Gait & Posture 44 (2016) 155–160

Contents lists available at ScienceDirect

Gait & Posture

journal homepage: www.elsevier.com/locate/gaitpost

Full length Article

The impact of body fat on three dimensional motion of the paediatric foot during walking

Ryan Mahaffey [a,*], Stewart C. Morrison [b], Paul Bassett [c], Wendy I. Drechsler [a], Mary C. Cramp [d]

[a] School of Health, Sport and Bioscience, University of East London, Stratford, London E15 4LZ, England
[b] School of Health Sciences, University of Brighton, Brighton, UK
[c] Statsconsultancy Ltd. 40 Longwood Lane, Amersham, Bucks HP7 9EN, England
[d] Department of Allied Health Professions, Glenside Campus, University of West England, Blackberry Hill, Bristol BS16 1DD, England

ARTICLE INFO

Article history:
Received 27 November 2014
Received in revised form 24 August 2015
Accepted 3 December 2015

Keywords:
Pediatric obesity
Gait analysis
Foot kinematics
3D motion capture
Multivariate analysis

ABSTRACT

Childhood obesity is commonly associated with a pes planus foot type and altered lower limb joint function during walking. However, limited information has been reported on dynamic intersegment foot motion with the level of obesity in children. The aim of this study was to explore the relationships between intersegment foot motion during gait and body fat in boys age 7–11 years.

Fat mass was measured in fifty-five boys using air displacement plethysmography. Three-dimensional gait analysis was conducted on the right foot of each participant using the 3DFoot model to capture angular motion of the shank, calcaneus, midfoot and metatarsals. Two multivariate statistical techniques were employed; principle component analysis reduced the multidimensional nature of gait analysis, and multiple linear regression analysis accounted for potential confounding factors.

Higher fat mass predicted greater plantarflexion of the calcaneus during the first half and end of stance phase and at the end of swing phase. Greater abduction of the calcaneus throughout stance and swing was predicted by greater fat mass. At the midfoot, higher fat mass predicted greater dorsiflexion and eversion throughout the gait cycle.

The findings present novel information on the relationships between intersegment angular motion of the foot and body fat in young boys. The data indicates a more pronated foot type in boys with greater body fat. These findings have clinical implications for pes planus and a predisposition for pain and discomfort during weight bearing activities potentially reducing motivation in obese children to be physically active.

1. Introduction

Childhood obesity is associated with significant comorbidity and disability [1]. Worldwide prevalence of childhood overweight and obesity increased from 4.2% in 1990 to 6.7% in 2010 and is expected to reach 9.1% in 2020 [2]. Recent data from the UK National Child Measurement Programme estimated rates of overweight and obesity in England at 29% and 15% respectively [3]. Childhood obesity is associated with reduced physical activity and engagement in childhood activities [4], along with multiple health co-morbidities [5]. Childhood obesity has been reported to impact on the functional characteristics of the lower limb, potentially predisposing children to pain and discomfort during gait and musculoskeletal comorbidities [6]. Recent studies have reported reduced hip and knee flexion during gait and greater valgus positioning of the knee [7]. These findings support the view that obesity predisposes joint dysfunction and underpins a theoretical association with musculoskeletal pathology. Despite this, few studies have documented the impact of childhood obesity on the foot. Given the distal location and flexibility of the paediatric foot there is an increased susceptibility to pathology and deformation. It follows that any external influence upon the developing foot, such as obesity, may affect its function during gait [8].

Research on the plantar loading profiles of the paediatric foot have demonstrated childhood obesity to increase peak vertical forces [9], increase plantar contact area [10] and elevate plantar

* Corresponding author at: Health, Sport & Bioscience, University of East London, Stratford Campus Water Lane, London E15 4LZ, United Kingdom.
Tel.: +44 20 8223 4110.
E-mail addresses: r.mahaffey@uel.ac.uk (R. Mahaffey), S.C.Morrison@brighton.ac.uk (S.C. Morrison), paul@statsconsultancy.co.uk (P. Bassett), W.Drechsler@uel.ac.uk (W.I. Drechsler), Mary.Cramp@uwe.ac.uk (M.C. Cramp).

http://dx.doi.org/10.1016/j.gaitpost.2015.12.009
0966-6362/

pressures [11] under the medial longitudinal arch. Emerging from this is the view that childhood obesity is associated with a pes planus foot type which, coupled with altered joint function, may predispose to the development of foot discomfort and pathologies [9–11]. Recent work supports the association between obesity and structural foot changes but given plantar pressure analysis is limited to two-dimensional analysis of the foot during stance more work is required to characterise the impact of childhood obesity on the three-dimensional foot during the gait cycle. A recent study looking at the kinematics of sagittal and frontal plane lower limb motion in overweight boys [12] reported greater rear-foot eversion during gait. This finding supports the view of pes planus and a pronated foot type and suggests that obesity affects the function of the paediatric foot during walking. However, the findings are limited as this work did not take into account the complex motion of the multiple foot segments. Determining the intersegmental motion of the foot during gait can help to inform current approaches to rehabilitation and underpin clinical interventions where foot and joint problems in childhood obesity are indicated. The aim of this study was to explore the relationships between intersegmental foot motion during gait and obesity (measured by body fat) in boys between the age of 7 and 11 years. It was hypothesised that body fat (obesity level) would be associated with altered intersegment foot motion over the gait cycle, particularly in the midfoot.

2. Methods

2.1. Selection and description of participants

Fifty-five boys, aged 7–11 years, participated in the study and participant characteristics are presented in Table 1. Ethical approval was obtained from the host institution (Ref No. ETH/13/11) and parental consent was obtained prior to testing. All participants were recruited from local school children. Exclusion criteria included medical conditions affecting neuromuscular and orthopaedic integrity or any complications contributing to altered foot posture and/or gait disturbance.

2.2. Instrumentation and procedures

2.2.1. Measures of anthropometrics and body fat

Body fat (level of obesity) was measured by air displacement plethysmography using a Bodpod (Life Measurement, Inc, Concord, CA, USA). Estimates of body volume were derived from pressure measures within the Bodpod chamber under isothermal and adiabatic conditions [13]. The Bodpod has been shown to be a reliable and accurate measure of body fat in healthy and obese children [14,15]. Each participant wore swimming shorts and a swimming cap and was asked to enter the Bodpod chamber and remain still for 40 s for three successive trials. Changes in pressure were measured and averaged across the three trials to calculate body volume. Raw body volumes were corrected for isothermal air in the lungs and close to the skin surface using child-specific equations [16,17]. Corrected body volumes were converted to body percentages using age- and gender- specific equations [18]. Body fat was expressed as percentage fat mass relative to total body mass. Weight was measured to the nearest 0.1 kg using Bodpod scales and height measured to the nearest 0.5 cm using a portable Leicester stadiometer (Seca Leicester portable stadiometer; Seca Vogel, Hamburg, Germany). Body Mass Index (BMI) score was calculated as height/weight^2 and reported as an age and sex specific Z-score (standard deviation score). This was based on the distribution of BMI in the UK90 growth reference [19] using a Microsoft Excel macro developed for use with this growth reference (Child Growth Foundation, Chiswick, UK).

Table 1
Mean, SD and range of age, anthropometric and spatiotemporal characteristics of sample population ($n = 55$).

	Mean	SD	Range
Age (years)	9.55	1.18	7–11
Height (m)	1.40	0.08	1.19–1.59
Weight (kg)	37.69	10.67	22.3–68.6
BMI (kg/m^2)	18.41	4.00	12.34–29.62
BMI Z-score	0.55	1.58	−2.87–3.54
BMI centile (%)	59.99	36.08	0.21–99.98
Body fat mass (%)	23.78	9.33	9.46–42.06
Walking velocity (m s^{-1})	1.33	0.19	0.95–1.81
Cadence (steps/min)	131.69	15.66	105.77–171.52
Stance phase duration (%)	57.29	2.32	52.60–65.16
Total single support duration (%)	49.86	1.85	41.59–56.70
Step Width (mm)	81.59	28.18	29.47–156.38
Step length (m)	0.60	0.06	0.41–0.79

2.2.2. Measures of spatiotemporal and 3D intersegment foot motion during gait

An eight-camera Vicon Nexus motion capture system (Vicon Motion Systems Ltd, Oxford, UK) was used to track and record the motion of skin mounted reflective markers at 200 Hz during barefoot walking at self-selected speed. Fifteen 9 mm retro-reflective markers were attached to the right shank and foot of each participant in line with the 3DFoot model [20]. Previous research has demonstrated the reliability of this foot model in a paediatric population [21]. A four segment model of the foot was constructed for calculation of relative intersegment angular motion in Visual 3D software (C-Motion Inc., MD, USA). Two floor mounted force plates (Bertec, Model MIE Ltd, Leeds, UK) recorded ground reaction forces during gait trials at 1000 Hz. The gait cycle was defined from initial contact (determined as an increase in vertical force (Fz) above 20 N) through foot-off and the subsequent initial contact of the same foot. Sagittal, frontal and transverse planar motion was described for the shank-calcaneus, calcaneus-midfoot and midfoot-metatarsals segments of the right foot. 3D intersegment foot angles from each participant were extracted as 51 data points normalised over the gait cycle representing angular waveform patterns of foot segment motion. Mean 3D intersegment angles were calculated for each participant based on ten gait cycles captured.

2.3. Statistical analysis

2.3.1. Principal component analysis (PCA)

Principle component analysis (PCA) was employed to reduce the major modes of variation in the data in order to fully explore foot segment motion over the entire gait cycle. Previous research on paediatric gait has employed PCA to analyse multiple waveforms utilising separate matrices [22]). In the current study, nine matrices (3 segmental angles of shank-calcaneus, calcaneus-midfoot, midfoot-metatarsals each in 3 planes of sagittal, frontal and transverse) were constructed for 3D foot angle waveforms based on the 55 participants and the 51 points (55×51). The features of variation in the waveform data were extracted using PCA by orthogonally rotating the variables, using a varimax method, into components which maximally explained variability in the original waveforms. Principal components (PC) were retained that cumulatively explained at least 90% of the waveform variation. The rotated loadings (describing the proportion of variance explained by the underlying data points) were assessed to determine which data points contributed to each component. Rotated loadings in excess of 0.722 or below −0.722 were considered as contributing to a component [23]. A regression score (estimated coefficient representing a participants score on a