Are flexible flat feet associated with proximal joint problems in children?

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Keywords: flat foot, kinematics, kinetics, ground reaction force, symptoms

A. Kothari is supported by a research training fellowship from the charity Action Medical Research (Ref: GN2019).

Accepted for publication in *Gait & Posture* on 7 February 2016

Abstract

The role of flexible flat feet (FF) in the development of musculoskeletal symptoms at joints proximal to the ankle is unclear. We undertook an observational study to investigate the relationship between foot posture and the proximal joints in children. It was hypothesised that reduced arch height would be associated with proximal joint symptoms and altered gait kinematics and kinetics particularly in the transverse plane at the hip and knee. Ninety-five children between the ages of 8-15 were recruited into this ethically approved study. Foot posture was classified using the arch height index (AHI). The frequency of knee and hip/back pain was documented, and each child underwent three dimensional gait analysis. Reduced arch height was associated with increased odds of knee symptoms ($p < 0.01$) and hip/back symptoms ($p = 0.01$). A flat foot posture was also significantly associated with a reduction in the second peak of the vertical ground reaction force ($p = 0.03$), which concomitantly affected late stance hip and knee moments. A reduced AHI was also associated with increased pelvic retraction and increased knee valgus in midstance. No kinematic and kinetic parameter associated with a flat foot posture related to increased proximal joint symptoms in the FF group. Children with a flatter foot posture are more likely to have pain or discomfort at the knee, hip and back; however, the mechanisms by which this occurs remain unclear. Treating FF without explicit understanding of how it relates to symptoms is difficult, and further work in this area is required.

1. Introduction

Flexible flat feet (FF) in children are common, with a reported prevalence of between 2.7% and 18.1% [1, 2]. Defined as having reduced medial longitudinal arch height and increased hindfoot eversion, FF can cause foot and ankle symptoms and functional impairment in some children [3, 4]. The role of foot posture in the development of musculoskeletal symptoms at joints proximal to the ankle, however, is less clear, particularly in children.

As the majority of weight-bearing activities involve the closed chain coupling of the foot, ankle, knee and hip, it is conceivable that a change in foot posture could lead to a change in the posture and motion of the proximal joints. It has been proposed that excessive hindfoot eversion throughout the gait cycle is coupled with excessive internal rotation of the tibia [5]. This in turn would lead to increased altered shear stresses on the knee articular contact areas [5]. Based on the observations of Souza et al. [6], an everted hindfoot may also be coupled with increased internal rotation of the hip, which could detrimentally alter the lever arm of the hip abductors and increase the Q-angle at the knee, overloading the lateral patellar facet. At the spine, studies have demonstrated that arch height can affect the magnitude of lumbar accelerations during running [7], pelvis alignment [8] and gluteal and erector spinae activity [9]. These factors could all relate to the generation of symptoms.

Some clinical studies in adults have associated a flat foot posture with knee and lower back pain [10, 11]. However there is still little evidence that FF are contributory to proximal joint symptoms in children and that the proposed pathomechanic theories are correct.

Thus, the objective of this study was to investigate the relationship between arch height and the proximal joints in children. Our primary aim was to determine the association of proximal joint symptoms with foot posture. The secondary aim was to identify, using three dimensional gait analysis (3DGA), any biomechanical factors that might explain how symptoms could be caused. The hypotheses of this study were firstly that children with reduced arch height were more likely to have proximal joint symptoms, and secondly, that children with symptoms and reduced arch height would demonstrate altered gait kinematics and kinetics particularly in the transverse plane at the knee and hip.

2 Methods

2.1 Participants

Ninety-five children between eight and fifteen were recruited into this ethically approved study (ref:- OxREC 12/SC/0334)(45 female, 50 male; age = 11.0 ± 2.9). This age range was used to ensure that developmental flat feet were excluded and to represent the age of patients commonly referred to our hospital with flat feet. Inclusion criteria were either a neutral (NF) or flat foot posture based on clinical assessment and no concurrent use of in-shoe orthotics. Exclusion criteria were any other co-existent musculoskeletal pathologies or previous spinal/lower limb surgery. The majority of the FF group were recruited from the orthopaedic or orthotic clinic and were referred because of their FF (either symptomatic or asymptomatic). The majority of the NF controls were recruited from the community. A convenience recruitment approach was utilised to have similar NF and FF group sizes.

2.2 Foot posture classification

As the clinical assessment of foot posture is non-standardized, purely categorical and has poor reliability, the arch height index (AHI) as proposed by Williams and McClay [12] was used as a continuous objective measure of foot posture. This measure has been shown to have good to excellent inter- and intra-rater reliability. The AHI is calculated as the arch height at 50% foot length divided by the truncated foot length (length of foot minus toes). To ensure consistency the first author (AK) performed all measurements.

2.3 Equipment and procedure

As part of a standard clinical assessment, the flexibility of each child was evaluated using the Lower Limb Assessment Score (LLAS) [14], and body mass index (BMI) was calculated. Each child was also asked about the frequency of knee, and hip/back pain/discomfort during the last month using a simple 5 point Likert scale (never = 1, rarely = 2, sometimes = 3, often = 4, on a daily basis = 5).

Each subject underwent 3DGA using a 12 or 16 infra-red camera system (Vicon MX/T40, Vicon, Oxford, UK). The Oxford Foot Model (OFM) [15] and plug-in-gait (PiG) [16] marker sets were used and lower limb marker trajectories were captured at 100 Hz. Ground reaction force data were measured at 1000 Hz using three AMTI force plates (OR6, Advanced Medical Technology, Inc. Watertown, MA, USA). After a static calibration trial, subjects undertook barefoot walking at self-selected speed along a 10 m walkway. All data were collected using Nexus software v1.7 (Vicon, Oxford, UK). Data collection continued until a minimum of three clean force plate strikes were obtained for each foot.

2.4 Data processing, analysis and statistics

The distribution of proximal joint symptom scores was skewed, thus to adhere to regression analysis assumptions, these were converted to binary variables: either the presence (Likert score of 2 to 5) or absence (Likert score of 1) of symptoms. The presence of hip/back symptoms was pooled as participants found it difficult to differentiate between anatomical regions. Logistic regression was used to assess the effect of the predictors AHI (used as a continuous variable), age, BMI, sex and flexibility on the presence of symptoms. To make the results more intuitive AHI was converted to a percentage and inverted such that a larger value represented a flatter foot.

A Woltring filtering algorithm was used to reduce marker trajectory noise (predicted mean square error setting of 20 mm^2). Oxford Foot and PiG models were run in Vicon Nexus software v1.7 (Vicon, Oxford, UK). Lower limb kinematics and internal joint moments, as well as vertical ground reaction force data (VGRF) were exported to Matlab R2012b (The Mathworks Inc., Natick, USA) and analysed using the Zoosystem toolbox [17]. The VGRF was included in analysis as it was deemed that this would be helpful in interpreting any kinetic differences related to arch height. Kinetics and VGRF were normalized by subject body weight. Traces were inspected for each subject with removal of inconsistent trials. From the remaining trials, a representative trial per subject was selected (defined as the trial with the minimum root mean squared difference from the averaged data from all trials from that subject). Kinematic traces for the whole gait cycle were normalized to 101 data points, as were kinetic and VGRF traces for the stance phase of gait. Walking speed was computed by taking the average of the time derivative of the sacral marker position in the direction of progression over a number of steps. Walking speed was not normalized as per the reasons outlined by Dixon et al [18].

Due to the large amount of gait data, the first stage of analysis involved inspection of the gait curves to identify regions of interest (ROIs) to be explored in further detail. This necessitated the provisional dichotomous grouping of data by foot type (NF or FF) based on AHI cut-off values derived from Butler et al. [13] (low arch (< 0.31), neutral arch (0.31 to 0.37) and high arch (> 0.37). Based on these values, 48 children were classed as FF and 47 as NF. Data were pooled within groups for VGRF and PiG joint angles and moments, and mean curves and 95% confidence interval bands for the FF and NF groups were plotted. Regions of interest were identified on the gait graphs where potentially significant differences between FF and NF groups were observed. These were defined as areas where a section of mean curve of one group was not within the 95% confidence band of the other. This also had to correspond to a readily defined point in the gait cycle. The points included local maxima (MAX), minima (MIN) and for kinematic analysis also included heel strike (HS), midstance (MID) and toe-off (TO). In the kinematic analysis where MAX or MIN values were located near the end of the stance phase, values at TO were used in preference. Midstance was defined as 50% of the stance phase.

The relationship between discrete ROIs and foot posture defined by the continuous AHI was assessed using stepwise multiple linear regression controlling for the potential confounding effects of age, gender, and BMI (not for VGRF or kinetics since these were normalized by body weight). As VGRF and kinetic variables are sensitive to walking speed it was added into the regression analysis as a potential confounding variable.

Student's t-test analysis was then used to determine if the gait kinematic and kinetic ROIs identified as having a significant association with the continuous AHI differed significantly between those with and without symptoms in the FF group.

Alpha was set at 0.05 to define significance. All assumptions for logistic and linear regression were met. Statistical analysis was undertaken using Stata v13.0 (Statacorp LP, Texas, USA).

3. Results

3.1 Relationship between arch height and proximal joint symptoms

Thirty-seven of ninety-five children had knee symptoms (39%) and thirty-three had hip/back symptoms (35%). There was a significant association between AHI and knee symptoms with odds ratio (OR) of 1.33 (95% CI: 1.10-1.61, p <0.01). A significant association was also observed between AHI and hip/back symptoms with OR of 1.22 (95% CI: 1.03-1.45, p = 0.01). Of the other predictors BMI was also found to have a significant association with hip/back symptoms with OR of 1.23 (95% CI: 1.03-1.47, p = 0.02). Increased LLAS scores did not relate to increased odds of proximal joint symptoms.

3.2 Relationship between foot posture and gait parameters

i) Vertical ground reaction force

Visual inspection of the pooled by group VGRF graphs (Figure 1) demonstrated two regions of interest, the trough between peaks (VMin) and the second peak (VMax2). Regression analysis demonstrated that of these only VMax2 had a significant association with AHI ($p = 0.03$) (Table 1), such that a low AHI was associated with a reduction in VMax2.

ii) Lower limb kinematics

Kinematic traces between FF and NF groups were generally similar, aside from a few regions of interest highlighted in Figure 2. Of these, peak pelvis external rotation (PERMax) and knee varus at midstance (KVarMid) were significantly associated with AHI ($p = 0.03$ and $p = 0.02$ respectively) (Table 1). Thus a flatter foot posture was associated with increased pelvic external rotation (retraction) in late stance, and increased knee valgus at midstance.

iii) Lower limb kinetics

Visual inspection of kinetic graphs demonstrated larger differences between FF and NF groups, particularly in late stance with seven discrete ROIs identified (Figure 3). Of these regions, regression analysis demonstrated that three were significantly associated with AHI (Table 1). Thus a low AHI was associated with a reduced peak hip extension moment (HExtMax, $p <0.01$), second peak knee varus moment (KVarMax2, $p = 0.01$) and peak knee internal rotation moment (KIntMax, $p = 0.01$).

The potential confounding effect of age, gender, BMI and walking speed on the relationship between gait parameters and AHI is also summarised in Table 1. Of these variables age was noted to have statistically significant associations with a number of kinematic, kinetic and VGRF variables. Gender and BMI were only significantly associated with dynamic knee varus/valgus. As expected walking speed was significantly associated with the majority of VGRF and kinetic variables.

3.3 Relationship between kinematic/kinetic parameters and proximal joint symptoms.

From the analysis presented earlier, a shortlist of two kinematic and three kinetic variables were found that had significant associations with AHI. In the FF group alone, none of these variables had a significant relationship with the presence or absence of lower limb symptoms (Table 2).

4. Discussion

The purpose of this study was to investigate the relationship between foot posture and the proximal lower limb joints. The first stage was to explore the association between a flat foot posture and proximal joint symptoms. Subsequently the aim was to establish a potential causative pathway from a flattened arch to abnormal biomechanics, with these being directly associated with proximal joint symptoms. Whilst it was possible to demonstrate the association between a reduced AHI and lower limb symptoms, and also between AHI and abnormal lower limb biomechanics (particularly hip and knee kinetics), the biomechanical parameters identified did not seem to relate to the presence or absence of proximal joint symptoms.

4.1 Foot posture and proximal joint symptoms

Arch height index was a significant predictor of knee symptoms and hip/back symptoms in the study participants. Based on the odds ratios presented in the results, in absolute terms for every 0.01 reduction in AHI, the odds of having knee symptoms were increased by just under a third. The same phenomenon was observed with hip/back symptoms. The link between foot posture and proximal joint symptoms presented in this study is consistent with a common perspective in clinical practice, and observation in adult populations [10, 11].

In this study it was also noted that increased BMI was associated with an increased risk of hip/back pain. The association between BMI and musculoskeletal symptoms is well established in the literature; indeed Stovitz et al. [19] demonstrated that the back was the most common site of pain in overweight children. This gives another potential avenue for therapeutic intervention in an overweight child with FF.

4.2 Relationship between foot posture and gait parameters

i) Vertical ground reaction force

In normal gait the second GRF peak is generally of a similar magnitude to the first peak. It has been suggested that reduction in the VMax2 as observed in many children with cerebral palsy, represents a degree of failure to adequately decelerate the body COM in late stance, and has been coined ‘decelerator deficiency’ [20]. Williams et al. [20] believed that in cerebral palsy this can represent instability or weakness and may relate to the severity of the pathology. The significant association between a reduction in VMax2 and a lower AHI in this study may be representative of foot and ankle instability due to impairment of the midtarsal locking mechanism in late stance to provide an adequate lever to push off against. Alternatively this behaviour may be adaptive to reduce symptoms or discomfort caused by the FF.

ii) Lower limb kinematics

As a flat foot posture is associated with increased hindfoot eversion in the static and dynamic settings, it was hypothesized that increased dynamic internal tibial rotation would also be observed. This however was not the case, with little difference in knee rotation between the NF and FF groups for the majority of stance. In fact, it initially appeared that the FF group had reduced peak internal knee rotation, although this relationship was not statistically significant. This contrasts with the findings of Levinger et al. [5] who did demonstrate increased tibial internal rotation with an everted hindfoot in a population of adults with medial knee osteoarthritis. However, that cohort is a significantly different population to the one investigated in this study. In comparison to the literature from similar populations, neither Twomey et al. [21] nor Shih et al. [22] demonstrated increased internal knee rotation in their FF populations. Twomey et al. [21], however, did observe increased external hip rotation in their FF group, which contradicts the observations of Souza et al. [6] who found increased hindfoot eversion to be associated with increased internal hip rotation. In this study no relationship was noted between hip rotation and foot posture.

At the pelvis a flatter foot posture was associated with increased peak external pelvis rotation in late stance. The significance of this finding is unclear, but it may be related to proximal adaptation to counteract the adverse effect of lever arm dysfunction associated with FF.

A flatter foot posture was also associated with increased knee valgus in midstance. The reason why this relationship was observed may be in part explained by the findings of Guichet et al. [23] who demonstrated that hindfoot eversion leads to greater lateral deviation of the lower limb mechanical axis. At the knee this could drive a degree of valgus knee deformity. The effect size of the relationship between AHI and knee valgus reported was however small, and of questionable clinical significance.

iii) Lower limb kinetics

It was again hypothesized that the majority of differences in joint moments would be in the transverse plane. However unlike the kinematics, the proximal joint kinetics demonstrated much larger group deviations. All of the ROIs in the kinetic graphs which demonstrated a significant relationship with AHI were in late stance at around 80%. This coincided with the observed reduction in VMax2. This would explain why a reduction in AHI was associated with a reduction in peak joint moment for these ROIs. Even without assessing the correlation between the kinetic deviations and the presence of symptoms, one would think that it is unlikely that these gait adaptations are the cause of the proximal joint symptoms, and are merely the response to the reduced VGRF second peak.

4.3 Relationship between kinematic/kinetic parameters and proximal joint symptoms

None of the kinematic or kinetic parameters identified as having a significant relationship with AHI were significantly related to the presence of proximal joint symptoms in the FF group. It is accepted that using a dichotomous classifier of symptoms served to reduce study power. However the kinematic and kinetic adaptations that were observed to be related to reduced arch height would not be expected to directly relate to the presence of symptoms. As such any significant results would have been hard to explain from a mechanistic perspective.

4.4 Limitations and other considerations

These findings raise the obvious question, ‘why do children with FF develop proximal joint symptoms?’ Firstly the method by which we can measure joint kinematics and kinetics may not be sensitive enough to pick up small but clinically significant differences. Lower limb coronal and transverse plane kinematics and kinetics are smaller in range compared to the sagittal plane, this combined with broad confidence intervals, and marked within group variability, leads to an adverse signal to noise ratio. Indeed the variability of joint moments particularly in the transverse plane has been the subject of debate, with the resulting moments being highly sensitive to change in reference planes [24]. These factors partially negate the relatively large sample size in this study (in the context of gait analysis studies) reducing statistical power. Standard gait models also do not model the patellofemoral joint. Patellar kinematics and kinetics may play an important role in the development of knee symptoms. Finally formal assessment of trunk kinematics and kinetics may cast further light on the presence of back symptoms.

In this study foot posture was quantified using the AHI, which was devised in the adult population. It was felt appropriate to use the AHI for two reasons. Firstly as it is well accepted that foot development would definitely be complete by the age of eight, we did not expect the relationship between truncated foot length and arch height to change as the child gets older [25, 26]. Secondly using the AHI in a continuous manner for the majority of the analyses also means that even if cut-off values for different foot posture groups in children were different to the adult population the findings of the study remain the same. Without using the AHI to define foot posture groups it would not have been possible to identify ROIs on the gait curves. The alternative approach of undertaking regression analysis on all gait curves for all time points could be regarded as data mining and would increase the risk of type 1 error. Also if all the data were analysed in a pooled fashion without discrete groups, it is likely that all gait variables significantly related to AHI would have also significantly related to the presence or absence of proximal joint symptoms. An important purpose of this study was to identify if these significant gait variables could account for symptoms in a population ostensibly regarded as having a flat foot posture. This would not have been possible without using cut-offs for AHI to define groups. Further validation of the AHI is however required in the paediatric population.

It is also conceivable that the relationship between FF and proximal joint symptoms is not primarily mediated by mechanical factors, and that there may be other mechanisms that can account for the symptoms. There may also be other confounding factors that relate to both a flat foot posture and proximal joint symptoms. The obvious candidates in this case are increased joint mobility and increased BMI, although these variables could not always significantly predict the presence of proximal joint symptoms.

It is accepted that the method of measuring proximal joint symptoms had potential flaws, in that a simple question was used as opposed to a formally validated questionnaire. Currently there are no appropriate validated site-specific knee and hip health-related quality of life measures for the paediatric population.

4.5 Conclusion

Children with a flatter foot posture are more likely to have pain or discomfort at the hip, knee and back. Using 3DGA a number of kinematic and kinetic variables were found to correlate with arch height, but the findings were not consistent with prevailing pathomechanic theories. The majority of positive kinetic findings could be explained by the reduction in the second peak of vertical ground reaction force. Without explicit understanding of how FF relates to proximal joint symptoms, planning and delivering treatment is difficult, and further work is required in this area.

References

1. Garcia-Rodriguez A, Martin-Jimenez F, Carnero-Varo M, Gomez-Gracia E, Gomez-Aracena J, Fernandez-Crehuet J. Flexible Flat Feet in Children: A Real Problem? Pediatrics 1999;103:e84-e84.
2. Craxford AD, Minns RJ, Park C. Plantar pressures and gait parameters: a study of foot shape and limb rotations in children. Journal of Pediatric Orthopaedics 1984;4:477-81.
3. Hösl M, Böhm H, Multerer C, Döderlein L. Does excessive flatfoot deformity affect function? A comparison between symptomatic and asymptomatic flatfeet using the Oxford Foot Model. Gait & Posture 2013;
4. Kothari A, Dixon P, Stebbins J, Zavatsky A, Theologis T. The relationship between quality of life and foot function in children with flexible flatfeet. Gait & Posture 2015;41:786-90.

5. Levinger P, Menz HB, Morrow AD, Feller JA, Bartlett JR, Bergman NR. Foot kinematics in people with medial compartment knee osteoarthritis. Rheumatology 2012;51:2191-8.
6. Souza TR, Pinto RZ, Trede RG, Kirkwood RN, Fonseca ST. Temporal couplings between rearfoot-shank complex and hip joint during walking. Clinical Biomechanics 2010;25:745-8.
7. Ogon M, Aleksiev AR, Pope MH, Wimmer C, Saltzman CL. Does arch height affect impact loading at the lower back level in running? Foot & Ankle Int 1999;20:263-66.
8. Khamis S, Yizhar Z. Effect of feet hyperpronation on pelvic alignment in a standing position. Gait & Posture 2007;25:127-34.
9. Bird AR, Bendrups AP, Payne CB. The effect of foot wedging on electromyographic activity in the erector spinae and gluteus medius muscles during walking. Gait & Posture 2003;18:81-91.
10. Riskowski JL, Dufour AB, Hagedorn TJ, Hillstrom HJ, Casey VA, Hannan MT. Associations of foot posture and function to lower extremity pain: results from a population-based foot study. Arthritis Care Res (Hoboken) 2013;65:1804-12.
11. Kosashvili Y, Fridman T, Backstein D, Safir O, Ziv YB. The Correlation between Pes Planus and Anterior Knee or Intermittent Low Back Pain. Foot & Ankle Int 2008;29:910-13.
12. Williams DS, McClay IS, Hamill J. Arch structure and injury patterns in runners. Clinical Biomechanics 2001;16:341-47.
13. Butler RJ, Hillstrom H, Song J, Richards CJ, Davis IS. Arch height index measurement system: establishment of reliability and normative values. J Am Podiatr Med Assoc 2008;98:102-6.

14. Ferrari J, Parslow C, Lim E, Hayward A. Joint hypermobility: The use of a new assessment tool to measure lower limb hypermobility. Clinical and experimental rheumatology 2005;23:413-20.
15. Carson MC, Harrington ME, Thompson N, O'Connor JJ, Theologis TN. Kinematic analysis of a multi-segment foot model for research and clinical applications: a repeatability analysis. Journal of Biomechanics 2001;34:1299-307.
16. Kadaba MP, Ramakrishnan HK, Wootten ME. Measurement of lower extremity kinematics during level walking. Journal of Orthopaedic Research 1990;8:383-92.
17. Dixon P, Loh J, Michaud-Paquette Y. The Zoosystem: an open-source movement analysis matlab toolbox. In: Proceedings of 23rd Meeting of the European Society of Movement Analysis in Adults and Children; 2014. p.
18. Dixon PC, Bowtell MV, Stebbins J. The use of regression and normalisation for the comparison of spatio-temporal gait data in children. Gait Posture 2014;40:521-5.
19. Stovitz SD, Pardee PE, Vazquez G, Duval S, Schwimmer JB. Musculoskeletal pain in obese children and adolescents. Acta Paediatr 2008;97:489-93.
20. Williams SE, Gibbs S, Meadows CB, Abboud RJ. Classification of the reduced vertical component of the ground reaction force in late stance in cerebral palsy gait. Gait & Posture 2011;34:370-73.
21. Twomey DM, McIntosh AS. The effects of low arched feet on lower limb gait kinematics in children. The Foot 2012;22:60-65.
22. Shih YF, Chen CY, Chen WY, Lin HC. Lower extremity kinematics in children with and without flexible flatfoot: a comparative study. BMC Musculoskelet Disord 2012;13:31.
23. Guichet JM, Javed A, Russell J, Saleh M. Effect of the foot on the mechanical alignment of the lower limbs. Clinical Orthopaedics and Related Research 2003;193-201.

24. Schache AG, Baker R, Vaughan CL. Differences in lower limb transverse plane joint moments during gait when expressed in two alternative reference frames. Journal of Biomechanics 2007;40:9-19.

25. Volpon JB. Footprint analysis during the growth period. Journal of Pediatric Orthopaedics 1994;14:83-85.

26. Onodera AN, Sacco ICN, Morioka EH, Souza PS, Sá MRd, Amadio AC. What is the best method for child longitudinal plantar arch assessment and when does arch maturation occur? The Foot 2008;18:142-49.

Appendix 1. Full results of regression analysis presented in Table 2.

Tables include overall model R^2 value, model predictor, coefficient, standard error (Std. Error), significance value (p-value) and 95% Confidence Intervals.

Regression model for PERMax

Model R^2 0.08

Predictor	Coefficient	Std. Error	p-value	95% Confidence Interval	
AHI	22.98	10.11	0.03	2.89	43.07
Sex	-0.37	0.59	0.54	-1.55	0.81
Age	0.18	0.16	0.26	-0.13	0.49
BMI	-0.18	0.10	0.08	-0.38	0.22

Regression model for HAbMax

Model R^2 0.04

Predictor	Coefficient	Std. Error	p-value	95% Confidence Interval	
AHI	-12.91	10.07	0.20	-32.91	7.08
Sex	-0.31	0.59	0.60	-1.48	0.86
Age	0.70	0.16	0.66	-0.24	0.38
BMI	0.09	0.10	0.36	-0.11	0.30

Regression model for KExtMin

Model R^2 0.07

Predictor	Coefficient	Std. Error	p-value	95% Confidence Interval	
AHI	-10.85	16.69	0.52	-44.00	22.29
Sex	-0.65	0.98	0.51	-2.59	1.29
Age	-0.57	0.26	0.03	-1.09	-0.05
BMI	0.09	0.17	0.59	-0.24	0.43

Regression model for KVarMid

Model R^2 0.26

Predictor	Coefficient	Std. Error	p-value	95% Confidence Interval	
AHI	24.79	10.31	0.02	4.31	45.27
Sex	1.26	0.60	0.04	0.06	2.46
Age	0.68	0.16	<0.01	0.36	1.00
BMI	-0.39	0.10	<0.01	-0.60	-0.18

Regression model for KIntMax

Model R^2 0.09

Predictor	Coefficient	Std. Error	p-value	95% Confidence Interval	
AHI	30.04	22.34	0.18	-14.35	74.43
Sex	1.90	1.31	0.15	-0.70	4.50
Age	0.67	0.35	0.06	-0.26	1.36
BMI	-0.37	0.23	0.11	-0.82	0.81

Regression model for Vmin

Model R^2 0.36

Predictor	Coefficient	Std. Error	p-value	95% Confidence Interval	
AHI	2.74	23.34	0.91	-43.64	49.12
Sex	-0.99	1.38	0.47	-3.73	1.75
Age	0.39	0.31	0.21	-0.22	1.01
Speed	-27.66	3.97	<0.01	-35.55	-19.76

Regression model for VMax2

Model R^2 0.25

Predictor	Coefficient	Std. Error	p-value	95% Confidence Interval	
AHI	62.55	25.77	0.02	11.32	113.73
Sex	-1.47	1.52	0.34	-4.49	1.56
Age	1.03	0.34	<0.01	0.35	1.72
Speed	15.56	4.39	<0.01	6.84	24.27

Regression model for HFlexMax

Model R^2 0.32

Predictor	Coefficient	Std. Error	p-value	95% Confidence Interval	
AHI	395.22	807.61	0.63	-1209.25	1999.68
Sex	23.01	47.34	0.63	-71.03	117.05
Age	-0.85	10.73	0.94	-22.17	20.46
Speed	875.94	137.46	<0.01	602.84	1149.03

Regression model for HExtMax

Model R^2 0.49

Predictor	Coefficient	Std. Error	p-value	95% Confidence Interval	
AHI	-1956.16	478.38	<0.01	-2906.55	-1005.78
Sex	27.85	28.04	0.32	-27.85	83.56
Age	-11.39	6.36	0.08	-24.02	1.24
Speed	-628.84	81.43	<0.01	-790.60	-467.08

Regression model for HIntMax

Model R^2 0.37

Predictor	Coefficient	Std. Error	p-value	95% Confidence Interval	
AHI	209.80	109.38	0.06	-7.51	427.11
Sex	-6.18	6.41	0.34	-18.92	6.55
Age	7.61	1.45	<0.01	4.72	10.49
Speed	80.91	18.62	<0.01	43.92	117.90

Regression model for KExtMin

Model R^2 0.29

Predictor	Coefficient	Std. Error	p-value	95% Confidence Interval	
AHI	-347.75	443.94	0.44	-1229.71	534.21
Sex	14.24	26.02	0.59	-37.46	65.93
Age	-25.78	5.90	<0.01	-37.50	-14.06

Speed	-294.13	75.56	<0.01	-444.25	-144.01

Regression model for KVarMax1	Model R^2	0.32

Predictor	Coefficient	Std. Error	p-value	95% Confidence Interval	
AHI	236.74	532.45	0.66	-821.08	1294.56
Sex	6.82	31.21	0.83	-55.18	68.82
Age	23.02	7.07	<0.01	8.97	37.08
Speed	483.50	90.63	<0.01	303.45	663.55

Regression model for KVarMax2	Model R^2	0.28

Predictor	Coefficient	Std. Error	p-value	95% Confidence Interval	
AHI	846.33	300.39	0.01	249.56	1443.10
Sex	9.21	17.61	0.60	-25.77	44.19
Age	17.95	3.99	<0.01	10.02	25.88
Speed	89.39	51.12	0.08	-12.19	190.97

Regression model for KIntMax	Model R^2	0.41

Predictor	Coefficient	Std. Error	p-value	95% Confidence Interval	
AHI	322.24	115.66	0.01	92.46	552.02
Sex	-0.21	6.78	0.98	-13.68	13.25
Age	9.91	1.54	<0.01	6.86	12.96
Speed	59.68	19.69	<0.01	20.57	98.79

Gait Parameter		Predictor				
		AHI	Sex	Age	BMI	Speed
Kinematics	PERMax	0.03*	0.54	0.26	0.08	N/A
	HAbMax	0.20	0.60	0.66	0.36	N/A
	KExtMin	0.52	0.51	0.03*	0.59	N/A
	KVarMid	0.02*	0.04*	<0.01*	<0.01*	N/A
	KIntMax	0.18	0.15	0.06	0.11	N/A
Ground reaction force	VMin	0.91	0.47	0.21	N/A	<0.01*
	VMax2	0.02*	0.34	<0.01*	N/A	<0.01*
Kinetics	HFlexMax	0.63	0.63	0.94	N/A	<0.01*
	HExtMax	<0.01*	0.32	0.08	N/A	<0.01*
	HIntMax	0.06	0.34	<0.01*	N/A	<0.01*
	KExtMin	0.44	0.59	<0.01*	N/A	<0.01*
	KVarMax1	0.66	0.83	<0.01*	N/A	<0.01*
	KVarMax2	0.01*	0.60	<0.01*	N/A	0.08
	KIntMax	0.01*	0.98	<0.01*	N/A	<0.01*

Table 1: Significance values of linear regression model predictors to predict gait parameter regions of interest. * denotes statistically significant result. N/A = not applicable. The full output from the regression models can be found in Appendix 1.

	KNEE					HIP / BACK				
	Symptoms (n=22)	No symptoms (n=26)	Between Groups			Symptoms (n=25)	No Symptoms (n=23)	Between Groups		
Parameter	Mean	Mean	Difference in means	95% Confidence Interval	p-value	Mean	Mean	Difference in means	95% Confidence Interval	p-value
PERMax (°)	-7.01	-9.92	-0.84	-1.65 – 1.49	0.92	-6.62	-7.33	0.71	-0.84 – 2.26	0.36
KVarMid (°)	-1.93	-1.34	-0.59	-2.52 – 1.34	0.54	-1.64	-1.57	-0.07	-2.01 – 1.86	0.94
HExtMax (Nmm/Kg)	-762.09	-794.17	32.08	-64.87 – 129.04	0.51	-767.67	-792.29	24.62	-72.27 – 121.52	0.61
KVarMax2 (Nmm/Kg)	172.95	208.20	-35.25	-87.68 – 17.17	0.18	182.63	202.28	-19.65	-72.65 – 33.35	0.46
KIntMax (Nmm/Kg)	107.95	115.13	-7.17	-28.91 – 14.55	0.51	110.06	113.78	-3.72	-25.47 – 18.04	0.73

Table 2. Summary of difference between gait parameters in FF group with respect to presence of absence of knee symptoms or hip / back symptoms.

Mean values per groups as well as difference in means with confidence intervals and significant value (p-value) shown.

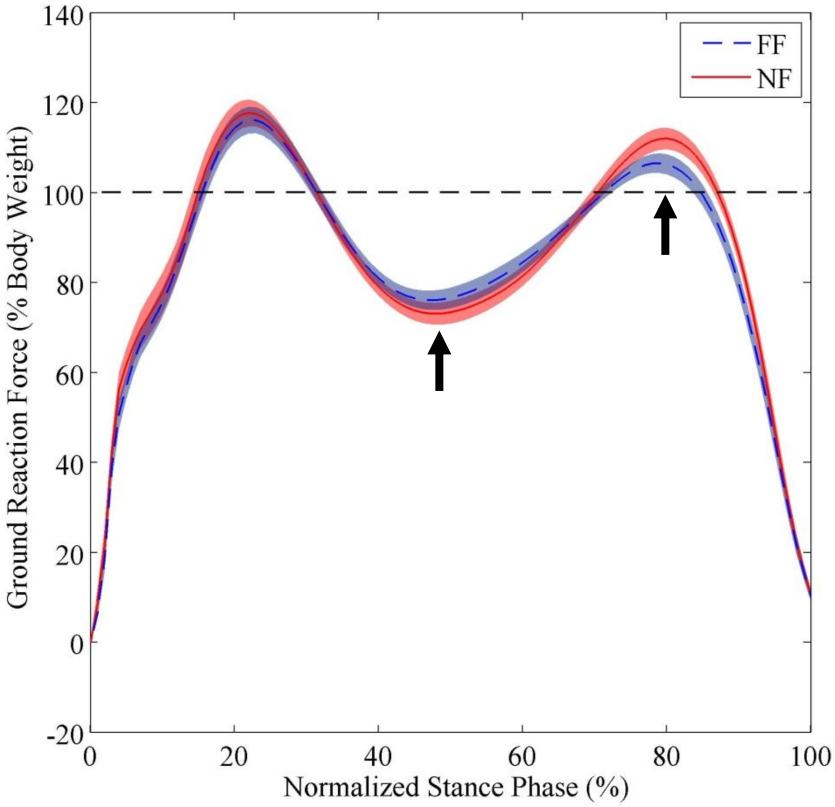

Fig. 1. Vertical ground reaction force for flexible flat foot (FF) (blue) and normal foot (NF) (red) groups with 95% confidence bands. Regions of interest marked with arrows: trough between peaks (VMin) and second peak force (VMax2). Dashed line represents 100% of body weight. Statistically significant relationship between parameter and AHI denoted by * (see Table 1). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

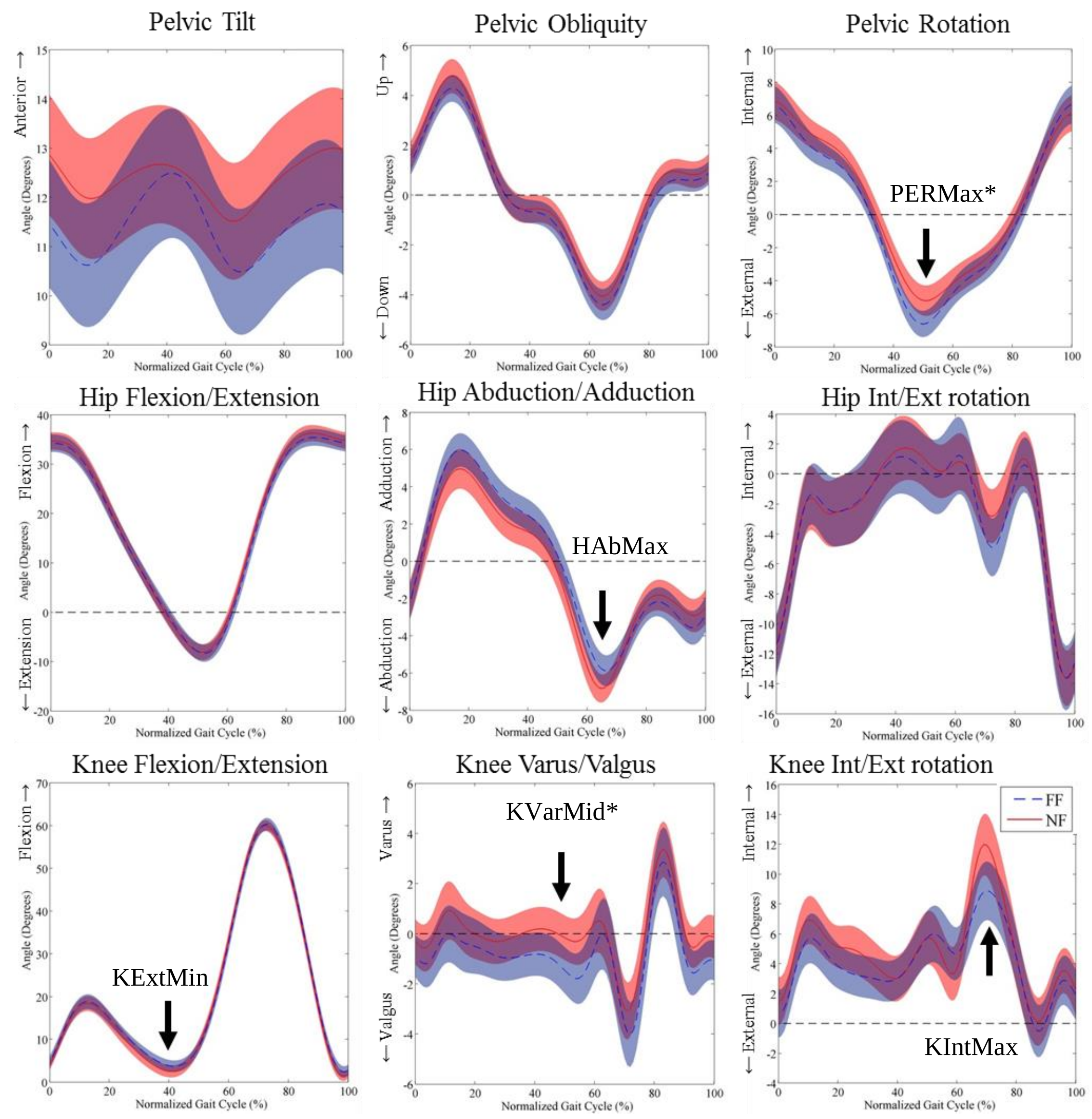

Fig. 2. Pelvis, hip and knee kinematic graphs for flexible flat foot (FF) (blue) and normal foot (NF) (red) groups with 95% confidence bands. Regions of interest marked with arrows: peak pelvis external rotation (PERMax), peak hip abduction (HAbMax), knee flexion trough (KExtMin), knee midstance varus (KVarMid), peak knee external rotation (KIntMax). Statistically significant relationship between parameter and AHI denoted by * (see Table 1). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

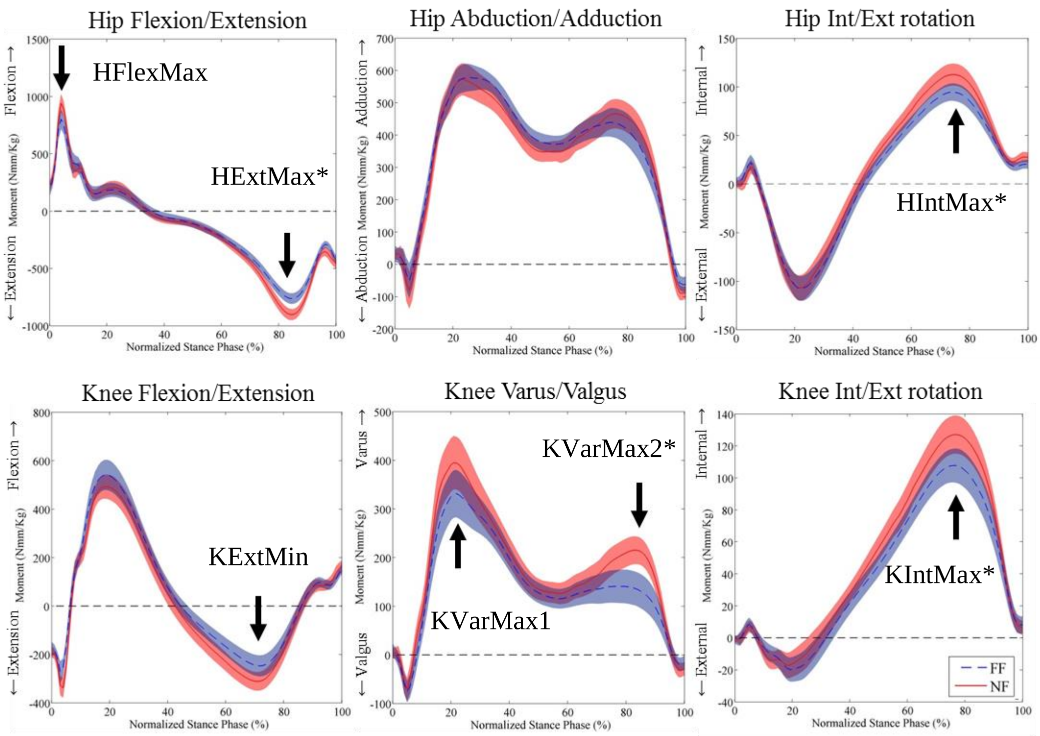

Fig. 3. Lower limb kinetic graphs for flexible flat foot (FF) (blue) and normal foot (NF) (red) groups with 95% confidence bands. Regions of interest marked with arrows: peak hip flexion moment (HFlexMax), peak hip extension moment (HExtMax), peak hip internal rotation moment (HIntMax), late stance peak knee extension moment (KExtMin), first peak knee varus moment (KVarMax1), second peak knee varus moment (KVarMax2), peak knee internal rotation moment (KIntMax). Statistically significant relationship between parameter and AHI denoted by * (see Table 1). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)