigate the kinematics of those with flatfoot during walking are summarised in Table 1 [1–7]. Most of these studies were able to detect differences in flat compared to neutral feet, suggesting that the models are appropriate for use in the flat foot population. Only the study of Hösl et al. [2] compared symptomatic and asymptomatic flatfoot. They found significantly increased dorsiflexion throughout stance at the hallux and

more range of motion during push-off at the hallux in asymptomatic compared to symptomatic flat feet. The traits of flatfoot detected in other previous studies include increased forefoot-hindfoot plantarflexion [5] and dorsiflexion [2], supination [1,2,6], and abduction [2,5]; at the hindfoot-tibia, increased eversion [1,2], plantarflexion [2], internal [5] and external [2] rotation; and increased hallux dorsiflexion [2]. Alarming, the studies provide few points of agreement and are occasionally contradictory. This may be due to different models, different (yet highly specific) groups, or different analysis methods.

Comparison of asymptomatic and symptomatic cases may lead to better treatment planning. Currently treatment is limited to symptomatic flat feet and intends to alleviate pain. Surgical treatment aims to transform these feet to resemble neutral feet. However, many flat feet are not symptomatic [2]. Since flat feet can be symptomatic or

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Table 1

Previous kinematic studies of flat and neutral feet listed chronologically. ↑ indicates an increase, ↓ indicates a decrease for the flatfooted group (or as described).

Article	Groups (age in years ± SD)	Results associated with flatfooted group
Kothari et al. 2015	41 Neutral foot (11.99 ± 2.32) 42 Flatfoot (11.85 ± 2.03)	↑ forefoot supination throughout stance ↓ peak hindfoot inversion
Hosl et al. 2014	14 symptomatic flatfoot (SF) (11.6 ± 2.0) 21 asymptomatic flatfoot (AF) (11.0 ± 2.6) 11 typically developing feet (TDF) (11.2 ± 3.1)	Hindfoot ↑ peak plantarflexion during loading response, ↓ peak dorsiflexion during stance, ↓ dorsiflexion ROM, ↓ plantarflexion ROM during push off ↑ eversion at initial contact, ↑ peak eversion in AF to TDF, ↓ peak inversion at end of stance, ↓ eversion ROM during stance ↑ external rotation at toe off Forefoot ↑ peak dorsiflexion ↑ supination throughout stance, ↑ pronation ROM during loading response ↑ abduction throughout stance Hallux ↑ dorsiflexion throughout stance in AF to TDF, ↑ dorsiflexion ROM during push off in AF to SF & TDF (all differences where not stated were found between AF and SF relative to TDF) ROM – range of motion
Shih et al. 2012	20 flexible flatfoot (9.7 ± 0.9) 10 normal (9.6 ± 1.2)	↓ peak hip internal rotation excursion ↑ peak knee internal rotation
Twomey & McIntosh 2012	12 low arched (12.2 ± 0.4) 12 Normal (12.2 ± 0.4)	↑ hip external rotation ↑ knee valgus
Levinger et al. 2010	10 normal (24.3 ± 8.7) 9 flat arched (20.1 ± 1.3)	↑ rearfoot internal rotation ↑ late stance peak forefoot plantarflexion ↑ midstance forefoot abduction ↓ terminal stance peak forefoot adduction
Twomey et al. 2010	25 normal arched (11.1 ± 1.2) 27 low arched (11.2 ± 1.2)	↑ forefoot supination (and some left or right side specific results)
Cobb et al. 2009	11 typical (25.2 ± 3.2) 11 low mobile (24.5 ± 6.1)	↑ pre-swing rearfoot inversion excursion ↓ pre-swing rearfoot eversion excursion ↓ midstance calcaneo-navicular abduction excursion

asymptomatic it can be argued that there may be structural or functional differences between the two groups. Kerr et al. [8] found structural differences during static stance between flat and neutral feet (increased hindfoot eversion, forefoot supination, and forefoot abduction), some of which were more pronounced in symptomatic cases (forefoot abduction and hindfoot eversion). The paper highlighted points for further attention; however, an exclusive threshold or feature was not identified. Walking may show characteristic differences between symptomatic and asymptomatic flat feet that could potentially help with treatment planning, since symptomatic flatfoot participants may demonstrate aversion strategies to avoid excessive loading and damage.

This paper investigated whether kinematic differences exist between populations of neutral feet and flat feet (with and without symptoms). Since it has been suggested that moderate and severe flat foot is associated with anterior knee pain and intermittent low back pain [9], we measured the kinematics of the entire lower limb – not just the foot – so that we could identify any gait deviations secondary (or compensatory) to altered kinematics at the foot. The null hypothesis was that no difference exists between the walking kinematics of children with neutral feet, flat feet without symptoms, and flat feet with symptoms.

2. Methods

The children included in the present study were all between 5 and 18 years old (Table 2). The asymptomatic children were recruited as part of a larger study of typical gait in children. The symptomatic children were identified from patient records in our Gait Laboratory approved for research use. All patients had a clinical referral because of idiopathic flatfoot. Symptoms and their frequencies of occurrence in this group were: foot pain (78%), ankle pain (28%), knee pain (17%), hip pain (11%), tendo-Achilles pain (14%), fatigue (17%), balance problems (22%), and developing or present midfoot break (55%). Collection of data and use of patient data was approved by the regional ethics board, and all participants or parent/guardians provided signed consent.

The hind-, mid-, and fore-feet of the asymptomatic volunteers were

assessed visually during standing by a physiotherapist, and each foot was subsequently assigned to one of three groups: asymptomatic “neutral” (AN), where no serious deviation from normal was noted; asymptomatic “mild” (AM), where a pronated rear foot (as assessed from a posterior aspect) and flattened arch were noted, but were described as mild; and asymptomatic “flat” (AF), where a pronated rear-foot and flattened arch were noted. All symptomatic patients had bilateral symptomatic flatfoot (SF). All subjects were assessed by one of three physiotherapists, who routinely participated in an audit of inter-rater reliability as part of the annual accreditation process of our gait laboratory.

Retro-reflective markers (radius 5 mm) were attached to the feet and limbs of the children at known anatomical landmarks including those of the Oxford Foot Model (OFM) and Plug In Gait (PIG) model. Twelve infra-red cameras (Vicon-MX, Oxford, UK) sampling at 100 Hz were used to track the marker positions. Data was recorded during three seconds of quiet standing and during walking trials approximately five metres in length. A minimum of three walking trials were recorded per child with data from one left and one right stance phase extracted from each trial. For each subject the trials were processed using Vicon Nexus software (Vicon Motion Systems Ltd.). A Woltring filtering algorithm was used [10] on the trajectory data. Thigh-wand marker offsets were iteratively determined with the assumption of minimal ab-/ad-duction occurring at the knee [11].

Three events were selected for statistical testing: foot strike, mid-stance, and foot off, all of which were determined from ground reaction force (GRF) data collected during the walking trials at 1000 Hz using three AMTI forceplates (Advanced Mechanical Technology, Inc., Watertown, MA). These time points were chosen because they relate to different functions of the foot (preparation for weight acceptance, maximal weight bearing, and push-off). Midstance was defined as the local vertical GRF minimum. The OFM was used to describe knee, ankle, midfoot, and hallux angles and the conventional PIG lower-limb model to describe the hip kinematics. The value of each angle (three at each of the hip, knee, hindfoot-tibia, and forefoot-hindfoot, and two at hallux-forefoot) at each of the three events was recorded. The median of these values (for the three or more trials) was taken as representative of

Table 2

Anthropometric data for children included in the study. F = female, M = male. Age, height, and weight are given as mean (standard deviation). AN = asymptomatic neutral foot, AM = asymptomatic mild flatfoot, AF = asymptomatic flatfoot, SF = symptomatic flatfoot.

Group	Number of participants		Sex	Age (years)	Height (m)	Weight (kg)	Foot group & sample size <i>n</i>
Asymptomatic	87	53	33 F, 20 M	10.7 (3.7)	1.43 (0.24)	37.4 (17.2)	AN 98
		27	11 F, 16 M	10.8 (3.5)	1.44 (0.22)	37.4 (16.7)	AM 47
		17	9 F, 8 M	9.6 (3.2)	1.39 (0.22)	34.9 (17.5)	AF 29
Symptomatic	19		12 F, 7 M	11.4 (2.2)	1.46 (0.16)	38.8 (14.3)	SF 38

Note that the total number of asymptomatic participants (87) is less than the total number of participants in the asymptomatic subgroups (97) because 20 participants had feet with different classifications (for example, left foot AN, right foot AM). Note also that the number of asymptomatic feet included in the study does not equal twice the number of participants since the data sets for a few feet were incomplete.

the individual foot (at each event and anatomical location), leaving 14 kinematic angles for analysis. Separately and additionally, for each subject, a representative trial was selected to allow a visual comparison of stance phase between groups. This required creating a cubic spline interpolation of the original curves to normalize the number of frames. The SMaRT method was used to select the representative trial [12]. This repeatable method relies on principal component (PC) analysis of each measure for each subject, then minimization of the sum of the Euclidean distance from median to trial PC-score. Data processing was carried out using the Matlab R2011b software package (The MathWorks Inc., Natick, MA). Temporal parameters (stride length, stride duration, and timing of midstance as a percentage of stance) were also calculated, along with relative stride length (stride length divided by leg length) which accounts for differences in height between subjects.

Statistical differences were tested by ANOVA using SPSS PASW statistics 18 (SPSS Inc., Chicago IL). Each foot was treated as an independent sample. All variables were normally distributed, but equality of variance between groups was not present for each angle. For consistency and robustness, significant differences between groups were required to meet the criteria of two post hoc tests: one which assumed the variances to be equal (Tukey) and one which did not (Games Howell). The level of significance was taken to be $\alpha = 0.05$.

3. Results

The children with symptomatic flat feet walked significantly more slowly than the other children (at $1.23 \pm 0.24 \text{ ms}^{-1}$, compared to $1.36 \pm 0.16 \text{ ms}^{-1}$ for the asymptomatic group). The driving parameter for this was relative stride length which was reduced in SF (1.47 ± 0.22 , compared to 1.63 ± 0.14 , 1.69 ± 0.15 , and 1.63 ± 0.20 in the AN, AM, and AF groups, respectively). Stride duration (AN $0.89 \pm 0.13 \text{ s}$, AM $0.92 \pm 0.11 \text{ s}$, AF $0.89 \pm 0.13 \text{ s}$, SF $0.95 \pm 0.08 \text{ s}$) and the timing of midstance as a percentage of stance phase (AN $46\% \pm 14\%$, AM $49\% \pm 5\%$, AF $47\% \pm 4\%$, SF $46\% \pm 3\%$) were consistent across groups. Given these results, it was decided to test post-hoc for statistical differences in the kinematic variables using ANCOVA with relative stride length as the covariate.

Significant differences in kinematics between the groups occurred at the hip, knee, hindfoot-tibia, and forefoot-hindfoot, but not at the hallux-forefoot (Table 3, Fig. 1, Supplementary Figures 1 and 2). Of the 18 kinematic variables identified by ANOVA as significant, only nine of these remained significant when relative stride length was taken into account by ANCOVA (Table 3). These were: hip flexion at foot strike, knee flexion at midstance and foot off, knee varus at midstance, hindfoot-tibia inversion at footstrike and midstance, and forefoot-hindfoot adduction at footstrike, midstance, and foot off. Only these nine variables will be considered in detail in the remainder of the paper. At none of the time points studied was the AM group significantly different from the AN group.

At *foot strike*, the AF group had a modest increase (4°) in hip flexion and more (3°) forefoot abduction compared to the AN group. The most noticeable difference (of up to 9°) between the SF group and the

asymptomatic groups was the abduction of the forefoot relative to the hindfoot. The SF group also had slightly more (4°) hindfoot-tibia eversion than the AN group.

At *midstance*, the AF group had increased forefoot-hindfoot abduction (3°) compared to AN. The SF group differed from the AN group in several ways – increased knee flexion (5°), increased knee valgus (3°), increased hindfoot-tibia eversion (4°), and increased forefoot-hindfoot abduction (8°). The SF group's forefoot-hindfoot abduction also differed from AF by 5° .

At *foot off*, the AF group had less forefoot-hindfoot adduction (4°) than AN, while the angular differences between the SF and asymptomatic groups in knee flexion and forefoot-hindfoot abduction were much larger (up to 8° and 13° , respectively).

4. Discussion

Significant kinematic differences between the groups studied were found at footstrike, midstance, and foot off. Around half these differences could be explained by taking into account the walking speeds of the participants (as indicated by relative stride length, which was reduced in the symptomatic group). The remaining significant results, when considered in detail, were found to be predominantly between the symptomatic and the asymptomatic neutral foot groups.

4.1. Comparison with previous studies

Forefoot abduction throughout stance was associated with symptomatic flatfoot in the present study; at foot strike and foot off it was also associated with asymptomatic flat compared to neutral feet (in agreement with Levinger et al. [5] and similar to Hösl et al. [2]). This suggests that forefoot abduction in the AF group may be an indication that symptoms will develop in these subjects, and monitoring may be warranted. The study of Moraleda and Mubarak [15] supports this idea – they found the most profound differences relating to the onset of symptoms in the transverse plane, but in the form of the talo-navicular coverage angle, with the difference (up to 13° between means) most pronounced at foot off.

Increased hindfoot eversion was associated with SF at foot strike and midstance (also found by Hösl et al. [2]). While significant increases in eversion have been previously observed in both asymptomatic and symptomatic flatfoot during static stance [8], increased eversion was not evident during walking in the asymptomatic group in this study.

Differences between the symptomatic group and the AN group in this study occurred not only at the foot, but also at the hip and knee, suggesting the presence of gait deviations secondary (or compensatory) to altered kinematics at the foot. At midstance, SF had significant knee valgus compared to AN. A previous kinematic study found knee valgus to be associated with flatfoot [4], and it is commonly referred to in textbooks [13,14]. From midstance onwards, increased knee flexion was associated with symptomatic flatfoot. There are several potential reasons for these findings: poor muscle strength, pain-avoidance, or

Table 3

Means and standard deviations (in degrees) and results of ANOVA and ANCOVA (with relative stride length as the covariate) statistical tests. p values significant at the 0.05 level are shown in bold. Square brackets indicate between which groups Tukey and Games Howell post-hoc testing revealed statistically significant differences ($p < 0.05$). FE – femur, TB – tibia, AN – Asymptomatic Neutral feet, AM – Asymptomatic Mild flat feet, AF – Asymptomatic Flat feet, SF – Symptomatic Flat feet

Segment Positive action	Foot Strike			Midstance			Foot off			Segment Positive action	Foot Strike			Midstance			Foot off				
	mean±sd	anova	ancova	mean±sd	anova	ancova	mean±sd	anova	ancova		mean±sd	anova	ancova	mean±sd	anova	ancova	mean±sd	anova	ancova		
Hip Flexion	AN	33±6			7±7			-6±7			AN	8±9			3±10			5±9			
	AM	35±5			7±6			-7±6			HF-TB	AM	10±8			5±8			7±9		
	AF	37±6			10±6			-3±7			Internal	AF	8±5			5±6			7±7		
	SF	34±7			11±8			-1±11			Rotation	SF	9±8			5±8			0±9		
	All	34±6	.013	.015	8±7	.004	.050	-5±8	.001	.115	All	8±8	.572	.584	4±9	.306	.261	5±9	.005	.105	
Hip Adduction	AN	-2±4			4±3			-6±3			AN	0±6			-4±5			3±7			
	AM	-2±3			5±3			-5±3			HF-TB	AM	-2±5			-6±6			3±6		
	AF	-1±3			5±3			-5±3			Inversion	AF	-3±5			-7±5			3±4		
	SF	-1±3			5±3			-4±3			SF	-4±6			-8±7			0±7			
	All	-2±3	.121	.438	4±3	.326	.234	-5±3	.025	.219	All	-2±6	.017	.005	-5±6	.002	.001	3±7	.134	.091	
Hip Rotation	AN	-9±7			1±7			1±7			AN	-3±4			1±4			-9±5			
	AM	-10±6			-1±7			-1±7			FF-HF	AM	-2±4			1±4			-10±4		
	AF	-10±8			0±8			1±6			Dorsiflexion	AF	-3±4			2±4			-9±3		
	SF	-12±6			-3±9			0±8			SF	-4±4			1±5			-8±6			
	All	-10±7	.317	.599	0±8	.071	.058	1±7	.336	.142	All	-3±4	.546	.779	1±4	.897	.828	-9±5	.241	.756	
FE-TB Flexion	AN	4±4			6±5			31±6			AN	1±6			0±5			8±6			
	AM	5±5			6±5			31±7			FF-HF	AM	0±5			0±5			8±5		
	AF	6±4			7±6			33±7			Adduction	AF	-2±4			-3±4			4±5		
	SF	7±5			11±5			39±7			SF	-8±8			-8±8			-5±9			
	All	5±5	.046	.175	7±5	.000	.031	33±7	.000	.002	All	-1±7	.000	.000	-2±7	.000	.000	5±8	.000	.000	
FE-TB (knee) Varus	AN	-1±3			0±3			0±3			AN	5±5			4±5			3±5			
	AM	-1±3			-1±3			-1±4			FF-HF	AM	8±6			6±6			4±7		
	AF	-2±2			-1±3			-1±4			Supination	AF	7±7			7±7			5±6		
	SF	-3±4			-3±4			-1±6			SF	8±8			7±7			6±8			
	All	-1±3	.008	.063	-1±3	.004	.039	0±4	.197	.203	All	7±6	.062	.069	5±6	.053	.056	4±6	.033	.125	
FE-TB (knee) Rotation	AN	-16±11			-14±12			-14±10			AN	11±10			-2±9			14±13			
	AM	-16±10			-12±9			-13±9			HX-FF	AM	11±12			0±9			17±16		
	Internal	-13±9			-12±8			-12±9			Dorsiflexion	AF	8±10			-4±8			14±14		
	Rotation	-11±10			-9±9			-8±10			SF	10±12			-2±10			21±16			
	All	-15±11	.085	.390	-12±11	.260	.433	-13±10	.024	.067	All	10±10	.483	.478	-2±9	.162	.182	16±15	.108	.077	
HF-TB Dorsiflexion	AN	-2±6			6±4			-11±6			AN	-7±7			3±7			-6±8			
	AM	-1±3			6±3			-10±4			HX-FF	AM	-6±6			3±6			-4±10		
	AF	-2±3			6±3			-9±5			Adduction	AF	-5±7			3±7			-2±7		
	SF	-3±5			5±4			-6±6			SF	-4±9			5±8			-4±11			
	All	-2±5	.665	.332	6±4	.591	.528	-9±6	.001	.102	All	-6±7	.174	.269	3±7	.317	.572	-5±9	.213	.215	

instability, as discussed below.

4.2. Linked motions

The foot has two main functional modes: flexible and rigid. The flexible mode allows adaptation to uneven surfaces during pronation, whereas the rigid mode is required to provide a stable structure after heel rise towards push off and is associated with supination. During the flexible mode, hindfoot eversion (a feature of flatfoot) allows an increased dorsiflexion range of motion at the midtarsal joint [16]. If the foot remains in flexible mode after heel rise, there is no support against which the soleus and gastrocnemius can work to provide propulsive force as the calcaneus can rotate relative to the tibia. This may result in strain of the passive structures of the foot, potentially leading to exacerbation of the condition and symptoms such as foot pain, plantar fasciitis, fatigue, and instability.

The symptomatic flat feet in the present study were more everted at the ankle and therefore potentially in a less stable posture that was not able to provide the rigid lever required for push off. This instability may be compensated for by delaying and reducing hindfoot-tibia plantarflexion, in order to delay the advancement of the trunk over the stance leg, to limit the load-bearing requirements of the arch and forefoot. Timing of the late stance peak in hindfoot-tibia dorsiflexion was assessed in order to verify this assumption, and was found to be significantly delayed in the SF group (77% stance), compared to the AM (65%), AF (64%) and AN (69%) groups.

The anatomy of the ankle-joint complex results in coupling between ankle (hindfoot-tibia) and midfoot (forefoot-hindfoot) [17,18]. Thus, the persistent forefoot abduction of the symptomatic flat feet may lead to a difficulty inverting the hindfoot during walking. The delayed peak dorsiflexion in late stance may further interfere with supination initiation. This may require further effort from the supinators, leading to

fatigue and overwork. Thus, in the symptomatic population, forefoot abduction may lead to poor quality of propulsion (suggested by [19]), instability during single support, and necessitate kinematic adaptations at the foot and more proximally.

4.3. Limitations

As with many human studies, a limitation is that the sample may not be representative of the population, and therefore the results may not apply to other groups, particularly those of different ethnic or socio-economic backgrounds. Recruitment is important to results, and although the asymptomatic group was recruited for a clinical gait laboratory's normal database and is intended to be a good representation of the general population, members of the symptomatic group are likely to have had relatively severe symptoms since they were patients referred to a gait analysis clinic. Another key limitation is that the study is cross-sectional. While links between phenomena can be highlighted, causality cannot be demonstrated. Furthermore, the identification of kinematic differences between asymptomatic groups relies on a subjective grouping of subjects by a physiotherapist. The lack of differences in walking between neutral and mild flat feet may indicate that the visual foot assessment of our physiotherapist is only relevant to a static foot posture. Future work could include a more objective classification, or quantitative information such as that obtained from imaging. Finally, the age range included in the study (5–18 years) is relatively large. While there is evidence that most children have developed an arch by age five [20], it may be that there was some variation in our study group.

Considering other features of the joint angle curves in Fig. 1, such as extreme values and ranges of motion, could lead to further insights into differences between symptomatic and asymptomatic flat feet; however, using peak angles for making comparisons between groups is not

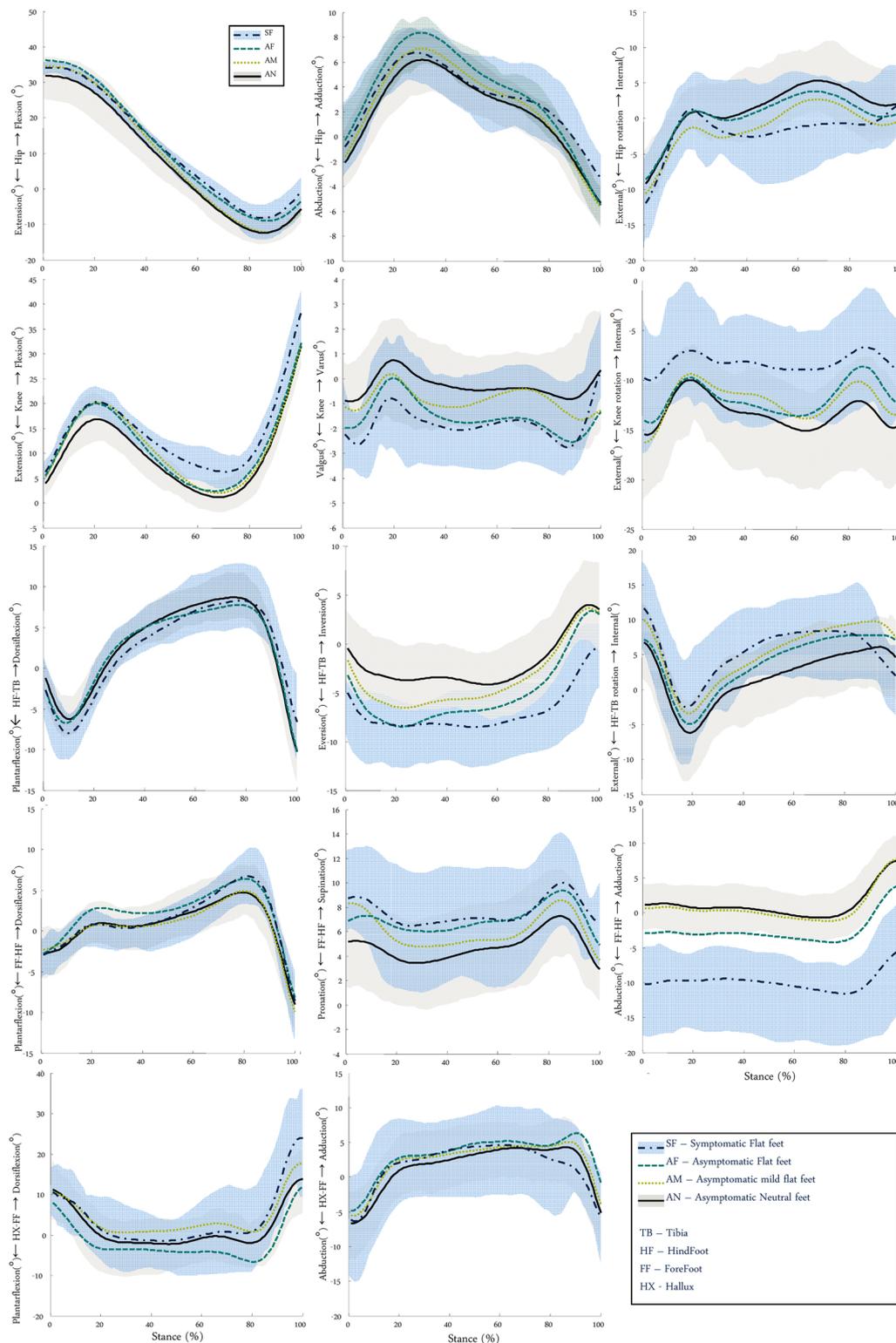


Fig. 1. Continuous data over stance phase. The thick line is the group mean; the shaded area is the interquartile range.

without its problems: some kinematics graphs have obvious peaks, but this is not always the case, and the timing of the peaks would also have to be considered. We chose to make comparisons between groups at specific time points related to the weight-bearing function of the foot (foot strike, midstance, foot off), but this approach is also not clear-cut since there are multiple definitions of “midstance” in the literature (see, for example, [21]). Another option would be to compare the joint angle curves as a whole using, for instance, confidence bands and

bootstrapping methods [22]. Regardless of the method used, it is important to relate the results back to foot anatomy and to identify results that are clinically relevant.

Finally, it could be argued that including both feet from each participant in the analysis artificially inflates the sample size for the study. This was investigated by re-running the ANOVA analysis on the 42 kinematic variables listed in Table 3 using data from the left feet only and from the right feet only. This exercise showed that, of the nine

variables identified as significant by ANCOVA, four of these (knee flexion at foot off and forefoot-hindfoot adduction at footstrike, midstance, and foot off) had a significant ANOVA result regardless of whether both feet or only one foot was included in the analysis. Three (knee flexion and knee varus at midstance and hindfoot-tibia inversion at midstance) had a significant result when both feet and either the left or right foot was included in the analysis. The other two variables (hip flexion and hindfoot-tibia inversion at footstrike) were significant only when both feet were included in the ANOVA. (See Supplementary Table 1 for the full set of comparisons.) The implication is that the last two results should be treated with caution until their significance is confirmed or refuted in future studies.

4.4. Conclusions

Foot motion in the transverse plane is closely associated with the presence of symptoms in flat feet, with the symptomatic flatfooted group having significantly increased forefoot abduction throughout the stance phase compared to all asymptomatic groups. The symptomatic flat feet also showed significant differences from asymptomatic groups (most commonly the neutral feet) in terms of hip flexion, knee flexion and varus, hindfoot inversion-eversion, and forefoot abduction-adduction.

Declarations of interest

None.

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Each of the authors has read and concurs with the content in the final manuscript. The material within has not been and will not be submitted for publication elsewhere except as an abstract.

Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the

online version, at <https://doi.org/10.1016/j.gaitpost.2018.10.015>.

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