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Abstract

It has been speculated that high plantar pressures might cause foot pain and discomfort which, in turn, may discourage children from being physically active and result in them spending more time in sedentary activities. The purpose of this study was to determine whether plantar pressure distributions generated by preschool children were correlated with objectively measured time spent in physical activity and sedentary behaviour. Dynamic plantar pressures were measured for 33 preschool children (age = 4.3 ± 0.6 years; height = 1.06 ± 0.1 m; mass = 18.4 ± 2.9 kg; 17 boys) as they walked across an emed AT-4 pressure platform. Physical activity was objectively assessed using MT ActiGraph accelerometers. Total physical activity (counts per minute), percentage of time spent in moderate-to-vigorous physical activity (MVPA), light activity and sedentary behaviour were then calculated. Peak pressures across the heel were found to significantly correlate with total physical activity ($r = -0.53$; $p = 0.03$) and time in MVPA ($r = -0.47$; $p = 0.05$) in boys. Similarly, the correlation data suggested that girls who generated higher peak pressures in the toe region spent more time in sedentary behaviour ($r = 0.53$; $p = 0.04$). As high plantar pressures appear to be a potential negative correlate of physical activity and sedentary behaviour, it is recommended that further research be conducted to design, test and evaluate the potential of interventions to reduce plantar pressures in inactive children so they can enjoy the benefits associated with participating in a more active lifestyle.

Keywords

preschool, sedentariness, activity, physical, pressures, plantar, between, relationship, children, among

Disciplines

Arts and Humanities | Life Sciences | Medicine and Health Sciences | Social and Behavioral Sciences

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Title: Relationship between plantar pressures, physical activity and sedentariness among preschool children

Running head: Plantar pressures and physical activity

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Abstract

It has been speculated that high plantar pressures might cause foot pain and discomfort which, in turn, may discourage children from being physically active and result in them spending more time in sedentary activities. The purpose of this study was to determine whether plantar pressure distributions generated by preschool children were correlated with objectively measured time spent in physical activity and sedentary behaviour. Dynamic plantar pressures were measured for 33 preschool children (age = 4.3 ± 0.6 yr; height = 1.06 ± 0.1 m; mass = 18.4 ± 2.9 kg; 17 boys) as they walked across an emed AT-4 pressure platform. Physical activity was objectively assessed using MTI ActiGraph accelerometers. Total physical activity (counts per minute), and percentage of time spent in moderate-to-vigorous physical activity (MVPA), light activity and sedentary behavior were then calculated. Peak pressures across the heel were found to significantly correlate with total physical activity ($r = -0.53$; $p = 0.03$) and time in MVPA ($r = -0.47$; $p = 0.05$) in boys. Similarly, the correlation data suggested that girls who generated higher peak pressures in the toe region spent more time in sedentary behaviour ($r = 0.53$; $p = 0.04$). As high plantar pressures appear to be a potential negative correlate of physical activity and sedentary behaviour, it is recommended that further research be conducted to design, test and evaluate the potential of interventions to reduce plantar pressures in inactive children so they can enjoy the benefits associated with participating in a more active lifestyle.

Key words: foot structure; foot function; sedentary behaviour; foot pain; biomechanics

Introduction

Participation in physical activity provides numerous benefits for children including improved cardiovascular risk factors, muscular strength and endurance, skeletal health, mental health and academic performance [1]. Moreover, given the current worldwide childhood obesity epidemic [2], one of the most important benefits of participating in physical activity is its potential to prevent unhealthy weight gain [1]. Prevalence studies, however, indicate that approximately 45% of preschool children do not meet the United States' National Association for Sport and Physical Education (NASPE) physical activity guidelines of at least 60 minutes of structured and at least 60 minutes of unstructured activity per day [3]. Likewise, young British children appear to accumulate high levels of sedentary behaviour [4], with another study suggesting that around 30% of Australian preschool children do not meet the American Academy of Pediatrics recommendation of ≤ 2 hours per day of television viewing [5]. Given the health benefits of physical activity for preschool children, and the proportions who do not meet recommendations for physical activity or sedentary behaviour, better understanding factors that influence such behaviours among young children is paramount for successful intervention efforts and for public health promotion.

One potential barrier to participating in physical activity is the structure and function of children's feet. The foot is a highly unique and flexible structure, which is required to perform very diverse functions particularly during weight-bearing activities. Whilst the structurally normal foot can adequately perform these tasks, deviations from its normal posture can place the foot under excessive stress, often leading to discomfort or pain [6]. For example, overweight and obese children as young as 3 years have been found to have flatter feet and generate higher dynamic plantar pressures during walking relative to non-overweight children [7-9]. It is speculated that these higher plantar pressures might cause foot pain and

discomfort which, in turn, may discourage these children from being physically active and result in them spending more time in sedentary activities. However, the relationship between plantar pressures, physical activity and sedentary behaviour is only speculative, with no evidence published to support this notion. Therefore, the purpose of this study was to determine whether plantar pressure distributions generated by preschool children were related to their time spent in physical activity and sedentary behaviour.

Methods

Fifty-four girls (mean age = 4.2 ± 0.6 years) and 41 boys (mean age = 4.3 ± 0.6 years) between the ages of 3 and 5 years, who had no disability that would affect their foot structure or physical activity, who could walk independently and whose parents gave written consent, were recruited from 10 randomly selected preschools in the Illawarra region of New South Wales, Australia. All recruiting and testing procedures were approved by the University of Wollongong Human Research Ethics Committee (HREC No. 04/059).

After removing their shoes and socks, each child's height was measured to the nearest 0.1 cm using a PE87 portable stadiometer (Mentone Educational, Victoria, Australia), and their mass measured to the nearest 0.05 kg using electronic scales (Tanita HD646, Japan). From height and mass data, each child's BMI (kg/m^2) was calculated.

An emed AT-4 pressure platform (25 Hz; Novel_{gmbh}, Munich) was used to measure the dynamic plantar pressures generated underneath each child's feet during walking. Due to the young age of the children, the one-step method was used to collect the dynamic plantar pressures [10]. That is, holding an assistant's hand and looking straight ahead the child stepped onto the pressure platform with their first step landing in the centre of the platform and continued to walk for another five steps. Although the one-step method tends to reflect gait initiation, peak pressures have been found to be unaffected by gait initiation protocols in

adults [11, 12]. The use of an assistant allowed walking speed to be controlled and ensured that the children walked in a straight line without targeting the pressure platform.

To ensure repeatability, up to six successful trials were collected for each child's right and left lower limb. The dynamic plantar pressure footprints generated by each child were divided into five regions and masked using Novel-ortho automask software (Novel_{gmbh}, Munich). The masks (see Figure 1) were based around the following anatomical landmarks: heel, midfoot, forefoot, hallux and toes 2-5. The mean peak pressure footprints were then analysed using Novel-win multimask software (Novel_{gmbh}, Munich, version 9.35) to determine the peak pressure ($\text{N}\cdot\text{cm}^{-2}$) generated in each of the masked areas.

<insert Figure 1 about here>

Physical activity was objectively assessed using MTI ActiGraph 7164 uniaxial accelerometers (Manufacturing Technology Inc, Fort Walton Beach, FL, USA), which have established validity in preschool children [13]. Accelerometers measure changes in body movement in real-time, and the output, known as activity "counts", represents the magnitude of the acceleration force produced during movement [14]. Each child was fitted with an accelerometer by a trained research staff member [DPC] and the child's parents received an information sheet detailing the monitoring protocol, as well as a monitoring log. Parents were asked to indicate on the log when the monitor was placed on their child, and when the monitor was taken off and the reason for doing so. Participants' parents were instructed to fit the monitor on their child's right hip during waking hours, and to take the monitor off during aquatic activities. A seven-day monitoring period was used, and activity counts were accumulated and stored to the accelerometer over one minute epochs. The use of one minute epochs for physical activity assessment via accelerometry in young children may have the potential to underestimate time spent in vigorous physical activity, although there is currently limited evidence available on this issue [14, 15]. Strings of "0" counts ≥ 20 were considered

periods of non-monitoring and were removed from the total minutes monitored during data reduction. Participant data were included in analyses if they recorded greater than 360 min (6 hours) of monitoring time each day, over at least three days [16]. The raw activity output, or accelerometer counts per minute averaged over the monitoring period, was used in the analyses as a measure of total physical activity. Percent of time spent in moderate-to-vigorous physical activity (MVPA) was calculated for each child using validated age-specific definitions [13]. MVPA was defined as ≥ 2460 , ≥ 3248 , and ≥ 3564 counts/minute for 3-, 4- and 5-year-olds, respectively. Percent time in light activity (between 1100 counts/minute and $< \text{MVPA cut-point for age}$) and sedentary behaviour (< 1100 counts/minute) were also calculated [17].

Preliminary analysis of the data indicated little difference in peak plantar pressures between the right and left feet of each child. Therefore, one foot (right or left) was randomly selected for each child, and data pertaining to that foot were included in the statistical analysis. A Kolmogorov-Smirnov test (with Lilliefors' correction) was used to test all data for normality. Independent t-tests were used to determine any differences in the plantar pressure and physical activity variables between boys and girls. In order to establish the strength of the relationships among peak pressure and the physical activity variables, Pearson product moment correlations were calculated for boys and girls separately as foot structure and dynamic pressure patterns have been shown to differ between boys and girls [18-21]. A relationship was deemed significant at $p \leq 0.05$. All statistical analyses were conducted using SPSS software (SPSS 15 for Windows).

Results

Complete data sets of both plantar pressures and physical activity were available for 17 boys and 16 girls (age = 4.3 ± 0.6 yr; height = 1.06 ± 0.1 m; mass = 18.4 ± 2.9 kg; BMI = $16.3 \pm$

1.5; see Table 1); therefore, data are reported for these children. Although more children were recruited to the study, non-compliance ($n = 22$), monitor malfunction ($n = 7$) and one of the preschools non-consent to the physical activity component of the assessments ($n = 27$) resulted in missing physical activity data while six children did not have complete plantar pressure data.

<insert Table 1 about here>

Peak plantar pressure data and time spent in physical activity and in sedentary behaviour are displayed in Figure 2 and Table 1, respectively. There were no significant differences between the boys and girls for any of the plantar pressure or physical activity variables. High standard deviations, which are evident in the physical activity data, may have masked actual differences in these variables, although the values in this study are not dissimilar to those found for physical activity in a larger, community sample of young children [22].

<insert Figure 2 about here>

Table 2 displays the relationships between the three physical activity outcomes (total, light and MVPA), sedentary behaviour, and the peak plantar pressures generated over the whole foot (total) and the five foot regions. For boys, mean accelerometer counts per minute were negatively correlated with heel peak pressure generated during walking ($r = -0.53$; $p = 0.03$), and there was a trend of an inverse relationship of this same variable with peak pressure generated across the whole foot ($r = -0.4$; $p = 0.1$). Likewise, the percentage of time spent in MVPA was significantly correlated with peak plantar pressures in boys ($r = -0.47$; $p = 0.05$). Again, this significant relationship was only evident in the heel region for boys, whereby boys who generated higher plantar pressures in the heel region spent a smaller proportion of time in MVPA. Additionally, the percentage of time spent in sedentary behaviour was significantly correlated with peak plantar pressure in the toe region for girls (r

= 0.53; $p = 0.04$). No significant correlations were found between the plantar pressure variables and the percentage of time spent in light physical activity.

<insert Table 2 about here>

Discussion

This study is the first to investigate the relationship between peak plantar pressures generated during walking and time spent in physical activity and sedentary behaviour in preschool-aged children. Data from this exploratory study found that preschool boys who generated higher peak pressures under the heel tended to be less physically active or spent less time in MVPA than boys who generated lower heel pressures, whereas girls who generated higher peak pressures under the toe region spent more time in sedentary behaviour than girls who generated lower toe pressures.

The percentage of time spent in MVPA was slightly higher in our sample compared with a larger community sample of young children, particularly among boys (6% and 4%, respectively) [22]. Our sample of young children also spent a larger proportion of time in sedentary behaviour compared with the same community sample of preschool children [22] (82% and 65%, respectively). However, differing definitions of MVPA would contribute to the apparent differences between studies [23]. Thus, the sample's physical activity and sedentary behaviour patterns, or methodological factors, may have accentuated relationships between plantar pressures and these behaviours.

It is speculated that children who experience greater pressures on the plantar surface of the foot may suffer more pain and discomfort during weight-bearing activities which, in turn, may act as a barrier to physical activity. Boys in the present study generated their highest pressures under the heel region of the foot. As the heel is typically the first part of the foot to contact the ground during walking, acting to absorb the impact peak of the ground

reaction forces, it is typically the region of the foot under which the highest plantar pressures are generated [24, 25]. Interestingly, generating high pressures under the heel was also associated with lower total physical activity and MVPA in boys. An unexpected finding was that girls in the present study generated their highest pressures under the hallux and not the heel (see Figure 2); however, girls have been shown to generate higher pressure under the hallux compared to boys in a previous study [21]. Although high plantar pressures under the hallux were not significantly correlated with physical activity, they had the strongest association with MVPA in girls.

The relationships between higher plantar pressures and lower amounts of physical activity were reinforced when investigating the association between the amount of time spent in sedentary behavior and plantar pressures. That is, girls who generated higher peak pressure values under the toes and boys who generated higher peak pressure values under the heel and total foot regions spent a larger percentage of their time being sedentary. The finding that the association between physical activity levels and plantar pressures differed between foot regions for boys and girls was unexpected. However, this between-gender difference may be due to structural foot differences between the genders, whereby boys have been shown to have a flatter foot than girls at the same age [18, 19, 26]. Conversely, the small sample size, which is acknowledged as a limitation of this study, may have influenced the associations, as no significant difference was seen between boys and girls for any of the plantar pressure or physical activity variables. The small sample size limits statistical power, potentially masking real relationships between variables. Despite the small number of children who participated in the study, the significant and moderate correlations suggest potentially robust relationships between peak plantar pressures and the physical activity measures. However, further research is warranted with a larger sample size to determine

whether the relationships between plantar pressures and physical inactivity are gender specific.

It is acknowledged that this is a cross-sectional study and therefore we cannot determine the causality of any associations. In addition, plantar pressure distributions across the plantar surface of the foot may change as the roll-over process matures during growth and development. Therefore, a longitudinal study that examines changes in plantar pressures and physical activity over time is needed to determine whether higher plantar pressures are a cause of higher sedentary behaviour. Although overweight and obese children have been shown to generate higher plantar pressures than normal weight children [7-9], the two boys and three girls who were overweight/obese in this sample, did not display different physical activity/sedentary behaviours and therefore should not have biased the relationship.

Pre-school children are at a vulnerable age in terms of structural development of the foot. The feet of infants grow most rapidly in the first three years life [27], continually changing shape until around 5-6 years of age when they attain characteristic features of adult feet [28, 29]. Although no direct link between high plantar pressures and foot pain has been investigated in children, higher plantar pressures have been shown to be associated with a greater incidence of foot pain in adults [6, 30, 31]. If higher pressures are causing pain and discomfort, it may be impacting on children's physical activity levels without parents realising, unless the child was to complain about having pain.

Conclusion

Peak plantar pressures generated during walking are significantly associated with physical activity behaviours in preschool-aged children whereby preschool boys who generated higher peak pressures across the total foot and heel tended to be less physically active and spent less time in MVPA than boys who generated lower pressures. Furthermore, girls who generated

higher peak pressures in the toe region spent more time in sedentary behaviour than girls who generated lower pressures. As high plantar pressures appear to be a potential barrier to physical activity it is recommended that further research be conducted to determine the potential efficacy of interventions designed to reduce plantar pressures in these children on time spent in physical activity and sedentary behaviour.

Practical implications

- Identifying children who have foot discomfort associated with high plantar pressures may be an important step in removing a potential barrier to these children participating in physical activity.
- Providing comfortable, well-fitting shoes that reduce pressure under the foot may reduce foot discomfort whilst children participate in physical activity.
- Promoting activities that reduce loading on the feet, such as cycling and swimming, may also encourage children with foot discomfort to be more physically active.

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Conflict of Interest

None of the authors received financial support for this study.

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Table 1: Mean (SD) descriptive characteristics and time spent sedentary, or in light or moderate-to-vigorous physical activity (MVPA) for the boys (n=17) and girls (n=16).

Variable	Boys	Girls	<i>p</i>
Age (years)	4.4 (0.6)	4.2 (0.6)	0.46
Height (cm)	107.7 (4.7)	104.1 (6.5)	0.08
BMI (kg.m ⁻²)	16.6 (1.8)	16.0 (1.2)	0.33
Total physical activity (counts/min)	911 (254)	809 (133)	0.16
Sedentary behaviour (% time)	81.0 (6.3)	84.4 (3.1)	0.06
Light activity (% time)	13.1 (4.2)	11.8 (3.5)	0.34
MVPA (% time)	6.0 (4.5)	3.9 (2.5)	0.11

Table 2: Pearson product moment correlation coefficients between total physical activity and peak plantar pressures generated under each region of the foot for the boys (n=17) and girls (n=16).

Foot region	Boys				Girls			
	Total PA	Sedentary behaviour	Light PA	MVPA	Total PA	Sedentary behaviour	Light PA	MVPA
Total	-0.40	0.47	-0.38	-0.31	-0.18	0.06	-0.05	-0.01
Heel	-0.53*	0.43	-0.14	-0.47*	-0.17	-0.20	0.15	0.04
Midfoot	0.13	-0.25	0.36	0.01	0.23	-0.33	0.17	0.18
Forefoot	0.01	-0.01	0.11	-0.10	-0.34	-0.35	0.28	0.04
Hallux	0.23	0.01	-0.30	0.26	-0.28	0.26	-0.06	-0.24
Toes 2-5	0.22	-0.05	-0.05	0.11	-0.04	0.53*	-0.45	-0.02

* denotes a significant correlation ($p \leq 0.05$).

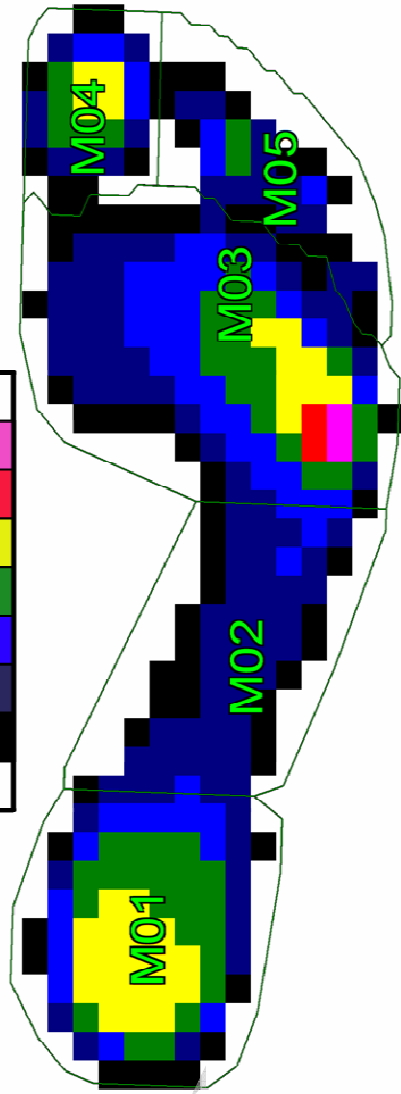
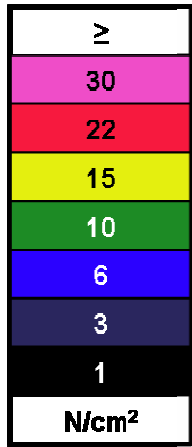
PA = physical activity; MVPA = moderate-to-vigorous physical activity

Figure Legends

Figure 1: An example of a mean peak pressure picture showing the masked regions based around the heel (M01), midfoot (M02), forefoot (M03), hallux (M04) and toes 2-5 (M05).

Figure 2: Peak pressures generated underneath each region of the foot for the boys (n = 17) and girls (n = 16).

Accepted version



version

Accepted

