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International normative data for paediatric foot posture assessment: a large-scale cross-sectional investigation.

[Short title: Children's flatfeet – what is normal?]

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Contributors GG-N, AM-N, and AME contributed to the conception of this study. GG-N, AM-N, and AME did the statistical analysis. Data collectors were collected in Spain JM-A and PG-A and in Australia AME. GG-N, AM-N, PG-A, JM-A and AME were involved in the writing and in the review of the manuscript.

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Abstract

Objectives: Frequent confusion about paediatric foot posture, and a lack of defined values, result in overdiagnosis of 'flatfoot', or pronated foot, and unnecessary treatment. The objective of this study was to establish international reference data for foot posture across childhood, and influence of Body Mass Index (BMI) on paediatric foot posture.

Design: Cross-sectional study

Setting and participants: The dataset comprised 3217 healthy children, aged from three to 15 years. Contributing data were acquired from Spain, UK, and Australia.

Interventions : Foot posture was described by means and z-score of the foot posture index (FPI) and the height and weight of each subject was measured and the body mass index (BMI) was calculated

Results: The mean FPI score was 4.11 (SD 2.92) and 4.20 (3.00) for left and right feet respectively, ranging from -4 to +12 (left and right). Flatfeet (FPI ≥+6) were found in 1087 (33.7%) and non-flatfeet (FPI <+6) in 1776 (55.2%). FPI ≥ +10 was found in 127 children (3.9%). Approximating 20% of children were overweight/obese, but correlation between BMI and FPI was weak and inverse ($r = -0.066$, $p< 0.01$), refuting the relationship between increased body mass and flatfeet.

Conclusions: Pronated or 'flat', is the normal foot posture of childhood, with a wide range of normal variation. A supinated foot posture is an abnormal finding in children aged less than five years. This reference data enables standardised clinical assessment.

Strengths and limitations of this study

- This study confirms the pronated foot as the normal foot posture of childhood
- Clinicians must move beyond flatfoot posture appearance as an indicator for intervention
- The sample does not balance the number of children from each country

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- The disproportionate numbers of children within each age year group

Key Words: Foot, Children, Posture

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Introduction

Paediatric foot posture is a common parental concern, a frequent presentation to clinicians, and an area of dispute regarding the need for treatment [1]. The term 'flatfoot', has referred to a foot which is nearly or completely contacting the ground [2], and has been evaluated using foot posture [3], footprints [4], radiological and anthropometric measures [5] and is often poorly defined [6].

There is no well-constructed, agreed reference for normal paediatric foot posture as the child's foot grows and changes across childhood [7]. Children's foot posture has been interpreted with footprint assessments in many studies, with inference of problematic 'flatfoot' when footprint area increases. Throughout early childhood, children continue to develop a skeletal medial longitudinal foot arch [8], different from the adult population [9], and altered children's foot posture must be evaluated in context of developmental stage and the presence/absence of systemic influences, such as Down or Marfan's syndromes.

Despite the fact that paediatric flatfoot is a frequent concern [1, 10], the evidence for treatment is weak. The paucity of definition for 'flatfoot' contributes to a lack of consensus for best practice [11–13]. There is no 'gold standard' for categorising foot type, and few clinical measures are validated in children. Further, it is common for clinicians to make diagnostic decisions based on their personal clinical experience [14]. The availability of normal reference data for paediatric foot posture, based on a valid measure, will provide a 'benchmark' for clinical evaluation of this frequent clinical concern.

Ten years ago the Foot Posture Index (FPI) [15] emerged with the objective to standardise the assessment of foot posture in stance across three discrete foot regions (rearfoot, midfoot, forefoot). Both Evans et al [16] and Gijon-Nogueron et al [17] have previously utilised the FPI to investigate the paediatric foot. The FPI is a quick, and easy-to-use clinical tool, not requiring equipment. The FPI is demonstrably repeatable and validated [3].

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Methods

Data acquisition

Data was acquired from multiple sources where the FPI had been assessed in healthy children, who were recruited for screening studies or who acted as comparative controls. Three datasets were acquired from the authors' previous works (n= 1032, n=1457, n = 728) [9, 16, 17]. Overall, the datasets comprised foot posture measures from Spain (n=2489), the UK (n = 225), and Australia (n = 503), to realise an amalgamated dataset of 3217 observations for FPI in children aged from three to 15 years.

Participants

The inclusion criterion across studies was that the children be 'healthy' and aged between three and 15 years. Exclusion criteria were: foot pain at the time of examination, history of injury to the lower limbs (eg musculoskeletal injuries during the previous six months), congenital foot abnormalities, cerebral palsy, motor dysfunction, or foot surgery. Informed consent had been gained from parents/carers of the children for study participation. All studies contributing data to the amalgamated dataset were conducted in accordance with the Declaration of Helsinki and was approved by University Human Ethics Committees in each country (Universities of: Malaga, Extremadura, South Australia).

Protocol

Foot posture was assessed using the standard protocol for the FPI [18]. The FPI consists of six items referring to positions of the forefoot, midfoot and hindfoot, and the three planes of motion: 1) talar head palpation; 2) symmetry of supra and infra lateral malleolar curvature; 3) inversion/eversion of the calcaneus; 4) prominence in the region of the talus-scaphoid joint; 5) height of the medial longitudinal arch; 6) abduction/adduction of the forefoot. The FPI score may range from -12 (highly supinated) to +12 (highly pronated).

The BMI was calculated from the children's height and weight, calculated as, BMI = weight(kg)/height(m)^2). In Spain, the Orbegozo[19] BMI classification is used and in Australia, the Australian Health Survey guide for BMI is used [20]. Accordingly, we classified children by their BMI score, using the systems proposed by Orbegozo and Australian Health Survey, and allocated to one of four categories: underweight - percentile less than 3 (P<3), normal weight - percentile between 3 and 90 (P3–90), overweight - percentile between 90 and 97 (P90–97) and obesity - percentile greater than 97 (P>97), based on BMI, and according to age.

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Patient involvement

No patients were involved in setting the research question or the outcome measures, nor were they involved in the design or conduct of the study. No patients were asked to advise on interpretation or writing up of results. There are no plans to disseminate the results of the research to study participants.

Data analysis

Data were entered and all analyses were performed using constructed data sets in SPSS version 24 (SPSS Inc, Chicago, Illinois) software packages. Testing for normality using a Kolmogorov–Smirnov test, found non-normally distribution of all data, indicating the suitability of the data for non-parametric analysis (Mann–Whitney U and Kruskal–Wallis). Descriptive statistics (mean, standard deviation, minimum, maximum, frequencies) were used to examine the basic anthropometrical characteristics of the study populations. The FPI was analysed as continuous data, rather than as z-score data, and analysis of variance was conducted to determine the association between the different BMI groups (underweight, normal, overweight and obesity), gender, age, and the FPI for left foot. To preserve the independence of data[21], and based on the strong correlation between FPI scores for left and right feet [22], only the right foot (chosen at random) was used in the statistical analyses, applying the Games-Howell post hoc correction to identify significant differences. The significance level was set at $p < 0.05$, and all the analyses and tests were two-sided.

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Results

The mean age of the study population of 3217 children was 8.67 years (SD 2.02), ranging from three years to 15 years. The mean BMI was 19.08 kg/m^2 (SD 4.05), ranging from 10.57 kg/m^2 to 39.14 kg/m^2. The mean FPI score was 4.11 (SD 2.92) and 4.20 (3.00) for left and right feet respectively, with whole scores ranging from -4 to +12 (left and right). The total study population gender distribution was 1699 male, 1518 female (Table 1).

In the study population of 3217 children, flatfeet (FPI ≥+6) were found in 1087 (33.7%) children and non-flatfeet (FPI <+6) in 1776 (55.2%) children and FPI ≥ +10 yielded flatfeet in 127 (3.9%) cases.

There was strong correlation between FPI scores on left and right sides (r = 0.9014, p < 0.01), from which the left side was arbitrarily used for subsequent analyses. Similarly, we found little gender bias, with the mean FPI for males 4.2 (2.9), range -4 to +12, and for females, mean FPI 3.99 (2.9), range -4 to +12. The correlation between FPI and gender used z-score was very weak, if significant (F=4.073, p=0.04). Between countries there was significant difference (p<0.01), with Spanish children's mean FPI = 4.00(2.9), and in UK and Australian children combined, the FPI = 4.9(3.3).

Table 2 used designated FPI categories to define and explore the range of foot posture across childhood.

Table 3 displays the frequency of FPI scores for each year of age.

Table 4 shows the standard deviation of the mean FPI scores, and enables the mean FPI and one and two standard deviations above and below to be referenced as normally expected for each year of age.

Figure 1 displays and explores the relationship between foot posture and age across childhood for the study population, using error bars for average Z-scores (95% confidence intervals).

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Significant correlation was found between BMI and age (r = 0.276, p < 0.01). The correlation between BMI and FPI, whilst also statistically significant, was very weak and also inverse (r = -0.066, p< 0.01), refuting the strength of relationship between body mass and foot posture. BMI cut-points and percentiles were used to define underweight, normal weight, overweight, and obese. Within the total 3217 children, 142 (4.4%) were underweight, 2407 (74.8%) were normal weight, 469 (16.1%) were overweight, and 199 (6.2%) were obese.
Combining categories, 668 (20.8%) of all children were overweight or obese.

The foot posture categories were analysed for distribution across the BMI categories (Table 5). The largest overlap of FPI and BMI categories were: normal weight / normal FPI range, n= 1325; normal weight / pronated foot posture, n= 728; overweight or obese / normal foot posture, n=383.
Exploring the association between the pronated foot and BMI across FPI ranges showed that 960 children had foot posture that was pronated, FPI > 6. Of these, 44 (4.5%) were underweight, 728 (75.8%) were normal weight, 188 were overweight, or obese (19.5%). Further, 127 children had highly pronated foot posture, FPI > 10. Of these, 12 (9.4%) were underweight, 94 (74.0%) were normal weight, and 21 (16.5%) were overweight or obese.

Discussion

This study is the largest investigation of paediatric foot posture using the FPI, paediatric anthropometry using BMI, and exploration of both foot posture across childhood with the regularly cited influence of increased body weight, as potentiating factors for flatfeet. This investigation of paediatric foot posture includes children aged from three to 15 years, superseding previous, smaller or age-limited, studies[16, 17].

This study confirms the pronated foot as the normal foot posture of childhood, with mean FPI of +4, and 3-point standard deviation, such that average normal FPI range for children aged three to 14 years was between the FPI range +1 to +7 (mean +/- SD). These findings concur with the recent cross-sectional investigation of 1762 children aged six to 11 years [17]. Similarly to Gijon-Nogueron et al [17], we found that the mean FPI scores reduced with age, in non-linear pattern, and within a wide range. The standard deviation approximated 75% of the FPI mean at every age, confirming the considerable and normal variation in foot posture across childhood.

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The greatest number of children across all ages (n=1776) displayed FPI within the 0 to +5 FPI range, ie normal foot posture. Next common were children within the FPI range +6 to +9, ie pronated feet (n=960). The least common FPI ranges were: -1 to -4, supinated foot posture (n=354) and >+10, highly pronated (n=127), indicative of the foot types that should arrest the attention of clinicians, as less frequent presentations. Flatfoot or pronated foot posture was generally found to decline with age, but mean reduction was non-linear and modest, from +6 at age three years, to +3 at 14 years. Importantly, the normal FPI range of variation was broad: -1 to +11 at age three years, and FPI +3 to +9 at age 14 years.

The relationship between increased BMI and flatfeet is again refuted by the findings of this study which found that only 16.5% of the 127 children (4%) with highly pronated feet, were also overweight or obese (Table 5). Similar results have been found in other recent studies [16] [23], refuting many older studies which asserted that heavier, fatter children have flatter feet. Importantly, the older studies all assessed foot posture using a footprint based method of foot posture assessment [4, 7, 24], a method which may well represent adipose tissue area spread with weight bearing, rather than anatomical foot morphology, more directly evaluated using the FPI [15, 16]. Whilst it is concerning to find that 21% of the children in this study were overweight or obese, the association with flatfeet is again refuted.

The availability of average FPI whole scores, enables clinicians to inform parents as to what is “average” and what is “normal” at any age, as statistically defined. The availability of FPI scores within one standard deviation above and below the mean, enables clinicians to confirm for parents that their child falls within 68% of children for a specific age. Further, FPI scores within two standard deviations above and below the mean, enable clinicians to inform parents that their child is still within the normal 95% range, and similar to 27% of same age children. Such reference data helps appreciation of the range of “normal” for foot posture, similarly to that for the onset of independent walking (age range of 10 to 16 months, mean age approximating 12 to 13 months)[8].

The focus of this investigation has been to better elucidate the normal range of foot posture across childhood, as is commonly assessed by many clinicians using the FPI. Simultaneously, the authors aimed to provide clinicians with a robust reference guide of normal values within statistical bounds. The culmination of this aim is provided as a reference Table (Table 4). The scale of this investigation renders its findings stronger than those of the 1000 Norms protocol

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for most age (year) groups, as the comparative number of participants reveals. The 1000 Norms protocol will include: ages 3 to 9 years, 140 (20 per age year); ages 10 to 19 years, 160 (16 per age year)[25]. By comparison, this study informs for: ages 3 to 9 years, 2796 (20 to 764 per age year); ages 10 to 15 years, 1304 (1 to 634 per age year).

Clinicians must move beyond flatfoot posture appearance as an indicator for intervention, and instead appreciate the range of normal variation, and only respond to more pertinent factors as outlined by the 3QQ (3 Quick Questions) screening tool (addressing pain presentations, left versus right limb symmetry, paediatric age range)[10]. Clinicians need to appreciate the normal range of many developmental features, yet simultaneously be alert to the level at which clinical concern should be raised. The Tabulated reference guide provided from this study, will be of immediate clinical relevance.

The striking finding of this study is not that paediatric flexible flatfoot is largely normal, it is that the supinated paediatric foot is far more likely to be abnormal, especially at age three and four years. An FPI of -2 or less, must be considered “abnormal” until shown otherwise, as it is outside normal range at any age.

Limitations of this investigation include the cross-sectional nature of the design and the ethnicity of participants (largely Caucasian) and the sample does not balance the number of children from each country. Prospective data would avail stronger evidence of foot posture change over time. A further limitation is the disproportionate numbers of children within each age year group, although this is pragmatically ameliorated to an extent as mid-childhood, a time a frequent parent concerns, is best represented.

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Conclusions

This is the largest study of paediatric foot posture to date. Importantly, the main finding to have emerged from this study is to denounce the appearance of paediatric flatfoot as deviant. This study confirms that the 'flat' or pronated foot is the normal foot posture of childhood, with FPI score of +4 the average finding. The wide and normal range of foot posture across childhood is confirmed (16 FPI points ie -2 to +12). The reference data produced from the findings of this study will assist clinicians in standardising their assessments and decision-making.

Increased paediatric BMI was not associated with flatter feet, again questioning the validity as to what footprint-derived measures actually measure. Childhood overweight and obesity remain wider and prevalent health concerns.

The extremes of foot posture, ie the highly pronated foot and the supinated foot should produce clinical alert, and the presentation of a supinated foot posture in children less than five years of age should be regarded as abnormal.

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Legend text

Figure 1

Simple error bars display the relationship between foot posture and age across childhood.

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Table 1

Descriptive statistics for the amalgamated data sets. Due to variation between the constituent datasets, main results emerged from the variables of age, BMI, FPI Left. Gender ratio was 1699 males: 1518 females.

Variable	N	Range	Minimum	Maximum	Mean	SD
Age (years)	3217	12	3	15	8.67	2.02
BMI (kg/m^2)	3217	28.57	10.57	39.14	19.08	4.05
FPI Right	3217	16	-4	12	4.20	3.00
FPI Left	3217	16	-4	12	4.11	2.92

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Table 2

The FPI range which refer to foot posture categories. were collated for each year of age. The median FPI total score across the study population was 4(3) points. with the trend of reduced FPI with increased age confirmed.

Age (yrs)	No. /Age	FPI-6 total score – *Foot posture category cut-offs*							
		< -5	-1 to -4	0 to +5	+6 to +9	> +10	Mean FPI	SD	Range
3	21	0	2	4	14	1	6.38	3.03	11
4	20	0	1	5	12	2	6.7	2.60	11
5	55	0	5	34	13	3	4.15	2.81	12
6	388	0	29	213	132	14	4.45	2.80	15
7	536	0	51	296	164	25	4.3	2.93	16
8	473	0	48	271	131	23	4.01	2.95	16
9	625	0	74	362	175	14	3.82	2.77	16
10	497	0	62	291	123	21	3.69	2.86	15
11	377	0	50	194	119	14	4.24	3.02	16
12	144	0	24	65	48	7	4.22	3.23	14
13	33	0	1	17	12	3	5.18	2.98	10
14	22	0	4	12	6	0	3.14	3.40	12
15	26	0	3	12	11	0	4.19	3.31	12
Total	3217	0	354	1776	960	127	4.2	3	16
Mean age (SD) 8.67 yrs (2.02)							FPI score		
% Total (N=3217)		0	11	55.2	29.84	3.95	Median 4	SD 3	Range 16

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Table 3

FPI total scores versus age year groups. The general trend showed FPI scores declining with age, which supports the clinical observation of less flatfoot in older children.

FPI/ Age	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	Total / n
3	0	0	0	1	1	0	0	1	2	1	2	0	3	4	4	0	2	21
4	0	0	0	0	1	0	0	0	3	3	5	2	2	1	1	2	0	20
5	0	0	1	0	6	3	7	11	7	3	6	2	2	1	1	4	1	55
6	0	1	3	6	24	31	45	46	47	38	69	30	19	11	6	8	4	388
7	1	6	4	3	39	43	48	72	69	55	90	33	22	27	14	7	3	536
8	1	2	1	8	36	47	55	45	49	48	89	27	24	17	13	7	4	473
9	3	3	5	11	55	61	60	72	81	78	92	48	21	14	9	8	4	625
10	0	5	3	14	41	59	68	71	54	39	61	23	17	12	17	9	4	497
11	1	3	4	10	29	22	31	48	58	32	52	29	26	14	10	3	5	377
12	0	2	2	6	17	9	12	7	19	11	19	14	12	6	5	3	0	144
13	0	0	0	0	1	2	1	6	2	5	2	7	2	2	3	0	0	33
14	0	1	2	0	1	3	2	3	4	0	1	2	0	2	1	0	0	22
15	0	1	2	0	0	1	3	4	3	2	2	3	0	3	2	0	0	26
Total/ FPI	6	24	27	59	251	281	332	386	398	315	490	220	150	114	86	51	27	3217
%	0,2	0,7	0,8	1,8	7,8	8,7	10,3	12	12,4	9,8	15,2	6,8	4,7	3,5	2,7	1,6	0,8	100

%: Percentage, SD: Standard Deviation, R: Range

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Table 4

FPI total scores versus age year groups. The general trend showed FPI scores declining with age, which supports the clinical observation of less flatfoot being seen in older children. Clinical alert is indicated for foot posture > +/- 2SD, representing 5% of expected abnormality.

Age	-2SD	-1SD	**Mean**	+1SD	+2SD	Sample size	SD	FPI Median (+/- 1SD)	FPI Median (+/- 2SD)	**Clinical Alert FPI > +/-2SD**
3	0,02	3,60	**7,19**	10,78	10,78	21	3.6	8 (4 – 12)	8 (0 – 12)	**< 0 or > 12**
4	1,11	3,76	**6,4**	9,04	9,04	20	2.6	6 (3 – 9)	6 (0 – 12)	**< 0 or > 12**
5	-2,41	0,91	**4,22**	7,54	7,54	55	3.3	3 (0 – 6)	3 (-3 – 9)	**< -3 or > 9**
6	-1,37	1,50	**4,36**	7,22	7,22	388	2.9	4 (1 – 7)	4 (-2 – 10)	**< -2 or > 10**
7	-1,53	1,40	**4,32**	7,24	7,24	536	2.9	4 (1 – 7)	4 (-2 – 10)	**< -2 or > 10**
8	-1,64	1,33	**4,29**	7,25	7,25	473	2.9	4 (1 – 7)	4 (-1 – 10)	**< -1 or > 10**
9	-1,74	1,11	**3,96**	6,81	6,81	625	2.8	4 (1 – 7)	4 (-1 – 10)	**< -1 or > 10**
10	-2,31	0,73	**3,77**	6,81	6,81	497	3.0	3 (0 – 6)	4 (-3 – 9)	**< -3 or > 9**
11	-1,77	1,28	**4,33**	7,38	7,38	377	3.0	4 (1 – 7)	4 (-2 – 10)	**< -2 or > 10**
12	-2,43	0,92	**4,26**	7,61	7,61	144	3.3	4 (1 – 7)	4 (-2 – 10)	**< -2 or > 10**
13	-0,03	2,71	**5,45**	8,19	8,19	33	2.7	5 (2 – 8)	5 (-1 – 11)	**< -1 or > 11**
14	-3,89	-0,28	**3,32**	6,92	6,92	22	3.6	4 (1 – 7)	4 (- 2 – 9)	**< -2 or > 9**
15	-2,84	0,77	**4,38**	7,99	7,99	26	3.6	4 (0 - 8)	4 (-4 - 12)	**<-4 or >12**

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Table 5

FPI and BMI category distributions, showing greatest concordance between normal FPI and normal BMI.

		Underweight	Normal	Overweight or Obese	Total
Supinated	Count	18 [a]	260 [a]	76 [a]	354
	Expected count	15.6	264.9	73.5	354
Normal	Count	68 [a]	1325 [a]	383 [a]	1776
	Expected count	78.4	1328.8	368.8	1776
Pronated	Count	44 [a]	728 [a]	188 [a]	960
	Expected count	42.4	718.3	199.3	960
Highly Pronated	Count	12 [a]	94 [b]	21 [b]	127
	Expected count	5.6	95	26.4	127
Total	Count	142	2407	668	3217

Note: superscript letters denote a subset of FPI (Left) categories whose column proportions did not differ significantly from each other at the level of 0.05.

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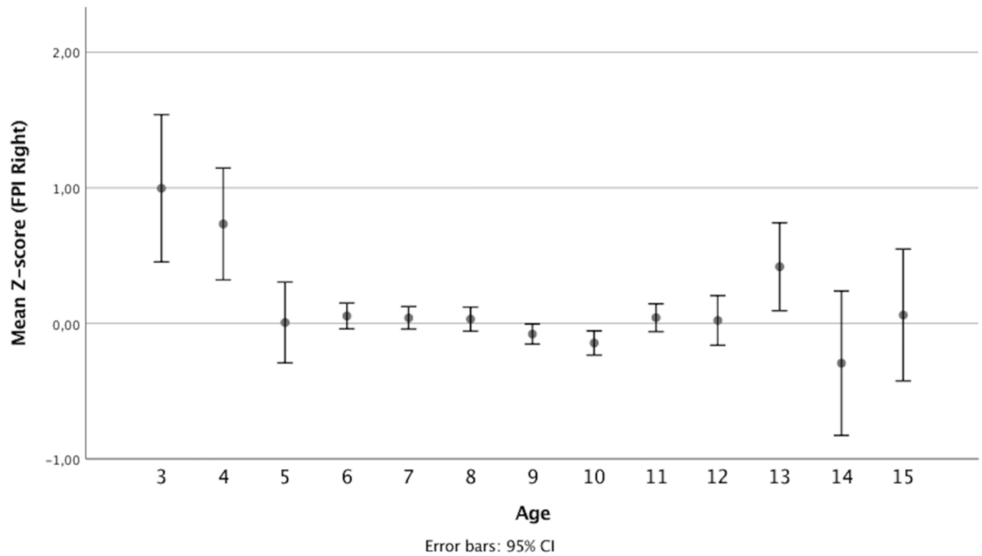

Figure 1 Simple error bars display the relationship between foot posture and age across childhood

89x52mm (600 x 600 DPI)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1-2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	5
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*5*
Bias	9	Describe any efforts to address potential sources of bias	-
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	6
		(*b*) Describe any methods used to examine subgroups and interactions	6
		(*c*) Explain how missing data were addressed	-
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	6
		(*e*) Describe any sensitivity analyses	

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Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	7
		(b) Give reasons for non-participation at each stage	-
		(c) Consider use of a flow diagram	-
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	7-8
		(b) Indicate number of participants with missing data for each variable of interest	-
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	*7-8*
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	7-8
		(*b*) Report category boundaries when continuous variables were categorized	7-8
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	8
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	8-9
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	8-9
Generalisability	21	Discuss the generalisability (external validity) of the study results	8-9
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	1

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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Manuscripts

International normative data for paediatric foot posture assessment: a cross-sectional investigation.

[Short title: Children's flatfeet – normal or not?]

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Informed consent: Informed consent was obtained from all individual participants (parents), whose children were included in the study.

Data sharing statement: Available data can be obtained by contacting the corresponding author.

Contributors: GG-N, AM-N, and AME contributed to the conception of this study. GG-N, AM-N, and AME did the statistical analysis. Data collectors were collected in Spain JM-A and PG-A and in Australia AME. GG-N, AM-N, PG-A, JM-A and AME were involved in the writing and in the review of the manuscript.

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Abstract

Objectives: Frequent confusion about paediatric foot posture, and a lack of defined values, results in overdiagnosis of 'flatfoot', or pronated foot, and unnecessary treatment. The objective of this study was to establish international reference data for foot posture across childhood, and influence of Body Mass Index (BMI) on paediatric foot posture.

Design: Cross-sectional study

Setting and participants: The dataset comprised 3217 healthy children, aged from three to 15 years. Contributing data were acquired from Spain, UK, and Australia.

Interventions: Foot posture was described by means and z-score of the foot posture index (FPI) and the height and weight of each subject was measured and the body mass index (BMI) was calculated**.**

Results: Pronated (FPI ≥+6) were found in 1087 (33.7%) and normal (FPI 0 to +6) in 1776 (55.2%). FPI ≥ +10 (highly pronated) was found in 127 children (3.9%). Approximating 20% of children were overweight/obese, but correlation between BMI and FPI was weak and inverse (r = -0.066, p< 0.01), refuting the relationship between increased body mass and flatfeet.

Conclusions: This study confirms that the 'flat' or pronated foot is the common foot posture of childhood, with FPI score of +4(3) the average finding. A wide normal range of foot posture across childhood is confirmed.

Strengths and limitations of this study

- First study to measure foot posture with any method in a sample of 3217 children
- Comparison between different countries strengthens the study findings
- The sample does not balance the number of children from each country
- The disproportionate numbers of children within each age year group

Key Words: Foot, Children, Posture, Paediatric, Foot posture index, Flatfoot

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Introduction

Paediatric foot posture is a common parental concern, a frequent presentation to clinicians, and an area of dispute regarding the need for treatment [1]. The term 'flatfoot', has referred to a foot which is nearly or completely contacting the ground [2], and has been evaluated using foot posture [3], footprints [4], radiological and anthropometric measures [5] and is often poorly defined [6]. From a clinical practice perspective, there is no single universally accepted diagnostic technique.

Yet, as Banwell et al indicate in their systematic review [7] about flatfoot and clinical measures, in healthy children, normative data indicates 'flatfoot' is usual at or before eight years of age [8], due to young osseous structures, ligament laxity, increased adipose tissue, and immature neuromuscular control [9, 10]. With variation, flatfoot posture reduces across a child's first ten years [11–13]. Some children with flexible flatfeet experience lower limb pain [[14] with compromised gait [15]. The quandary for clinicians is discerning when a child's foot is within the developmental range, so that parents may be reassured, advised to monitor with growth, or to treat [16, 17]. Foot posture measures needs to be robust to enable valid assessment of children's foot posture and detection of those 'too flat' for normal range limits.

Children's foot posture has been interpreted with footprint assessments in many studies, with inference of a problematic 'flatfoot' when the footprint area is increased. Throughout early childhood, children continue to develop a skeletal medial longitudinal foot arch [18], different from the adult population [19], and altered children's foot posture must be evaluated in context of developmental stage and the presence/absence of systemic influences, such as hypotonia and hypermobility, which may be non-specific or syndromic, eg Down or Marfan's syndromes.

Despite the fact that paediatric flatfoot is a frequent concern [1, 20], the evidence for treatment is weak. The lack of definition for 'flatfoot' has contributed to varying opinions and a lack of consensus for best practice [21–23]. There is no 'gold standard' for categorising foot type, with the margins of flat / rectus / high arch often undefined. Further, few clinical measures are validated in children, hence it is common for clinicians to make diagnostic decisions based on their personal clinical experience of foot types [24]. The availability of normal reference data for paediatric foot posture, based on a valid measure, will provide a 'benchmark' for clinical evaluation of this frequent clinical concern. The paediatric flatfoot proforma (p-FFP) has attempted to standardise diagnoses, and direct when intervention is required, using a combination of subjective assessment points and a range of foot posture measures [17]. However, the extent to which the p-FFP is used by clinicians is unknown and the proforma does not specify management techniques.

Ten years ago the Foot Posture Index (FPI-6) [25] emerged with the objective to standardise the assessment of foot posture in stance across three discrete foot regions (rearfoot, midfoot, forefoot) enabling feet to be scored and categorised. Both Evans et al [26] and Gijon-Nogueron et al [27] have previously utilised the FPI to investigate the paediatric foot. The FPI is a quick, and easy-to-use clinical tool, not requiring equipment. Scrutiny of the FPI demonstrates it repeatable and valid [3], with excellent inter-rater reliability in assessment of the paediatric foot[28]. Recently, Banwell indicated the FPI as a preferred method of paediatric foot posture measurement in future research[7].

Methods

Data acquisition

Data was acquired from multiple sources where the FPI had been assessed in different children, recruited for screening studies, or acting as comparative controls. Three datasets were acquired from the authors' previous works (n= 1032, n=1457, n = 728) [19, 26, 27]. Measurements were taken during 2010 and 2016, some from 10 schools randomly selected from 25 schools located in the provinces of Málaga, Granada and Plasencia (Spain) (n=2489). In the UK (n = 225), and Australia (n = 503), two datasets were acquired from the author's previous works investigating the reliability of clinical assessment measures (n = 170)[10, 29], and further datasets were acquired from other authors in the UK investigating foot posture in young children (n = 225) [30], and Australia investigating (301 subjects) (n = 303)[31], and the control group from an idiopathic toe-walking study (n = 30)[32]. A total of 3217 observations of the FPI in children aged from three to 15 years were collated.

Participants

The inclusion criterion across the studies was for children, of both genders, and aged between three and 15 years. Exclusion criteria were: foot pain at the time of examination, history of injury to the lower limbs (eg musculoskeletal injuries during the previous six months), congenital foot abnormalities, cerebral palsy, motor dysfunction, inflammatory disorders, or foot surgery. Informed consent had been gained from parents/carers of the children for study participation. All studies contributing data to the amalgamated dataset were conducted in

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accordance with the Declaration of Helsinki and was approved by University Human Ethics Committees in each country (Universities of Malaga CEUMA 91/2016H, Extremadura ID 59/2012, University of Wales Institute, Cardiff and University of South Australia Charles Sturt University Ethics Committees approval number 10/291 and 89/2012).

Protocol

Foot posture was assessed with all subjects barefoot, in a relaxed standing position using the standard protocol for the FPI [33] . The FPI evaluates the multi-segmental nature of foot posture in all three planes, and does not require the use of specialised equipment. Each item of the FPI is scored between −2 and +2, with the total six items referring to positions of the forefoot, midfoot and hindfoot, and the three planes of motion: 1) talar head palpation; 2) symmetry of supra and infra lateral malleolar curvature; 3) inversion/eversion of the calcaneus; 4) prominence in the region of the talo-navicular joint; 5) height of the medial longitudinal arch; 6) abduction/adduction of the forefoot. The FPI score may range from -12 (highly supinated) to +12 (highly pronated). The statistical analysis was independent of the outcome assessors. The FPI assessors were blinded with the data passed directly to the database for entry and analyses. Good inter-observer reliability was recorded (ICC 0.852–0.895) across the studies.

The BMI was calculated from the children's height and weight, calculated as, BMI = weight(kg)/height(m)^2). In Spain, the Orbegozo[34] BMI classification is used; in Australia, the Australian Health Survey [35]; and in UK the National Child Measurement Programme [36]. Accordingly, we classified children by their BMI score, using the systems proposed by Orbegozo, Australian Health Survey, and Public Health England, allocating children to one of four categories: underweight - percentile less than 3 (P<3), normal weight - percentile between 3 and 90 (P3–90), overweight - percentile between 90 and 97 (P90–97) and obesity - percentile greater than 97 (P>97), based on BMI z-score, and age.

Patient involvement

No patients were involved in setting the research question or the outcome measures, nor were they involved in the design or conduct of the study. No patients were asked to advise on interpretation or writing up of results. There are no plans to disseminate the results of the research to study participants.

Data analysis

Data were entered and all analyses were performed using constructed data sets in SPSS version 24 (SPSS Inc, Chicago, Illinois) software packages. The data from the contributing

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studies were collated in a separate database, with statistical analysis performed by an external person, previously blind to the results.

Testing for normality using a Kolmogorov–Smirnov test, found non-normal distribution of all data, indicating suitability for non-parametric analysis (Mann–Whitney U and Kruskal–Wallis). Descriptive statistics (mean, standard deviation, minimum, maximum, frequencies) were used to examine the basic anthropometrical characteristics of the study populations. The FPI was analysed as continuous data, rather than as z-score data, and analysis of variance was conducted to determine the association between the different BMI groups (underweight, normal, overweight and obesity), gender, age, and the FPI. To preserve the independence of data[37], and based on the strong correlation between FPI scores for left and right feet [38], only the left foot (chosen at random) was used in the statistical analyses, applying the Games-Howell post hoc correction to identify significant differences. With reference to the available normative data [25], three FPI-6 scores levels were used to 'define and explore' the range supinated (-12 to -1), neutral (0 to +5), pronated (+6 to +8), and overpronated (+9 to +12). The significance level was set at $p < 0.05$, and all the analyses and tests were two-sided

Results

The mean age of the study population of 3217 children was 8.67 years (SD 2.02), ranging from three years to 15 years. The mean BMI was 19.08 kg/m^2 (SD 4.05), ranging from 10.57 kg/m^2 to 39.14 kg/m^2. The mean FPI score was 4.11 (SD 2.92) and 4.20 (3.00) for left and right feet respectively, with whole scores ranging from -4 to +12 (left and right) (Figure 1, FPI right feet). The total study population gender distribution was 1699 male, 1518 female (Table 1).

In the study population of 3217 children, flatfeet or pronated (FPI ≥+6) were found in 1087 (33.7%) children and normal (FPI <+6) in 1776 (55.2%) children and FPI ≥ +10 yielded flatfeet in 127 (3.9%) cases. Table 2 used designated FPI categories to define and explore the range of foot posture across childhood.

There was strong correlation between FPI scores on left and right sides ($r = 0.9014$, $p < 0.01$), from which the left side was arbitrarily used for subsequent analyses. Similarly, we found little gender bias, with the mean FPI for males 4.2 (2.9), range -4 to +12, and for females, mean FPI 3.99 (2.9), range -4 to +12 (Figure 2). The correlation between FPI and gender used z-score was very weak, if significant ($F=4.073$, $p=0.04$). Between countries there was

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significant difference ($p<0.01$), with Spanish children's mean FPI = 4.00(2.9), the UK mean FPI = 4.9(3.3), and the Australian children's mean FPI = 4.7(3.1).

The general trend showed FPI scores declining with age, which supports the clinical observation of less flatfoot in older children. The frequency of FPI scores for each year of age show that the maximum FPI score = +6, in 15.2% of children (Table 3).

Clinical alert is indicated for foot posture > +/- 2SD, representing 5% of expected abnormality. Table 4 shows the standard deviation of the mean FPI scores, and enables the mean FPI and one and two standard deviations above and below to be referenced as normally expected for each year of age. Figure 3 displays and explores the relationship between foot posture and age across childhood for the study population, using error bars for average z-scores (95% confidence intervals).

Significant correlation was found between BMI and age ($r = 0.276$, $p < 0.01$). The correlation between BMI and FPI, whilst also statistically significant, was very weak and also inverse ($r = -0.066$, $p< 0.01$), refuting the strength of relationship between body mass and foot posture. BMI cut-points and percentiles were used to define underweight, normal weight, overweight, and obese. Within the total 3217 children, 142 (4.4%) were underweight, 2407 (74.8%) were normal weight, 469 (16.1%) were overweight, and 199 (6.2%) were obese (Figure 4). Combining categories, 668 (20.8%) of all children were overweight or obese.

The foot posture categories were analysed for distribution across the BMI categories (Table 5). The largest overlap of FPI and BMI categories were: normal weight / normal FPI range, n= 1325 (41.2%); normal weight / pronated foot posture, n= 728 (22.6%); overweight or obese / normal foot posture, n=383(11.9%). Supinated feet across all BMI categories returned n=354(11.0%). Exploring the association between the pronated foot and BMI across FPI ranges showed that 960(29.8%) children had foot posture that was pronated, FPI > 6. Of these, 44 (4.5%) were underweight, 728 (75.8%) were normal weight, 188 were overweight, or obese (19.5%). Further, 127 children had highly pronated foot posture, FPI > 10. Of these, 12 (9.4%) were underweight, 94 (74.0%) were normal weight, and 21 (16.5%) were overweight or obese.

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Discussion

This study is the largest investigation to explore paediatric foot posture using the FPI, paediatric anthropometry using BMI, and to analyse the regularly cited influence of increased body weight as a potentiating factor for flatfeet across childhood. This investigation of paediatric foot posture includes children aged from three to 15 years, superseding previous, smaller or age-limited, studies[26, 27].

This study confirms the pronated foot as the common foot posture of childhood, with mean FPI of +4, and 3-point standard deviation, such that average normal FPI range for children aged three to 15 years was between the FPI range +1 to +7 (mean +/- SD). These findings concur with the recent cross-sectional investigation of 1762 children aged six to 11 years [27]. Similarly to Gijon-Nogueron et al [27], we found that the mean FPI scores reduced with age, in non-linear pattern, and within a wide range. The standard deviation approximated 75% of the FPI mean at every age, confirming the considerable and normal variation in foot posture across childhood.

The greatest number of children across all ages displayed FPI within the 0 to +5 FPI range, ie normal foot posture. Next common were children with pronated feet. The least common FPI categories were either supinated or highly pronated, indicative of the foot types that should arrest the attention of clinicians, as less usual presentations. Flatfoot or pronated foot posture was generally found to decline with age, but mean reduction was non-linear and modest, from +6 at age three years, to +3 at 14 years. Importantly, the normal FPI range of variation was broad: -1 to +11 at age three years, and FPI +3 to +9 at age 14 years.

The relationship between increased BMI and flatfeet is again refuted by the findings of this study which found that only 16.5% of the children with highly pronated feet, were also overweight or obese. Similar results have been found in other recent studies [26] [39], contrasting with many older studies which asserted that heavier, fatter children have flatter feet. Importantly, the previous studies all assessed foot posture using a footprint based method of foot posture assessment [4, 40, 41], a method which may well represent adipose tissue spread with weight bearing, rather than anatomical foot morphology, more directly evaluated using the FPI [25, 26]. Whilst it is concerning to find that 21% of the children in this study were overweight or obese, association with flatfeet is not found.

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The availability of average FPI whole scores, enables clinicians to inform parents as to what is ‘average’ and what is ‘normal’ at any age, as statistically defined. The availability of FPI scores within one standard deviation above and below the mean, enables clinicians to confirm for parents that their child approximates with two-thirds, or 68%, of children for a specific age. Further, FPI scores within two standard deviations above and below the mean, enable clinicians to inform parents that their child is within the normal 95% range, approximating one-quarter, or 27%, of same age children. Such reference data helps appreciation of the range of ‘normal range’ for foot posture, similarly to that for the onset of independent walking (age range of 10 to 16 months, mean age approximating 12 to 13 months)[18].

The focus of this investigation has been to better elucidate the normal range of foot posture across childhood, as is commonly assessed by many clinicians using the FPI. Simultaneously, the authors aimed to provide clinicians with a robust reference guide of normal values within statistical bounds. The culmination of this aim is provided as a reference Table (Table 4). The scale of this investigation renders its findings stronger than those of the 1000 Norms protocol for most age (year) groups, as the comparative number of participants reveals. The 1000 Norms protocol will include: ages 3 to 9 years, 140 (20 per age year); ages 10 to 19 years, 160 (16 per age year)[42]. By comparison, this study informs for: ages 3 to 9 years, 2796 (20 to 764 per age year); ages 10 to 15 years, 1304 (1 to 634 per age year).

Clinicians must move beyond flatfoot posture appearance as an indicator for intervention, and instead appreciate the range of normal variation, and only respond to more pertinent factors as outlined by the 3QQ (3 Quick Questions) screening tool (addressing pain presentations, left versus right limb symmetry, paediatric age range)[20]. Clinicians need to appreciate the normal range of many developmental features, yet simultaneously be alert to the level at which clinical concern should be raised. The tabulated reference guide provided from this study, will be of immediate clinical relevance.

The striking finding of this study is not that paediatric flexible flatfoot is largely normal, it is that the supinated paediatric foot is far more likely to be abnormal, especially at age three and four years. An FPI of -2 or less, must be considered ‘abnormal’ until shown otherwise, as it is outside normal range at any age, and should prompt neurological assessment.

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Limitations of this investigation include the cross-sectional nature of the design and the ethnicity of participants (largely Caucasian). Further, the sample does not evenly represent children from each country, nor each year of age, hence caution is indicated for ages three to seven years and 14 to15 years where sampling was least. In addition, consideration that this study is a collation of smaller discrete studies, and should be consider measurement errors, although all followed the same protocol [3]. Prospective data avails stronger evidence of foot posture change over time [10].

Conclusions

This is the largest study of paediatric foot posture to date. Importantly, the main finding is to denounce the paediatric flatfoot as deviant. This study confirms that the 'flat' or pronated foot is the common foot posture of childhood, with FPI score of +4(3) the average finding. A wide normal range of foot posture across childhood is confirmed (16 FPI points, ie -2 to +12).

The reference data produced from the findings of this study will assist clinicians in standardised decision-making.

Increased paediatric BMI was not associated with flatter feet, questioning the validity of footprint-derived measures.

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Legend text

Figure 1 Frequency plot of FPI values (n=3217)

Figure 2 FPI frequency plot for gender

Figure 3 Simple error bars display the relationship between FPI and age.

Figure 4 Frequency plot of BMI category versus FPI category

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Table 1

Descriptive statistics for the amalgamated data sets. Due to variation between the constituent datasets, main results emerged from the variables of age, BMI, FPI Left. Gender ratio was 1699 males: 1518 females.

Variable	N	Range	Minimum	Maximum	Mean	SD
Age (years)	3217	12	3	15	8.67	2.02
BMI (kg/m^2)	3217	28.57	10.57	39.14	19.08	4.05
FPI Right	3217	16	-4	12	4.20	3.00
FPI Left	3217	16	-4	12	4.11	2.92

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Table 2

The FPI range which refer to foot posture categories. were collated for each year of age. The median FPI total score across the study population was 4(3) points. with the trend of reduced FPI with increased age confirmed.

Age (yrs)	No. /Age	FPI-6 total score – *Foot posture category cut-offs*						
		Supinated	Normal	Pronated	High pronated	Mean FPI	SD	Range
3	21	2	4	14	1	6.38	3.03	11
4	20	1	5	12	2	6.7	2.60	11
5	55	5	34	13	3	4.15	2.81	12
6	388	29	213	132	14	4.45	2.80	15
7	536	51	296	164	25	4.3	2.93	16
8	473	48	271	131	23	4.01	2.95	16
9	625	74	362	175	14	3.82	2.77	16
10	497	62	291	123	21	3.69	2.86	15
11	377	50	194	119	14	4.24	3.02	16
12	144	24	65	48	7	4.22	3.23	14
13	33	1	17	12	3	5.18	2.98	10
14	22	4	12	6	0	3.14	3.40	12
15	26	3	12	11	0	4.19	3.31	12
Total	3217	354(11%)	1776(55.2%)	960(29.84%)	127(3.95%)	4.2	3	16

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Table 3

FPI total scores versus age year groups.

FPI/ Age	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	Total / n
3	0	0	0	1	1	0	0	1	2	1	2	0	3	4	4	0	2	21
4	0	0	0	0	1	0	0	0	3	3	5	2	2	1	1	2	0	20
5	0	0	1	0	6	3	7	11	7	3	6	2	2	1	1	4	1	55
6	0	1	3	6	24	31	45	46	47	38	69	30	19	11	6	8	4	388
7	1	6	4	3	39	43	48	72	69	55	90	33	22	27	14	7	3	536
8	1	2	1	8	36	47	55	45	49	48	89	27	24	17	13	7	4	473
9	3	3	5	11	55	61	60	72	81	78	92	48	21	14	9	8	4	625
10	0	5	3	14	41	59	68	71	54	39	61	23	17	12	17	9	4	497
11	1	3	4	10	29	22	31	48	58	32	52	29	26	14	10	3	5	377
12	0	2	2	6	17	9	12	7	19	11	19	14	12	6	5	3	0	144
13	0	0	0	0	1	2	1	6	2	5	2	7	2	2	3	0	0	33
14	0	1	2	0	1	3	2	3	4	0	1	2	0	2	1	0	0	22
15	0	1	2	0	0	1	3	4	3	2	2	3	0	3	2	0	0	26
Total/ FPI	6	24	27	59	251	281	332	386	398	315	490	220	150	114	86	51	27	3217
%	0,2	0,7	0,8	1,8	7,8	8,7	10,3	12	12,4	9,8	15,2	6,8	4,7	3,5	2,7	1,6	0,8	100

%: Percentage, SD: Standard Deviation, R: Range

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Table 4
FPI total scores versus age year groups.

Age	-2SD	-1SD	**Mean**	+1SD	+2SD	Sample size	SD	FPI Median (+/- 1SD)	FPI Median (+/- 2SD)	**Clinical Alert FPI > +/-2SD**
3	0,02	3,60	**7,19**	10,78	12.78	21	3.6	8 (4 – 12)	8 (0 – 12)	**< 0 or > 12**
4	1,11	3,76	**6,4**	9,04	11.79	20	2.6	6 (3 – 9)	6 (0 – 12)	**< 0 or > 12**
5	-2,41	0,91	**4,22**	7,54	10.68	55	3.3	3 (0 – 6)	3 (-3 – 9)	**< -3 or > 9**
6	-1,37	1,50	**4,36**	7,22	10.71	388	2.9	4 (1 – 7)	4 (-2 – 10)	**< -2 or > 10**
7	-1,53	1,40	**4,32**	7,24	10.67	536	2.9	4 (1 – 7)	4 (-2 – 10)	**< -2 or > 10**
8	-1,64	1,33	**4,29**	7,25	10.15	473	2.9	4 (1 – 7)	4 (-1 – 10)	**< -1 or > 10**
9	-1,74	1,11	**3,96**	6,81	9.83	625	2.8	4 (1 – 7)	4 (-1 – 10)	**< -1 or > 10**
10	-2,31	0,73	**3,77**	6,81	9.92	497	3.0	3 (0 – 6)	4 (-3 – 9)	**< -3 or > 9**
11	-1,77	1,28	**4,33**	7,38	10.20	377	3.0	4 (1 – 7)	4 (-2 – 10)	**< -2 or > 10**
12	-2,43	0,92	**4,26**	7,61	10.73	144	3.3	4 (1 – 7)	4 (-2 – 10)	**< -2 or > 10**
13	-0,03	2,71	**5,45**	8,19	11.18	33	2.7	5 (2 – 8)	5 (-1 – 11)	**< -1 or > 11**
14	-3,89	-0,28	**3,32**	6,92	9.92	22	3.6	4 (1 – 7)	4 (- 2 – 9)	**< -2 or > 9**
15	-2,84	0,77	**4,38**	7,99	11.18	26	3.6	4 (0 - 8)	4 (-4 - 12)	**<-4 or >12**

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Table 5

FPI and BMI category distributions, showing greatest concordance between normal FPI and normal BMI.

		Underweight	Normal	Overweight or Obese	Total
Supinated	Count	18 [a]	260 [a]	76 [a]	354
	Expected count	15.6	264.9	73.5	354
Normal	Count	68 [a]	1325 [a]	383 [a]	1776
	Expected count	78.4	1328.8	368.8	1776
Pronated	Count	44 [a]	728 [a]	188 [a]	960
	Expected count	42.4	718.3	199.3	960
Highly Pronated	Count	12 [a]	94 [b]	21 [b]	127
	Expected count	5.6	95	26.4	127
Total	Count	142	2407	668	3217

Note: superscript letters denote a subset of FPI (Left) categories whose column proportions did not differ significantly from each other at the level of 0.05.

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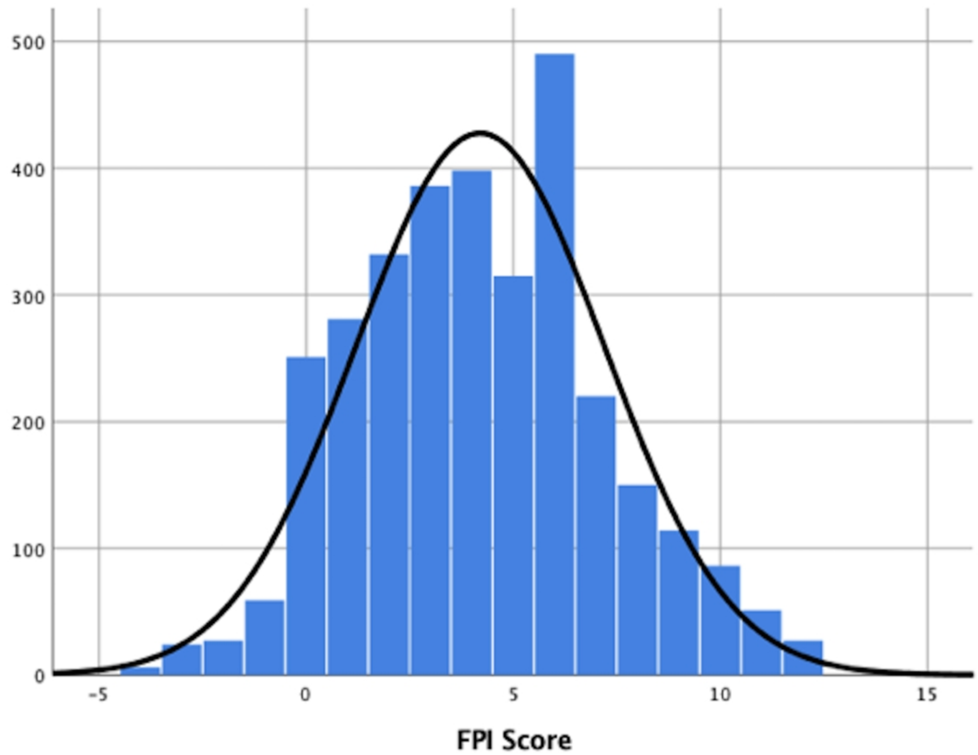

Figure 1 Frequency plot of FPI values (n=3217)

188x157mm (300 x 300 DPI)

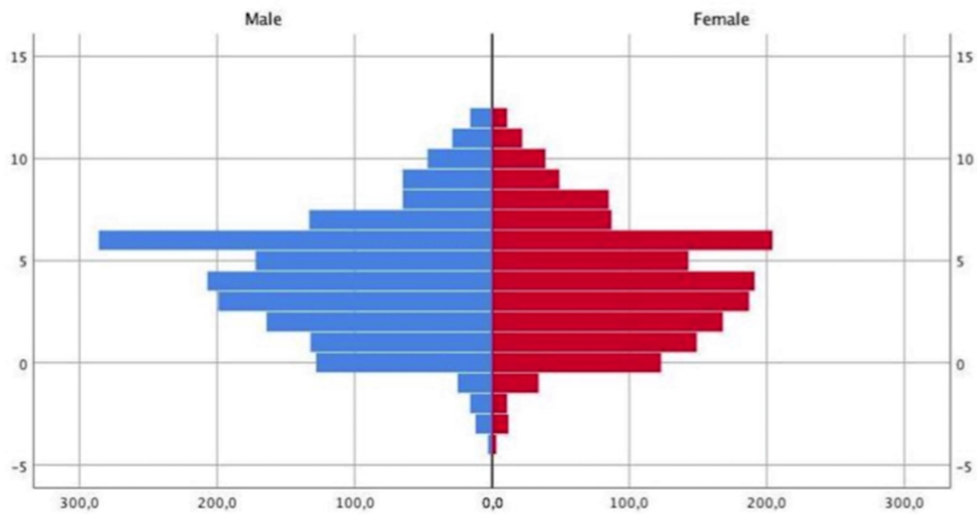

Figure 2 FPI frequency plot for gender

260x151mm (300 x 300 DPI)

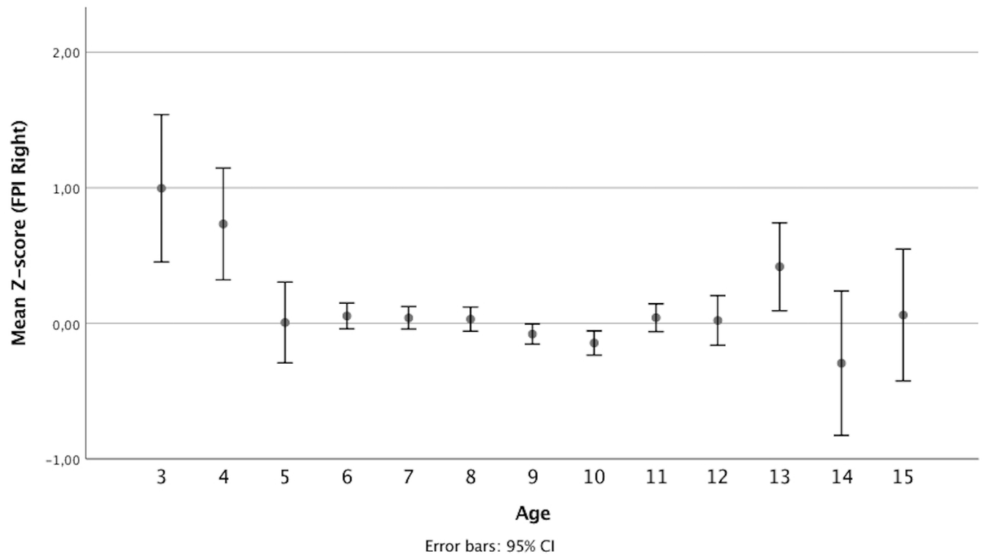

Figure 3 Simple error bars display the relationship between FPI and age.

99x58mm (300 x 300 DPI)

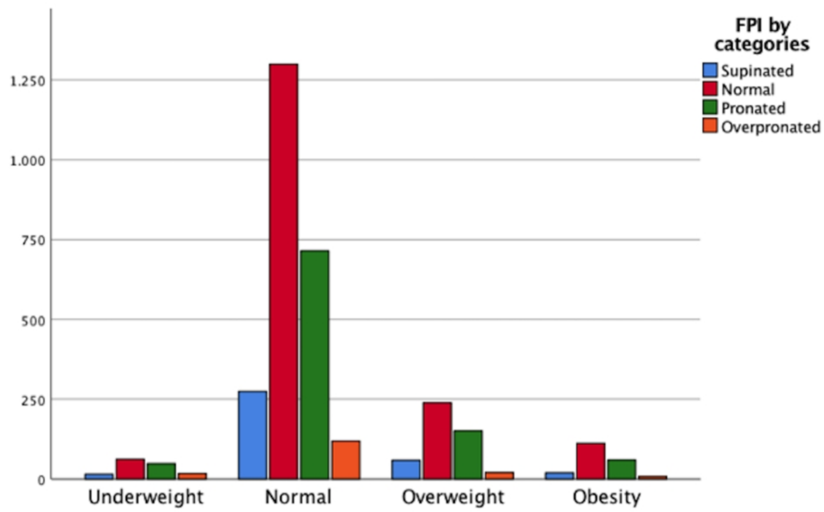

Figure 4 Frequency plot of BMI category versus FPI category

89x67mm (600 x 600 DPI)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1-2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	5
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*5*
Bias	9	Describe any efforts to address potential sources of bias	-
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	6
		(*b*) Describe any methods used to examine subgroups and interactions	6
		(*c*) Explain how missing data were addressed	-
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	6
		(*e*) Describe any sensitivity analyses	

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Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	7
		(b) Give reasons for non-participation at each stage	-
		(c) Consider use of a flow diagram	-
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	7-8
		(b) Indicate number of participants with missing data for each variable of interest	-
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	*7-8*
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	7-8
		(*b*) Report category boundaries when continuous variables were categorized	7-8
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	8
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	8-9
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	8-9
Generalisability	21	Discuss the generalisability (external validity) of the study results	8-9
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	1

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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International normative data for paediatric foot posture assessment: a cross-sectional investigation.

[Short title: Children's flatfeet – normal or not?]

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Ethical approval: All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. (Universities of Malaga CEUMA 91/2016H, Extremadura ID 59/2012, University of Wales Institute, Cardiff and University of South Australia Charles Sturt University Ethics Committees approval number 10/291 and 89/2012).

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Informed consent: Informed consent was obtained from all individual participants (parents), whose children were included in the study.

Data sharing statement: Available data can be obtained by contacting the corresponding author.

Contributors: GG-N, AM-N, and AME contributed to the conception of this study. GG-N, AM-N, and AME did the statistical analysis. Data collectors were collected in Spain JM-A and PG-A and in Australia AME. GG-N, AM-N, PG-A, JM-A and AME were involved in the writing and in the review of the manuscript.

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Abstract

Objectives: Frequent confusion about paediatric foot posture, and a lack of defined values, results in overdiagnosis of 'flatfoot', or pronated foot, and unnecessary treatment. The objective of this study was to establish international reference data for foot posture across childhood, and influence of Body Mass Index (BMI) on paediatric foot posture.

Design: Cross-sectional study

Setting and participants: The dataset comprised 3217 healthy children, aged from three to 15 years. Contributing data were acquired from Spain, UK, and Australia.

Interventions: Foot posture was described by means and z-score of the foot posture index (FPI) and the height and weight of each subject was measured and the body mass index (BMI) was calculated**.**

Results: Pronated (FPI ≥+6) were found in 1087 (33.7%) and normal (FPI 0 to +6) in 1776 (55.2%). FPI ≥ +10 (highly pronated) was found in 127 children (3.9%). Approximating 20% of children were overweight/obese, but correlation between BMI and FPI was weak and inverse (r = -0.066, p< 0.01), refuting the relationship between increased body mass and flatfeet.

Conclusions: This study confirms that the 'flat' or pronated foot is the common foot posture of childhood, with FPI score of +4(3) the average finding. **Trend indicated a less 'flat' foot with age, although non-linear.** A wide normal range of foot posture across childhood is confirmed.

Strengths and limitations of this study

- First study to measure foot posture with any method in a sample of 3217 children
- Comparison between different countries strengthens the study findings
- The sample does not balance the number of children from each country
- The disproportionate numbers of children within each age year group

Key Words: Foot, Children, Posture, Paediatric, Foot posture index, Flatfoot

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Introduction

Paediatric foot posture is a common parental concern, a frequent presentation to clinicians, and an area of dispute regarding **both** the need for treatment, **and unnecessary treatment** [1] [2]. The term 'flatfoot', has referred to a foot which is nearly or completely contacting the ground [3], and has been evaluated using foot posture [4], footprints [5], radiological and anthropometric measures [6] and is often poorly defined [7]. From a clinical practice perspective, there is no single universally accepted diagnostic technique.

A systematic review [8] **has addressed** flatfoot and clinical measures, in healthy children, **finding** 'flatfoot' **the expected foot posture before** eight years of age, due to young osseous structures, ligament laxity, increased adipose tissue, and immature neuromuscular control [9,10]. With variation, flatfoot posture reduces across a child's first ten years [11–13]. Some children with flexible flatfeet experience lower limb pain [14] with compromised gait [15]. The quandary for clinicians is discerning when a child's foot is within the developmental range, so that parents may be reassured, advised to monitor with growth, or to treat [16,17].

Children's foot posture has been interpreted with footprint assessments in many studies, with inference of a problematic 'flatfoot' when the footprint area is increased. Throughout early childhood, children continue to develop a skeletal medial longitudinal foot arch [18], different from the adult population [19], and altered children's foot posture must be evaluated in context of developmental stage and the presence/absence of systemic influences, such as hypotonia and hypermobility, which may be non-specific or syndromic, eg Down or Marfan's syndromes.

Despite the fact that paediatric flatfoot is a frequent concern [1,20], the evidence for treatment is weak. The lack of definition for 'flatfoot' has contributed to varying opinions and a lack of consensus for best practice [21–23]. There is no 'gold standard' for categorising foot type, with the margins of flat / rectus / high arch often undefined. Further, few clinical measures are validated in children, hence it is common for clinicians to make diagnostic decisions based on their personal clinical experience of foot types [24]. The availability of normal reference data for paediatric foot posture, based on a valid measure, will provide a 'benchmark' for clinical evaluation of this frequent clinical concern. The paediatric flatfoot proforma (p-FFP) has attempted to standardise diagnoses, and direct when intervention is required, using a combination of subjective assessment points and a range of foot posture

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measures [17]. However, the extent to which the p-FFP is used by clinicians is unknown and the proforma does not specify management techniques.

Ten years ago the Foot Posture Index (FPI-6) [25] emerged with the objective to standardise the assessment of foot posture in stance across three discrete foot regions (rearfoot, midfoot, forefoot) enabling feet to be scored and categorised. Both Evans et al [26] and Gijon-Nogueron et al [27] have previously utilised the FPI to investigate the paediatric foot. The FPI is a quick, and easy-to-use clinical tool, not requiring equipment. Scrutiny of the FPI demonstrates it repeatable and valid [4], with excellent inter-rater reliability in assessment of the paediatric foot[28]. Recently, the FPI **has been identified** as a preferred method of paediatric foot posture measurement in future research[29].

Methods

Data acquisition

Data was acquired from multiple sources where the FPI had been assessed in different children, recruited for screening studies, or acting as comparative controls. Three datasets were acquired from the authors' previous works (n= 1032, n=1457, n = 728) [19,26,27]. Measurements were taken during 2010 and 2016, some from 10 schools randomly selected from 25 schools located in the provinces of Málaga, Granada and Plasencia (Spain) (n=2489). In the UK (n = 225), and Australia (n = 503), two datasets were acquired from the author's previous works investigating the reliability of clinical assessment measures (n = 170)[10,30], and further datasets were acquired from other authors in the UK investigating foot posture in young children (n = 225) [31], and Australia investigating (301 subjects) (n = 303)[32], and the control group from an idiopathic toe-walking study (n = 30)[33]. A total of 3217 observations of the FPI in children aged from three to 15 years were collated.

Participants

The inclusion criterion across the studies was for children, of both genders, and aged between three and 15 years. Exclusion criteria were: foot pain at the time of examination, history of injury to the lower limbs (eg musculoskeletal injuries during the previous six months), congenital foot abnormalities, cerebral palsy, motor dysfunction, inflammatory disorders, or foot surgery. Informed consent had been gained from parents/carers of the children for study participation. All studies contributing data to the amalgamated dataset were conducted in accordance with the Declaration of Helsinki and was approved by University Human Ethics Committees in each country (Universities of Malaga CEUMA 91/2016H, Extremadura ID

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59/2012, University of Wales Institute, Cardiff and University of South Australia Charles Sturt University Ethics Committees approval number 10/291 and 89/2012).

Protocol

Foot posture was assessed with all subjects barefoot, in a relaxed standing position using the standard protocol for the FPI [34] . The FPI evaluates the multi-segmental nature of foot posture in all three planes, and does not require the use of specialised equipment. Each item of the FPI is scored between −2 and +2, with the total six items referring to positions of the forefoot, midfoot and hindfoot, and the three planes of motion: 1) talar head palpation; 2) symmetry of supra and infra lateral malleolar curvature; 3) inversion/eversion of the calcaneus; 4) prominence in the region of the talo-navicular joint; 5) height of the medial longitudinal arch; 6) abduction/adduction of the forefoot. The FPI score may range from -12 (highly supinated) to +12 (highly pronated). The statistical analysis was independent of the outcome assessors. The FPI assessors were blinded with the data passed directly to the database for entry and analyses. Good inter-observer reliability was recorded (ICC 0.852–0.895) across the studies.

The BMI was calculated from the children's height and weight, calculated as, BMI = weight(kg)/height(m)^2). In Spain, the Orbegozo[35] BMI classification is used; in Australia, the Australian Health Survey [36]; and in UK the National Child Measurement Programme [37]. Accordingly, we classified children by their BMI score, using the systems proposed by Orbegozo, Australian Health Survey, and Public Health England, allocating children to one of four categories: underweight - percentile less than 3 (P<3), normal weight - percentile between 3 and 90 (P3–90), overweight - percentile between 90 and 97 (P90–97) and obesity - percentile greater than 97 (P>97), based on BMI z-score, and age.

Patient involvement

No patients were involved in setting the research question or the outcome measures, nor were they involved in the design or conduct of the study. No patients were asked to advise on interpretation or writing up of results. There are no plans to disseminate the results of the research to study participants.

Data analysis

Data were entered and all analyses were performed using constructed data sets in SPSS version 24 (SPSS Inc, Chicago, Illinois) software packages. The data from the contributing studies were collated in a separate database, with statistical analysis performed by an external person, previously blind to the results.

Testing for normality using a Kolmogorov–Smirnov test, found non-normal distribution of all

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data, indicating suitability for non-parametric analysis (Mann–Whitney U and Kruskal–Wallis). Descriptive statistics (mean, standard deviation, minimum, maximum, frequencies) were used to examine the basic anthropometrical characteristics of the study populations. The FPI was analysed as continuous data, rather than as z-score data, and analysis of variance was conducted to determine the association between the different BMI groups (underweight, normal, overweight and obesity), gender, age, and the FPI. To preserve the independence of data[38], and based on the strong correlation between FPI scores for left and right feet [39], only the left foot (chosen at random) was used in the statistical analyses, applying the Games-Howell post hoc correction to identify significant differences. With reference to the available normative data [25], three FPI-6 scores levels were used to 'define and explore' the range supinated (-12 to -1), neutral (0 to +5), pronated (+6 to +8), and overpronated (+9 to +12). The significance level was set at $p < 0.05$, and all the analyses and tests were two-sided

Results

The mean age of the study population of 3217 children was 8.67 years (SD 2.02), ranging from three years to 15 years. The mean BMI was 19.08 kg/m^2 (SD 4.05), ranging from 10.57 kg/m^2 to 39.14 kg/m^2. The mean FPI score was 4.11 (SD 2.92) and 4.20 (3.00) for left and right feet respectively, with whole scores ranging from -4 to +12 (left and right) (Figure 1, FPI right feet). The total study population gender distribution was 1699 male, 1518 female (Table 1).

In the study population of 3217 children, flatfeet or pronated (FPI ≥+6) were found in 1087 (33.7%) children and normal (FPI <+6) in 1776 (55.2%) children and FPI ≥ +10 yielded flatfeet in 127 (3.9%) cases. Table 2 used designated FPI categories to define and explore the range of foot posture across childhood.

There was strong correlation between FPI scores on left and right sides ($r = 0.9014$, $p < 0.01$), from which the left side was arbitrarily used for subsequent analyses. Similarly, we found little gender bias, with the mean FPI for males 4.2 (2.9), range -4 to +12, and for females, mean FPI 3.99 (2.9), range -4 to +12 (Figure 2). The correlation between FPI and gender used z-score was very weak, if significant ($F=4.073$, $p=0.04$). Between countries there was significant difference ($p<0.01$), with Spanish children's mean FPI = 4.00(2.9), the UK mean FPI = 4.9(3.3), and the Australian children's mean FPI = 4.7(3.1).

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The general trend showed FPI scores declining with age, which supports the clinical observation of less flatfoot in older children. The frequency of FPI scores for each year of age show that the maximum FPI score = +6, in 15.2% of children (Table 3).
Clinical alert is indicated for foot posture > +/- 2SD, representing 5% of expected abnormality. Table 4 shows the standard deviation of the mean FPI scores, and enables the mean FPI and one and two standard deviations above and below to be referenced as normally expected for each year of age. Figure 3 displays and explores the relationship between foot posture and age across childhood for the study population, using error bars for average z-scores (95% confidence intervals).

Significant correlation was found between BMI and age ($r = 0.276$, $p < 0.01$). The correlation between BMI and FPI, whilst also statistically significant, was very weak and also inverse ($r = -0.066$, $p < 0.01$), refuting the strength of relationship between body mass and foot posture. BMI cut-points and percentiles were used to define underweight, normal weight, overweight, and obese. Within the total 3217 children, 142 (4.4%) were underweight, 2407 (74.8%) were normal weight, 469 (16.1%) were overweight, and 199 (6.2%) were obese (Figure 4). Combining categories, 668 (20.8%) of all children were overweight or obese.

The foot posture categories were analysed for distribution across the BMI categories (Table 5). The largest overlap of FPI and BMI categories were: normal weight / normal FPI range, n= 1325 (41.2%); normal weight / pronated foot posture, n= 728 (22.6%); overweight or obese / normal foot posture, n=383(11.9%). Supinated feet across all BMI categories returned n=354(11.0%). Exploring the association between the pronated foot and BMI across FPI ranges showed that 960(29.8%) children had foot posture that was pronated, FPI > 6. Of these, 44 (4.5%) were underweight, 728 (75.8%) were normal weight, 188 were overweight, or obese (19.5%). Further, 127 children had highly pronated foot posture, FPI > 10. Of these, 12 (9.4%) were underweight, 94 (74.0%) were normal weight, and 21 (16.5%) were overweight or obese.

Discussion

This study is the largest investigation to explore paediatric foot posture using the FPI, paediatric anthropometry using BMI, and to analyse the regularly cited influence of increased body weight as a potentiating factor for flatfeet across childhood. This investigation of

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paediatric foot posture includes children aged from three to 15 years, superseding previous, smaller or age-limited, studies[26,27].

This study confirms the pronated foot as the common foot posture of childhood, with mean FPI of +4, and 3-point standard deviation, such that average normal FPI range for children aged three to 15 years was between the FPI range +1 to +7 (mean +/- SD). These findings concur with the recent cross-sectional investigation of 1762 children aged six to 11 years [27]. Similarly to Gijon-Nogueron et al [27], we found that the mean FPI scores reduced with age, in non-linear pattern, and within a wide range. The standard deviation approximated 75% of the FPI mean at every age, confirming the considerable and normal variation in foot posture across childhood.

The greatest number of children across all ages displayed FPI within the 0 to +5 FPI range, ie normal foot posture. Next common were children with pronated feet. The least common FPI categories were either supinated or highly pronated, indicative of the foot types that should arrest the attention of clinicians, as less usual presentations. Flatfoot or pronated foot posture was generally found to decline with age, but mean reduction was non-linear and modest, from +6 at age three years, to +3 at 14 years. Importantly, the normal FPI range of variation was broad: -1 to +11 at age three years, and FPI +3 to +9 at age 14 years.

The relationship between increased BMI and flatfeet is again refuted by the findings of this study which found that only 16.5% of the children with highly pronated feet, were also overweight or obese. Similar results have been found in other recent studies [26] [40], contrasting with many older studies which asserted that heavier, fatter children have flatter feet. Importantly, the previous studies all assessed foot posture using a footprint based method of foot posture assessment [5,41,42], a method which may well represent adipose tissue spread with weight bearing, rather than anatomical foot morphology, more directly evaluated using the FPI [25,26]. Whilst it is concerning to find that 21% of the children in this study were overweight or obese, association with flatfeet is not found.

The availability of average FPI whole scores, enables clinicians to inform parents as to what is ‘average’ and what is ‘normal’ at any age, as statistically defined. The availability of FPI scores within one standard deviation above and below the mean, enables clinicians to confirm for parents that their child approximates with two-thirds, or 68%, of children for a specific age. Further, FPI scores within two standard deviations above and below the mean, enable

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clinicians to inform parents that their child is within the normal 95% range, approximating one-quarter, or 27%, of same age children. Such reference data helps appreciation of the range of 'normal range' for foot posture, similarly to that for the onset of independent walking (age range of 10 to 16 months, mean age approximating 12 to 13 months)[18].

The focus of this investigation has been to better elucidate the normal range of foot posture across childhood, as is commonly assessed by many clinicians using the FPI. Simultaneously, the authors aimed to provide clinicians with a robust reference guide of normal values within statistical bounds. The culmination of this aim is provided as a reference Table (Table 4). The scale of this investigation renders its findings stronger than those of the 1000 Norms protocol for most age (year) groups, as the comparative number of participants reveals. The 1000 Norms protocol will include: ages 3 to 9 years, 140 (20 per age year); ages 10 to 19 years, 160 (16 per age year)[43]. By comparison, this study informs for: ages 3 to 9 years, 2796 (20 to 764 per age year); ages 10 to 15 years, 1304 (1 to 634 per age year).

Clinicians must move beyond flatfoot posture appearance as an indicator for intervention, and instead appreciate the range of normal variation, and only respond to more pertinent factors as outlined by the 3QQ (3 Quick Questions) screening tool (addressing pain presentations, left versus right limb symmetry, paediatric age range)[20]. Clinicians need to appreciate the normal range of many developmental features, yet simultaneously be alert to the level at which clinical concern should be raised. The tabulated reference guide provided from this study, will be of immediate clinical relevance.

The striking finding of this study is not that paediatric flexible flatfoot is largely normal, it is that the supinated paediatric foot is far more likely to be abnormal, especially at age three and four years. An FPI of -2 or less, must be considered 'abnormal' until shown otherwise, as it is outside normal range at any age, and should prompt neurological assessment.

Limitations of this investigation include the cross-sectional nature of the design and the ethnicity of participants (largely Caucasian). Further, the sample does not evenly represent children from each country, nor each year of age, hence caution is indicated for ages three to seven years and 14 to15 years where sampling was least. In addition, consideration that this study is a collation of smaller discrete studies, and should be consider measurement errors,

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although all followed the same protocol [3]. Prospective data avails stronger evidence of foot posture change over time [4].

Conclusions

This is the largest study of paediatric foot posture to date. Importantly, the main finding is to denounce the paediatric flatfoot as deviant. This study confirms that the 'flat' or pronated foot is the common foot posture of childhood, with FPI score of +4(3) the average finding. A wide normal range of foot posture across childhood is confirmed (16 FPI points, ie -2 to +12).

The reference data produced from the findings of this study will assist clinicians in standardised decision-making.

Increased paediatric BMI was not associated with flatter feet, questioning the validity of footprint-derived measures.

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Legend text

Figure 1 Frequency plot of FPI values (n=3217)

Figure 2 FPI frequency plot for gender

Figure 3 Simple error bars display the relationship between FPI and age.

Figure 4 Frequency plot of BMI category versus FPI category

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Table 1

Descriptive statistics for the amalgamated data sets. Due to variation between the constituent datasets, main results emerged from the variables of age, BMI, FPI Left. Gender ratio was 1699 males: 1518 females.

Variable	N	Range	Minimum	Maximum	Mean	SD
Age (years)	3217	12	3	15	8.67	2.02
BMI (kg/m^2)	3217	28.57	10.57	39.14	19.08	4.05
FPI Right	3217	16	-4	12	4.20	3.00
FPI Left	3217	16	-4	12	4.11	2.92

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Table 2

The FPI range which refer to foot posture categories. were collated for each year of age. The median FPI total score across the study population was 4(3) points. with the trend of reduced FPI with increased age confirmed.

Age (yrs)	No. /Age	FPI-6 total score – *Foot posture category cut-offs*						
		Supinated	Normal	Pronated	High pronated	Mean FPI	SD	Range
3	21	2	4	14	1	6.38	3.03	11
4	20	1	5	12	2	6.7	2.60	11
5	55	5	34	13	3	4.15	2.81	12
6	388	29	213	132	14	4.45	2.80	15
7	536	51	296	164	25	4.3	2.93	16
8	473	48	271	131	23	4.01	2.95	16
9	625	74	362	175	14	3.82	2.77	16
10	497	62	291	123	21	3.69	2.86	15
11	377	50	194	119	14	4.24	3.02	16
12	144	24	65	48	7	4.22	3.23	14
13	33	1	17	12	3	5.18	2.98	10
14	22	4	12	6	0	3.14	3.40	12
15	26	3	12	11	0	4.19	3.31	12
Total	3217	354(11%)	1776(55.2%)	960(29.84%)	127(3.95%)	4.2	3	16

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Table 3

FPI total scores versus age year groups.

FPI/ age	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	Total / n
3	0	0	0	1	1	0	0	1	2	1	2	0	3	4	4	0	2	21
4	0	0	0	0	1	0	0	0	3	3	5	2	2	1	1	2	0	20
5	0	0	1	0	6	3	7	11	7	3	6	2	2	1	1	4	1	55
6	0	1	3	6	24	31	45	46	47	38	69	30	19	11	6	8	4	388
7	1	6	4	3	39	43	48	72	69	55	90	33	22	27	14	7	3	536
8	1	2	1	8	36	47	55	45	49	48	89	27	24	17	13	7	4	473
9	3	3	5	11	55	61	60	72	81	78	92	48	21	14	9	8	4	625
10	0	5	3	14	41	59	68	71	54	39	61	23	17	12	17	9	4	497
11	1	3	4	10	29	22	31	48	58	32	52	29	26	14	10	3	5	377
12	0	2	2	6	17	9	12	7	19	11	19	14	12	6	5	3	0	144
13	0	0	0	0	1	2	1	6	2	5	2	7	2	2	3	0	0	33
14	0	1	2	0	1	3	2	3	4	0	1	2	0	2	1	0	0	22
15	0	1	2	0	0	1	3	4	3	2	2	3	0	3	2	0	0	26
Total/ FPI	6	24	27	59	251	281	332	386	398	315	490	220	150	114	86	51	27	3217
%	0.2	0.7	0.8	1.8	7.8	8.7	10.3	12.0	12.4	9.8	15.2	6.8	4.7	3.5	2.7	1.6	0.8	100

%: Percentage, SD: Standard Deviation, R: Range

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Table 4
FPI total scores versus age year groups, **showing normal range, and FPI outside normal range.**

Age	-2SD	-1SD	**Mean**	+1SD	+2SD	Sample size	SD	FPI Median (+/- 1SD)	FPI Median (+/- 2SD)	**Clinical Alert FPI > +/-2SD**
3	0.02	3.60	**7.19**	10.78	12.78	21	3.6	8 (4 – 12)	8 (0 – 12)	**< 0 or > 12**
4	1.11	3.76	**6.40**	9.04	11.79	20	2.6	6 (3 – 9)	6 (0 – 12)	**< 0 or > 12**
5	-2.41	0.91	**4.22**	7.54	10.68	55	3.3	3 (0 – 6)	3 (-3 – 9)	**< -3 or > 9**
6	-1.37	1.50	**4.36**	7.22	10.71	388	2.9	4 (1 – 7)	4 (-2 – 10)	**< -2 or > 10**
7	-1.53	1.40	**4.32**	7.24	10.67	536	2.9	4 (1 – 7)	4 (-2 – 10)	**< -2 or > 10**
8	-1.64	1.33	**4.29**	7.25	10.15	473	2.9	4 (1 – 7)	4 (-1 – 10)	**< -1 or > 10**
9	-1.74	1.11	**3.96**	6.81	9.83	625	2.8	4 (1 – 7)	4 (-1 – 10)	**< -1 or > 10**
10	-2.31	0.73	**3.77**	6.81	9.92	497	3.0	3 (0 – 6)	4 (-3 – 9)	**< -3 or > 9**
11	-1.77	1.28	**4.33**	7.38	10.20	377	3.0	4 (1 – 7)	4 (-2 – 10)	**< -2 or > 10**
12	-2.43	0.92	**4.26**	7.61	10.73	144	3.3	4 (1 – 7)	4 (-2 – 10)	**< -2 or > 10**
13	-0.03	2.71	**5.45**	8.19	11.18	33	2.7	5 (2 – 8)	5 (-1 – 11)	**< -1 or > 11**
14	-3.89	-0.28	**3.32**	6.92	9.92	22	3.6	4 (1 – 7)	4 (- 2 – 9)	**< -2 or > 9**
15	-2.84	0.77	**4.38**	7.99	11.18	26	3.6	4 (0 - 8)	4 (-4 - 12)	**<-4 or >12**

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Table 5

FPI and BMI category distributions, showing greatest concordance between normal FPI and normal BMI.

		Underweight	Normal	Overweight or Obese	Total
Supinated	Count	18 [a]	260 [a]	76 [a]	354
	Expected count	15.6	264.9	73.5	354
Normal	Count	68 [a]	1325 [a]	383 [a]	1776
	Expected count	78.4	1328.8	368.8	1776
Pronated	Count	44 [a]	728 [a]	188 [a]	960
	Expected count	42.4	718.3	199.3	960
Highly Pronated	Count	12 [a]	94 [b]	21 [b]	127
	Expected count	5.6	95	26.4	127
Total	Count	142	2407	668	3217

Note: superscript letters denote a subset of FPI (Left) categories whose column proportions did not differ significantly from each other at the level of 0.05.

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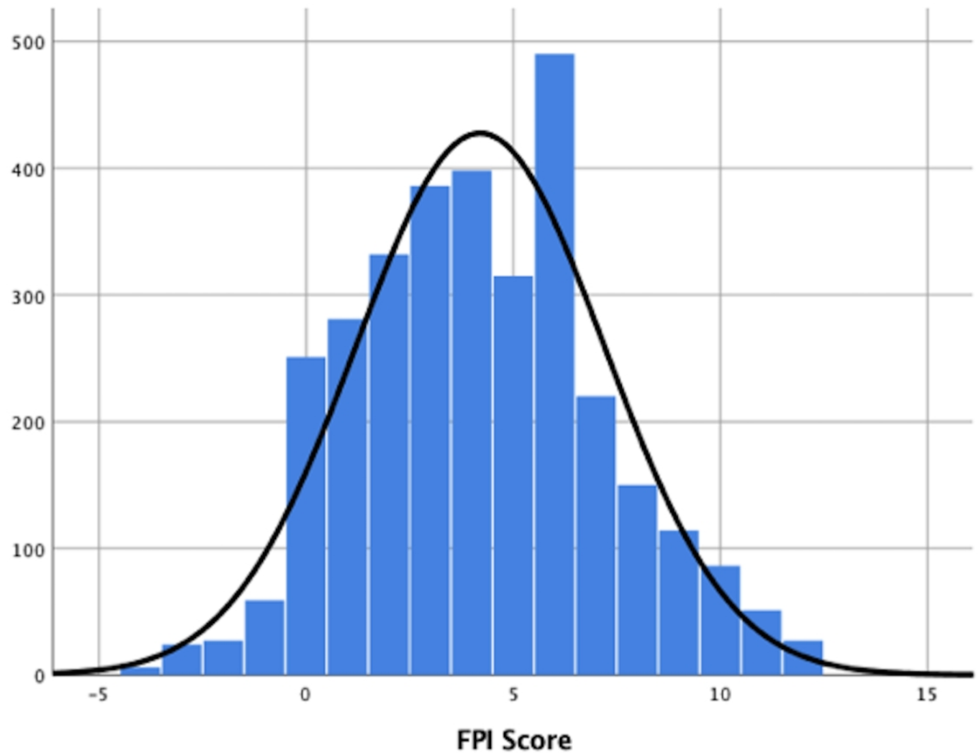

Figure 1 Frequency plot of FPI values (n=3217)

188x157mm (300 x 300 DPI)

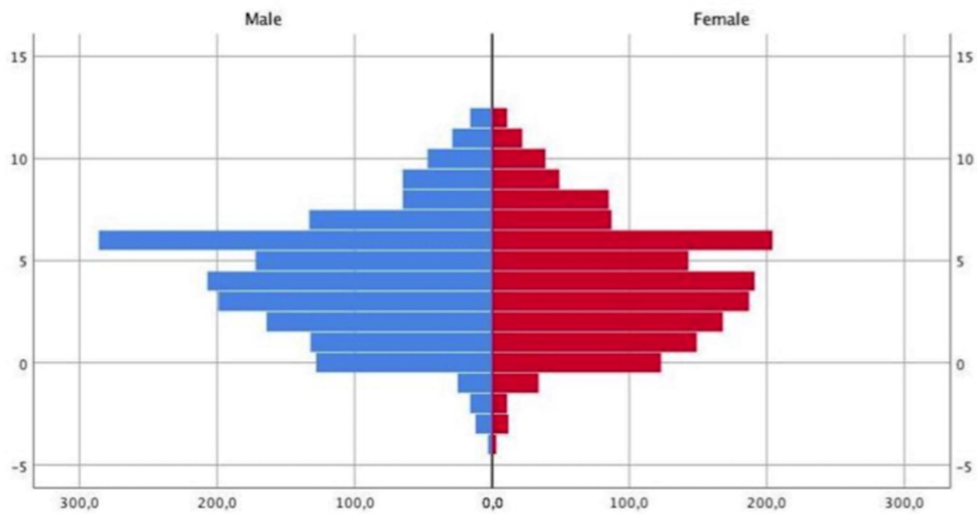

Figure 2 FPI frequency plot for gender

260x151mm (300 x 300 DPI)

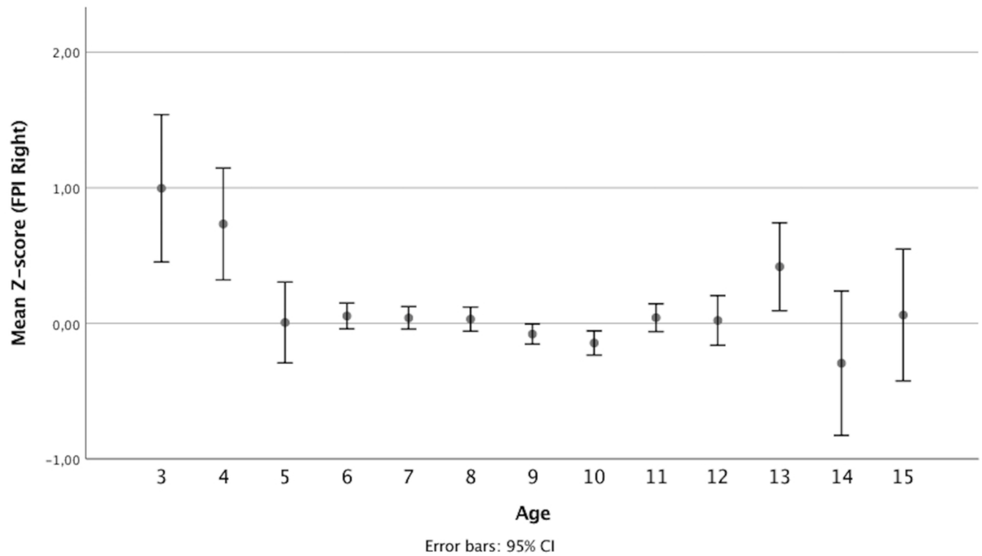

Figure 3 Simple error bars display the relationship between FPI and age.

99x58mm (300 x 300 DPI)

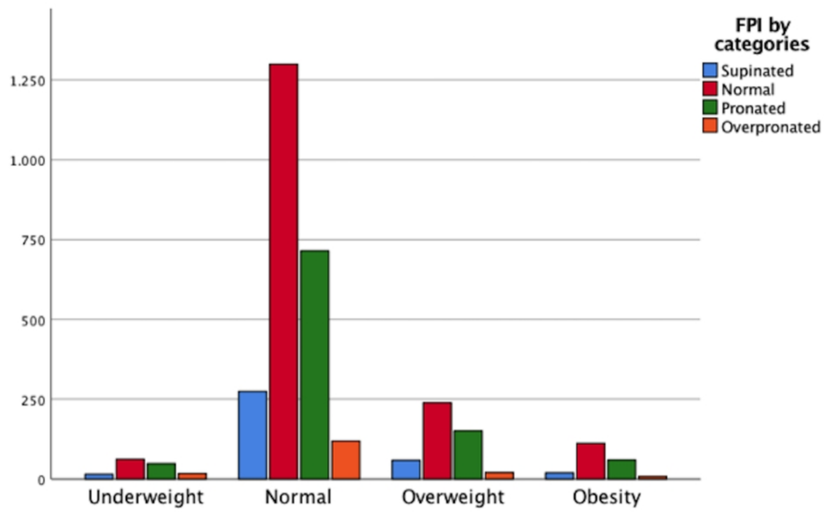

Figure 4 Frequency plot of BMI category versus FPI category

89x67mm (600 x 600 DPI)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1-2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	5
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	*5*
Bias	9	Describe any efforts to address potential sources of bias	-
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	6
		(*b*) Describe any methods used to examine subgroups and interactions	6
		(*c*) Explain how missing data were addressed	-
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	6
		(*e*) Describe any sensitivity analyses	

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Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	7
		(b) Give reasons for non-participation at each stage	-
		(c) Consider use of a flow diagram	-
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	7-8
		(b) Indicate number of participants with missing data for each variable of interest	-
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	*7-8*
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	7-8
		(*b*) Report category boundaries when continuous variables were categorized	7-8
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	8
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	8-9
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	8-9
Generalisability	21	Discuss the generalisability (external validity) of the study results	8-9
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	1

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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International normative data for paediatric foot posture assessment: a cross-sectional investigation.

[Short title: Children's flatfeet – normal or not?]

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and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards. (Universities of Malaga CEUMA 91/2016H, Extremadura ID 59/2012, University of Wales Institute, Cardiff and University of South Australia Charles Sturt University Ethics Committees approval number 10/291 and 89/2012).

Informed consent: Informed consent was obtained from all individual participants (parents), whose children were included in the study.

Data sharing statement: Available data can be obtained by contacting the corresponding author.

Contributors: GG-N, AM-N, and AME contributed to the conception of this study. GG-N, AM-N, and AME did the statistical analysis. Data collectors were collected in Spain JM-A and PG-A and in Australia AME. GG-N, AM-N, PG-A, JM-A and AME were involved in the writing and in the review of the manuscript.

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Abstract

Objectives: The Foot Posture Index (FPI) is an observational tool designed to measure the position of the foot. The objective of this study was to establish international reference data for foot posture across childhood, and influence of Body Mass Index (BMI) on paediatric foot posture.

Design: Cross-sectional study

Setting and participants: The dataset comprised 3217 healthy children, aged from three to 15 years. Contributing data were acquired from Spain, UK, and Australia.

Interventions: Foot posture was described by means and z-score of the foot posture index (FPI) and the height and weight of each subject was measured and the body mass index (BMI) was calculated.

Results: The foot posture of 3217 children were reviewed. A pronated (FPI ≥+6) foot posture was found in 960 (29.8%) children, a normal (FPI 0 to +6) foot posture in 1776 (55.2%), and a highly-pronated (FPI +10) foot posture was found in 127 children (3.9%), (range -4 to +12 FPI). Less than 11% were found to have a supinated foot type (n = 354). Approximately 20% of children were overweight/obese, but correlation between BMI and FPI was weak and inverse ($r = -0.066$, $p< 0.01$), refuting the relationship between increased body mass and flatfeet.

Conclusions: This study confirms that the 'flat' or pronated foot is the common foot posture of childhood, with FPI score of +4(3) the average finding. Trend indicated a less 'flat' foot with age, although non-linear. A wide normal range of foot posture across childhood is confirmed.

Strengths and limitations of this study

- First study to measure foot posture with any method in a sample of 3217 children
- Comparison between different countries strengthens the study findings
- The sample does not balance the number of children from each country
- The disproportionate numbers of children within each age year group

Key Words: Foot, Children, Posture, Paediatric, Foot posture index, Flatfoot

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Introduction

Paediatric foot posture is a common parental concern, a frequent presentation to clinicians, and an area of dispute regarding both the need for treatment[1] [2]. The term 'flatfoot', has referred to a foot which is nearly or completely contacting the ground [3], and has been evaluated using foot posture [4], footprints [5], radiological and anthropometric measures [6] and is often poorly defined [7]. From a clinical practice perspective, there is no single universally accepted diagnostic technique.

A systematic review [8] has addressed flatfoot and clinical measures, in healthy children, finding 'flatfoot' the expected foot posture before eight years of age, due to young osseous structures, ligament laxity, increased adipose tissue, and immature neuromuscular control [9,10]. With variation, flatfoot posture reduces across a child's first ten years [11–13]. Some children with flexible flatfeet experience lower limb pain [14] with compromised gait [15]. The quandary for clinicians is discerning when a child's foot is within or outside the developmental range, so that parents may be reassured, advised to monitor with growth, or to treat [16,17].

Children's foot posture has been interpreted with footprint assessments in many studies, with inference of a problematic 'flatfoot' when the footprint area is increased. Throughout early childhood, children continue to develop a skeletal medial longitudinal foot arch [18], different from the adult population [19], and altered children's foot posture must be evaluated in context of developmental stage and the presence/absence of systemic influences, such as hypotonia and hypermobility, which may be non-specific or syndromic, eg Down or Marfan's syndromes.

Despite the fact that paediatric flatfoot is a frequent concern [1,20], the evidence for treatment is weak. The lack of definition for 'flatfoot' has contributed to varying opinions and a lack of consensus for best practice [21–23]. There is no 'gold standard' for categorising foot type, with the margins of flat / rectus / high arch often undefined. Further, few clinical measures are validated in children, hence it is common for clinicians to make diagnostic decisions based on their personal clinical experience of foot types [24]. The availability of normal reference data for paediatric foot posture, based on a valid measure, will provide a 'benchmark' for clinical evaluation of this frequent clinical concern. The paediatric flatfoot proforma (p-FFP) has attempted to standardise diagnoses, and direct when intervention is

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required, using a combination of subjective assessment points and a range of foot posture measures [17]. However, the extent to which the p-FFP is used by clinicians is unknown and the proforma does not specify management techniques.

Ten years ago the Foot Posture Index (FPI-6) [25] emerged with the objective to standardise the assessment of foot posture in stance across three discrete foot regions (rearfoot, midfoot, forefoot) enabling feet to be scored and categorised. Both Evans et al [26] and Gijon-Nogueron et al [27] have previously utilised the FPI to investigate the paediatric foot. The FPI is a quick, and easy-to-use clinical tool, not requiring equipment. Scrutiny of the FPI demonstrates it repeatable and valid [4], with excellent inter-rater reliability in assessment of the paediatric foot[28]. Recently, the FPI has been identified as a preferred method of paediatric foot posture measurement in future research[29].

Methods

Data acquisition

Data was acquired from multiple sources where the FPI had been assessed in different children, recruited for screening studies, or acting as comparative controls. Three datasets were acquired from the authors' previous works (n= 1032, n=1457, n = 728) [19,26,27]. Measurements were taken during 2010 and 2016, some from 10 schools randomly selected from 25 schools located in the provinces of Málaga, Granada and Plasencia (Spain) (n=2489). In the UK (n = 225), and Australia (n = 503), two datasets were acquired from the author's previous works investigating the reliability of clinical assessment measures (n = 170)[10,30], and further datasets were acquired from other authors in the UK investigating foot posture in young children (n = 225) [31], and Australia investigating foot posture in young children with Sever's disease (n = 303)[32], and the control group from an idiopathic toe-walking study (n = 30)[33]. A total of 3217 observations of the FPI in children aged from three to 15 years were collated.

Participants

The inclusion criterion across the studies was for children, of both genders, and aged between three and 15 years. Exclusion criteria were: foot pain at the time of examination, history of injury to the lower limbs (eg musculoskeletal injuries during the previous six months), congenital foot abnormalities, cerebral palsy, motor dysfunction, inflammatory disorders, or foot surgery. Informed consent had been gained from parents/carers of the children for study participation. All studies contributing data to the amalgamated dataset were conducted in

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accordance with the Declaration of Helsinki and was approved by University Human Ethics Committees in each country (Universities of Malaga CEUMA 91/2016H, Extremadura ID 59/2012, University of Wales Institute, Cardiff and University of South Australia Charles Sturt University Ethics Committees approval number 10/291 and 89/2012).

Protocol

Foot posture was assessed with all subjects barefoot, in a relaxed standing position using the standard protocol for the FPI [34] . The FPI evaluates the multi-segmental nature of foot posture in all three planes, and does not require the use of specialised equipment. Each item of the FPI is scored between −2 and +2, with the total six items referring to positions of the forefoot, midfoot and hindfoot, and the three planes of motion: 1) talar head palpation; 2) symmetry of supra and infra lateral malleolar curvature; 3) inversion/eversion of the calcaneus; 4) prominence in the region of the talo-navicular joint; 5) height of the medial longitudinal arch; 6) abduction/adduction of the forefoot. The FPI score may range from -12 (highly supinated) to +12 (highly pronated). The statistical analysis was independent of the outcome assessors. The FPI assessors were blinded with the data passed directly to the database for entry and analyses. Good inter-observer reliability was recorded (ICC 0.852–0.895) across the studies.

The BMI was calculated from the children's height and weight, calculated as, BMI = weight(kg)/height(m)^2). In Spain, the Orbegozo[35] BMI classification is used; in Australia, the Australian Health Survey [36]; and in UK the National Child Measurement Programme [37]. Accordingly, we classified children by their BMI score, using the systems proposed by Orbegozo, Australian Health Survey, and Public Health England, allocating children to one of four categories: underweight - percentile less than 3 (P<3), normal weight - percentile between 3 and 90 (P3–90), overweight - percentile between 90 and 97 (P90–97) and obesity - percentile greater than 97 (P>97), based on BMI z-score, and age.

Patient involvement

No patients were involved in setting the research question or the outcome measures, nor were they involved in the design or conduct of the study. No patients were asked to advise on interpretation or writing up of results. There are no plans to disseminate the results of the research to study participants.

Data analysis

Data were entered and all analyses were performed using constructed data sets in SPSS version 24 (SPSS Inc, Chicago, Illinois) software packages. The data from the contributing

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studies were collated in a separate database, with statistical analysis performed by an external person, previously blind to the results.

Testing for normality using a Kolmogorov–Smirnov test, found non-normal distribution of all data, indicating suitability for non-parametric analysis (Mann–Whitney U and Kruskal–Wallis). Descriptive statistics (mean, standard deviation, minimum, maximum, frequencies) were used to examine the basic anthropometrical characteristics of the study populations. The FPI was analysed as continuous data, rather than as z-score data, and analysis of variance was conducted to determine the association between the different BMI groups (underweight, normal, overweight and obesity), gender, age, and the FPI. To preserve the independence of data[38], and based on the strong correlation between FPI scores for left and right feet [39], only the left foot (chosen at random) was used in the statistical analyses, applying the Games-Howell post hoc correction to identify significant differences. With reference to the available normative data [25], three FPI-6 scores levels were used to 'define and explore' the range supinated (-12 to -1), neutral (0 to +5), pronated (+6 to +8), and overpronated (+9 to +12). The significance level was set at $p < 0.05$, and all the analyses and tests were two-sided

Results

The mean age of the study population of 3217 children was 8.67 years (SD 2.02), ranging from three years to 15 years. The mean BMI was 19.08 kg/m^2 (SD 4.05), ranging from 10.57 kg/m^2 to 39.14 kg/m^2. The mean FPI score was 4.11 (SD 2.92) and 4.20 (3.00) for left and right feet respectively, with whole scores ranging from -4 to +12 (left and right) (Figure 1, FPI right feet). The total study population gender distribution was 1699 male, 1518 female (Table 1).

In the study population of 3217 children, flatfeet or pronated (FPI ≥+6) were found in 960 (29.8%) children and normal (FPI <+6) in 1776 (55.2%) children, FPI ≥ +10 yielded flatfeet in 127 (3.9%) cases and supinated foot were found in 354 (11%) children. Table 2 used designated FPI categories to define and explore the range of foot posture across childhood.

There was strong correlation between FPI scores on left and right sides ($r = 0.9014$, $p < 0.01$), from which the left side was arbitrarily used for subsequent analyses. Similarly, we found little gender bias, with the mean FPI for males 4.2 (2.9), range -4 to +12, and for females, mean FPI 3.99 (2.9), range -4 to +12 (Figure 2). The correlation between FPI and gender

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used z-score was very weak, if significant ($F=4.073$, $p=0.04$). Between countries there was significant difference ($p<0.01$), with Spanish children's mean FPI = 4.00(2.9), the UK mean FPI = 4.9(3.3), and the Australian children's mean FPI = 4.7(3.1).

The general trend showed FPI scores declining with age, which supports the clinical observation of less flatfoot in older children. The frequency of FPI scores for each year of age show that the maximum FPI score = +6, in 15.2% of children (Table 3).
Clinical alert is indicated for foot posture > +/- 2SD, representing 5% of expected abnormality. Table 4 shows the standard deviation of the mean FPI scores, and enables the mean FPI and one and two standard deviations above and below to be referenced as normally expected for each year of age. Figure 3 displays and explores the relationship between foot posture and age across childhood for the study population, using error bars for average z-scores (95% confidence intervals).

Significant correlation was found between BMI and age ($r = 0.276$, $p < 0.01$). The correlation between BMI and FPI, whilst also statistically significant, was very weak and also inverse ($r = -0.066$, $p< 0.01$), refuting the strength of relationship between body mass and foot posture. BMI cut-points and percentiles were used to define underweight, normal weight, overweight, and obese. Within the total 3217 children, 142 (4.4%) were underweight, 2407 (74.8%) were normal weight, 469 (16.1%) were overweight, and 199 (6.2%) were obese (Figure 4). Combining categories, 668 (20.8%) of all children were overweight or obese.

The foot posture categories were analysed for distribution across the BMI categories (Table 5). The largest overlap of FPI and BMI categories were: normal weight / normal FPI range, n= 1325 (41.2%); normal weight / pronated foot posture, n= 728 (22.6%); overweight or obese / normal foot posture, n=383(11.9%). Supinated feet across all BMI categories returned n=354(11.0%). Exploring the association between the pronated foot and BMI across FPI ranges showed that 960(29.8%) children had foot posture that was pronated, FPI > 6. Of these, 44 (4.5%) were underweight, 728 (75.8%) were normal weight, 188 were overweight, or obese (19.5%). Further, 127 children had highly pronated foot posture, FPI > 10. Of these, 12 (9.4%) were underweight, 94 (74.0%) were normal weight, and 21 (16.5%) were overweight or obese.

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Discussion

This study is the largest investigation to explore paediatric foot posture using the FPI, paediatric anthropometry using BMI, and to analyse the regularly cited influence of increased body weight as a potentiating factor for flatfeet across childhood. This investigation of paediatric foot posture includes children aged from three to 15 years, superseding previous, smaller or age-limited, studies[26,27].

This study confirms the pronated foot as the common foot posture of childhood, with mean FPI of +4, and 3-point standard deviation, such that average normal FPI range for children aged three to 15 years was between the FPI range +1 to +7 (mean +/- SD). We found that the mean FPI scores reduced with age, in non-linear pattern, and within a wide range. The standard deviation approximated 75% of the FPI mean at every age, confirming the considerable and normal variation in foot posture across childhood.

The greatest number of children across all ages displayed FPI within the 0 to +5 FPI range, ie normal foot posture. Next common were children with pronated feet. The least common FPI categories were either supinated or highly pronated, indicative of the foot types that should arrest the attention of clinicians, as less usual presentations. Flatfoot or pronated foot posture was generally found to decline with age, but mean reduction was non-linear and modest, from +6 at age three years, to +3 at 14 years. Importantly, the normal FPI range of variation was broad: -1 to +11 at age three years, and FPI +3 to +9 at age 14 years.

The relationship between increased BMI and flatfeet is again refuted by the findings of this study which found that only 16.5% of the children with highly pronated feet, were also overweight or obese. Our results contrasted with many older studies which asserted that heavier, fatter children have flatter feet. Importantly, the previous studies all assessed foot posture using a footprint based method of foot posture assessment [5,40,41], a method which may well represent adipose tissue spread with weight bearing, rather than anatomical foot morphology, more directly evaluated using the FPI [25,26,42]. Whilst it is concerning to find that 21% of the children in this study were overweight or obese, association with flatfeet is not found.

The availability of average FPI whole scores, enables clinicians to inform parents as to what is ‘average’ and what is ‘normal’ at any age, as statistically defined. The availability of FPI scores within one standard deviation above and below the mean, enables clinicians to confirm

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for parents that their child approximates with two-thirds, or 68%, of children for a specific age. Further, FPI scores within two standard deviations above and below the mean, enable clinicians to inform parents that their child is within the normal 95% range, approximating one-quarter, or 27%, of same age children. Such reference data helps appreciation of the range of 'normal range' for foot posture, similarly to that for the onset of independent walking (age range of 10 to 16 months, mean age approximating 12 to 13 months)[18].

The focus of this investigation has been to better elucidate the normal range of foot posture across childhood, as is commonly assessed by many clinicians using the FPI. Simultaneously, the authors aimed to provide clinicians with a robust reference guide of normal values within statistical bounds. The culmination of this aim is provided as a reference Table (Table 4). The scale of this investigation renders its findings stronger than those of the 1000 Norms protocol for most age (year) groups, as the comparative number of participants reveals. The 1000 Norms protocol will include: ages 3 to 9 years, 140 (20 per age year); ages 10 to 19 years, 160 (16 per age year)[43]. By comparison, this study informs for: ages 3 to 9 years, 2796 (20 to 764 per age year); ages 10 to 15 years, 1304 (1 to 634 per age year).

Clinicians must move beyond flatfoot posture appearance as an indicator for intervention, and instead appreciate the range of normal variation, and only respond to more pertinent factors as outlined by the 3QQ (3 Quick Questions) screening tool (addressing pain presentations, left versus right limb symmetry, paediatric age range)[20]. Clinicians need to appreciate the normal range of many developmental features, yet simultaneously be alert to the level at which clinical concern should be raised. The tabulated reference guide provided from this study, will be of immediate clinical relevance.

The striking finding of this study is not that paediatric flexible flatfoot is largely normal, it is that the supinated paediatric foot is far more likely to be abnormal, especially at age three and four years. An FPI of -2 or less, must be considered 'abnormal' until shown otherwise, as it is outside normal range at any age, and should prompt neurological assessment.

Limitations of this investigation include the cross-sectional nature of the design and the ethnicity of participants (largely Caucasian). Further, the sample does not evenly represent children from each country, nor each year of age, hence caution is indicated for ages three to seven years and 14 to15 years where sampling was least. In addition, consideration that this

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study is a collation of smaller discrete studies, and should be consider measurement errors, although all followed the same protocol [3]. Prospective data avails stronger evidence of foot posture change over time [4].

Conclusions

This is the largest study of paediatric foot posture to date. Importantly, the main finding is to denounce the paediatric flatfoot as deviant. This study confirms that the 'flat' or pronated foot is the common foot posture of childhood, with FPI score of +4(3) the average finding. A wide normal range of foot posture across childhood is confirmed (16 FPI points, ie -2 to +12).

The reference data produced from the findings of this study will assist clinicians in standardised decision-making.

Increased paediatric BMI was not associated with flatter feet, questioning the validity of footprint-derived measures.

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Legend text

Figure 1 Frequency plot of FPI values (n=3217)

Figure 2 FPI frequency plot for gender

Figure 3 Simple error bars display the relationship between FPI and age.

Figure 4 Frequency plot of BMI category versus FPI category

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Table 1

Descriptive statistics for the amalgamated data sets. Due to variation between the constituent datasets, main results emerged from the variables of age, BMI, FPI Left. Gender ratio was 1699 males: 1518 females.

Variable	N	Range	Minimum	Maximum	Mean	SD
Age (years)	3217	12	3	15	8.67	2.02
BMI (kg/m^2)	3217	28.57	10.57	39.14	19.08	4.05
FPI Right	3217	16	-4	12	4.20	3.00
FPI Left	3217	16	-4	12	4.11	2.92

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Table 2

The FPI range which refer to foot posture categories. were collated for each year of age. The median FPI total score across the study population was 4(3) points. with the trend of reduced FPI with increased age confirmed.

Age (yrs)	No. /Age	FPI-6 total score – *Foot posture category cut-offs*						
		Supinated	Normal	Pronated	High pronated	Mean FPI	SD	Range
3	21	2	4	14	1	6.38	3.03	11
4	20	1	5	12	2	6.7	2.60	11
5	55	5	34	13	3	4.15	2.81	12
6	388	29	213	132	14	4.45	2.80	15
7	536	51	296	164	25	4.3	2.93	16
8	473	48	271	131	23	4.01	2.95	16
9	625	74	362	175	14	3.82	2.77	16
10	497	62	291	123	21	3.69	2.86	15
11	377	50	194	119	14	4.24	3.02	16
12	144	24	65	48	7	4.22	3.23	14
13	33	1	17	12	3	5.18	2.98	10
14	22	4	12	6	0	3.14	3.40	12
15	26	3	12	11	0	4.19	3.31	12
Total	3217	354(11%)	1776(55.2%)	960(29.84%)	127(3.95%)	4.2	3	16

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Table 3

FPI total scores versus age year groups.

FPI/ age	-4	-3	-2	-1	0	1	2	3	4	5	6	7	8	9	10	11	12	Total / n
3	0	0	0	1	1	0	0	1	2	1	2	0	3	4	4	0	2	21
4	0	0	0	0	1	0	0	0	3	3	5	2	2	1	1	2	0	20
5	0	0	1	0	6	3	7	11	7	3	6	2	2	1	1	4	1	55
6	0	1	3	6	24	31	45	46	47	38	69	30	19	11	6	8	4	388
7	1	6	4	3	39	43	48	72	69	55	90	33	22	27	14	7	3	536
8	1	2	1	8	36	47	55	45	49	48	89	27	24	17	13	7	4	473
9	3	3	5	11	55	61	60	72	81	78	92	48	21	14	9	8	4	625
10	0	5	3	14	41	59	68	71	54	39	61	23	17	12	17	9	4	497
11	1	3	4	10	29	22	31	48	58	32	52	29	26	14	10	3	5	377
12	0	2	2	6	17	9	12	7	19	11	19	14	12	6	5	3	0	144
13	0	0	0	0	1	2	1	6	2	5	2	7	2	2	3	0	0	33
14	0	1	2	0	1	3	2	3	4	0	1	2	0	2	1	0	0	22
15	0	1	2	0	0	1	3	4	3	2	2	3	0	3	2	0	0	26
Total/ FPI	6	24	27	59	251	281	332	386	398	315	490	220	150	114	86	51	27	3217
%	0.2	0.7	0.8	1.8	7.8	8.7	10.3	12.0	12.4	9.8	15.2	6.8	4.7	3.5	2.7	1.6	0.8	100

%: Percentage, SD: Standard Deviation, R: Range

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Table 4
FPI total scores versus age year groups, **showing normal range, and FPI outside normal range.**

Age	-2SD	-1SD	**Mean**	+1SD	+2SD	Sample size	SD	FPI Median (+/- 1SD)	FPI Median (+/- 2SD)	**Clinical Alert FPI > +/-2SD**
3	0.02	3.60	**7.19**	10.78	12.78	21	3.6	8 (4 – 12)	8 (0 – 12)	**< 0 or > 12**
4	1.11	3.76	**6.40**	9.04	11.79	20	2.6	6 (3 – 9)	6 (0 – 12)	**< 0 or > 12**
5	-2.41	0.91	**4.22**	7.54	10.68	55	3.3	3 (0 – 6)	3 (-3 – 9)	**< -3 or > 9**
6	-1.37	1.50	**4.36**	7.22	10.71	388	2.9	4 (1 – 7)	4 (-2 – 10)	**< -2 or > 10**
7	-1.53	1.40	**4.32**	7.24	10.67	536	2.9	4 (1 – 7)	4 (-2 – 10)	**< -2 or > 10**
8	-1.64	1.33	**4.29**	7.25	10.15	473	2.9	4 (1 – 7)	4 (-1 – 10)	**< -1 or > 10**
9	-1.74	1.11	**3.96**	6.81	9.83	625	2.8	4 (1 – 7)	4 (-1 – 10)	**< -1 or > 10**
10	-2.31	0.73	**3.77**	6.81	9.92	497	3.0	3 (0 – 6)	4 (-3 – 9)	**< -3 or > 9**
11	-1.77	1.28	**4.33**	7.38	10.20	377	3.0	4 (1 – 7)	4 (-2 – 10)	**< -2 or > 10**
12	-2.43	0.92	**4.26**	7.61	10.73	144	3.3	4 (1 – 7)	4 (-2 – 10)	**< -2 or > 10**
13	-0.03	2.71	**5.45**	8.19	11.18	33	2.7	5 (2 – 8)	5 (-1 – 11)	**< -1 or > 11**
14	-3.89	-0.28	**3.32**	6.92	9.92	22	3.6	4 (1 – 7)	4 (- 2 – 9)	**< -2 or > 9**
15	-2.84	0.77	**4.38**	7.99	11.18	26	3.6	4 (0 - 8)	4 (-4 - 12)	**<-4 or >12**

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Table 5

FPI and BMI category distributions, showing greatest concordance between normal FPI and normal BMI.

		Underweight	Normal	Overweight or Obese	Total
Supinated	Count	18 [a]	260 [a]	76 [a]	354
	Expected count	15.6	264.9	73.5	354
Normal	Count	68 [a]	1325 [a]	383 [a]	1776
	Expected count	78.4	1328.8	368.8	1776
Pronated	Count	44 [a]	728 [a]	188 [a]	960
	Expected count	42.4	718.3	199.3	960
Highly Pronated	Count	12 [a]	94 [b]	21 [b]	127
	Expected count	5.6	95	26.4	127
Total	Count	142	2407	668	3217

Note: superscript letters denote a subset of FPI (Left) categories whose column proportions did not differ significantly from each other at the level of 0.05.

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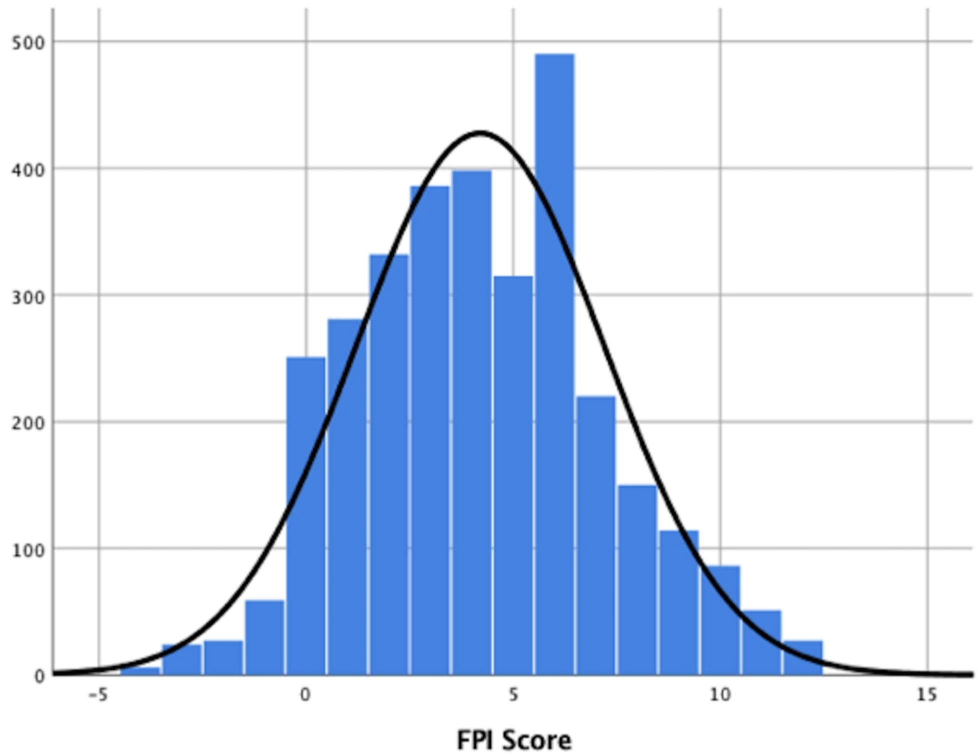

Figure 1 Frequency plot of FPI values (n=3217)

188x157mm (300 x 300 DPI)

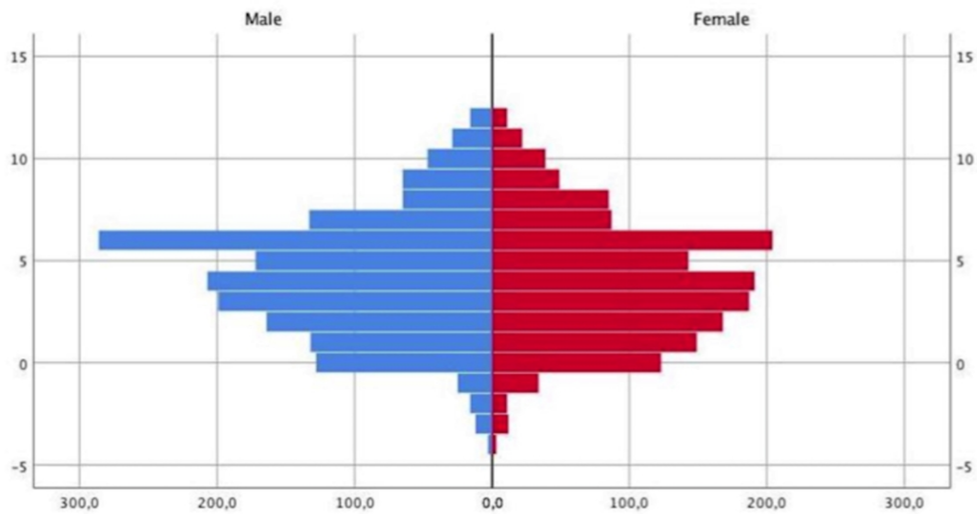

Figure 2 FPI frequency plot for gender

260x151mm (300 x 300 DPI)

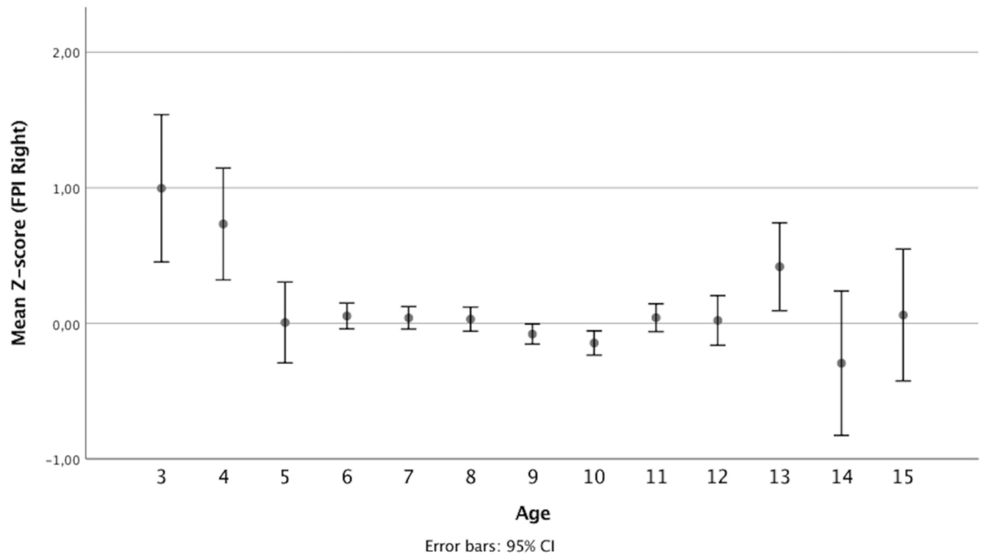

Figure 3 Simple error bars display the relationship between FPI and age.

99x58mm (300 x 300 DPI)

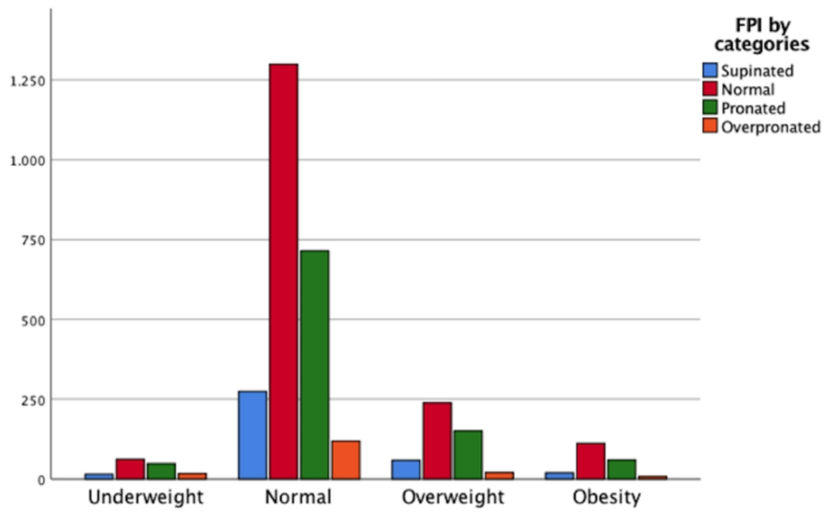

Figure 4 Frequency plot of BMI category versus FPI category

89x67mm (600 x 600 DPI)

STROBE Statement—checklist of items that should be included in reports of observational studies

	Item No	Recommendation	Page
Title and abstract	1	(*a*) Indicate the study's design with a commonly used term in the title or the abstract	1-2
		(*b*) Provide in the abstract an informative and balanced summary of what was done and what was found	2
Introduction			
Background/rationale	2	Explain the scientific background and rationale for the investigation being reported	4
Objectives	3	State specific objectives, including any prespecified hypotheses	4
Methods			
Study design	4	Present key elements of study design early in the paper	5
Setting	5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Participants	6	(*a*) *Cohort study*—Give the eligibility criteria, and the sources and methods of selection of participants. Describe methods of follow-up *Case-control study*—Give the eligibility criteria, and the sources and methods of case ascertainment and control selection. Give the rationale for the choice of cases and controls *Cross-sectional study*—Give the eligibility criteria, and the sources and methods of selection of participants	5
		(*b*) *Cohort study*—For matched studies, give matching criteria and number of exposed and unexposed *Case-control study*—For matched studies, give matching criteria and the number of controls per case	
Variables	7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	5
Data sources/ measurement	8*	For each variable of interest, give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group	5
Bias	9	Describe any efforts to address potential sources of bias	-
Study size	10	Explain how the study size was arrived at	5
Quantitative variables	11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen and why	6
Statistical methods	12	(*a*) Describe all statistical methods, including those used to control for confounding	6
		(*b*) Describe any methods used to examine subgroups and interactions	6
		(*c*) Explain how missing data were addressed	-
		(*d*) *Cohort study*—If applicable, explain how loss to follow-up was addressed *Case-control study*—If applicable, explain how matching of cases and controls was addressed *Cross-sectional study*—If applicable, describe analytical methods taking account of sampling strategy	6
		(*e*) Describe any sensitivity analyses	

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Results			
Participants	13*	(a) Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed	7
		(b) Give reasons for non-participation at each stage	-
		(c) Consider use of a flow diagram	-
Descriptive data	14*	(a) Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders	7-8
		(b) Indicate number of participants with missing data for each variable of interest	-
		(c) *Cohort study*—Summarise follow-up time (eg, average and total amount)	
Outcome data	15*	*Cohort study*—Report numbers of outcome events or summary measures over time	
		Case-control study—Report numbers in each exposure category, or summary measures of exposure	
		Cross-sectional study—Report numbers of outcome events or summary measures	*7-8*
Main results	16	(*a*) Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	7-8
		(*b*) Report category boundaries when continuous variables were categorized	7-8
		(*c*) If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	
Other analyses	17	Report other analyses done—eg analyses of subgroups and interactions, and sensitivity analyses	
Discussion			
Key results	18	Summarise key results with reference to study objectives	8
Limitations	19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias	8-9
Interpretation	20	Give a cautious overall interpretation of results considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence	8-9
Generalisability	21	Discuss the generalisability (external validity) of the study results	8-9
Other information			
Funding	22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	1

*Give information separately for cases and controls in case-control studies and, if applicable, for exposed and unexposed groups in cohort and cross-sectional studies.

Note: An Explanation and Elaboration article discusses each checklist item and gives methodological background and published examples of transparent reporting. The STROBE checklist is best used in conjunction with this article (freely available on the Web sites of PLoS Medicine at http://www.plosmedicine.org/, Annals of Internal Medicine at http://www.annals.org/, and Epidemiology at http://www.epidem.com/). Information on the STROBE Initiative is available at www.strobe-statement.org.

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