Accepted Manuscript

Title: Effects of different movement modes on plantar pressure distribution patterns in obese and non-obese Chinese children

Authors: Yan Song-hua, Wang Lu, Zhang Kuan

PII: S0966-6362(17)30183-2
DOI: http://dx.doi.org/doi:10.1016/j.gaitpost.2017.05.001
Reference: GAPOS 5415

To appear in: Gait & Posture

Received date: 21-1-2017
Revised date: 21-4-2017
Accepted date: 4-5-2017

Please cite this article as: Song-hua Yan, Lu Wang, Kuan Zhang. Effects of different movement modes on plantar pressure distribution patterns in obese and non-obese Chinese children. Gait and Posture http://dx.doi.org/10.1016/j.gaitpost.2017.05.001

This is a PDF file of an unedited manuscript that has been accepted for publication. As a service to our customers we are providing this early version of the manuscript. The manuscript will undergo copyediting, typesetting, and review of the resulting proof before it is published in its final form. Please note that during the production process errors may be discovered which could affect the content, and all legal disclaimers that apply to the journal pertain.
Effects of different movement modes on plantar pressure distribution patterns in obese and non-obese Chinese children

Yan Song-hua¹², Wang Lu³, Zhang Kuan¹²*

1. School of Biomedical Engineering, Capital Medical University, Beijing 100069, China; 2.Beijing Key Laboratory of Fundamental Research on Biomechanics in Clinical Application, Capital Medical University, Beijing 100069, China;

3. Beijing Children’s Hospital, Capital Medical University, Beijing 100045, China

Research Highlights:
1. Plantar pressure distribution during three movements changed differently between two groups.
2. Obese children and non-obese children have different running patterns.
3. Obese children perhaps shouldn’t jog to fight obesity.

Abstract:

Walking, slow running (jogging) and fast running often occur in daily life, Physical Education Class and Physical Fitness Test for children. However, potential impact of jogging and running on plantar pressure of children is not clear. The purpose of this study was to compare the characteristics of plantar pressure distribution patterns in obese and non-obese children during walking, jogging and running, and evaluate biomechanical effects of three movements on obese children. A 2-m footscan plantar pressure plate (RSscan International, Belgium) was used to collect the gait data of 20 obese children (10.69±2.11 years; 1.51±0.11m; 65.15±14.22kg) and 20 non-obese children (11.02±1.01 years; 1.48±0.07m; 38.57±6.09 kg) during three movements. Paired t-test and independent sample t-test were performed for statistical comparisons and ANOVA was used for comparisons of gait characteristics among three movements. Significance was defined as p<0.05. Propulsion phase during jogging for obese children was the longest among three movements (p=0.02). Peak pressures under metatarsal heads IV, V (M4, M5), midfoot (MF), 1
heal medial (HM) and heal lateral (HL) during jogging for obese children were the highest among three movements (p=0.005, p=0.003, p=0.004, p=0.03, p=0.01). Arch index (AI) of left foot during jogging for obese children was the largest (p=0.04). **Conclusions:** Plantar pressure distribution during three movements changed differently between two groups. The peak pressures under most plantar regions and AI during jogging for obese children were the largest among three movements, indicating that jogging caused more stress to their lower extremities. Obese children perhaps should not consider jogging as regular exercise.

Keywords: gait; obese children; non-obese children; different movement modes; slow running (jogging); plantar pressure distribution

1. **Introduction**

Pediatric obesity is growing at a staggering rate [1]. Twelve percent of Chinese children are overweight according to a study from the Chinese Center for Disease Control and Prevention [2]. An investigation showed that the city of Beijing has the highest overweight rate for children and adolescents in China at 20% [3].

The excessive body weight may cause enormous health risks such as hypertension, diabetes, and cardiovascular diseases [4] as well as diseases associated with musculoskeletal system dysfunction [5]. Excessive weight affects children’s normal development of bones, muscles and joints [6], and may cause shorter step length, slower speed and weaker stability etc. compared with normal weight children [7,8,9].

The gait studies of obese children with small samples by Hills and Parker in 1991 [7] and 1992 [10] demonstrated that the step length, cadence, and gait cycle of obese children under three walking speeds were all different from those of non-obese children. Studies on the
impact of obesity on children’s foot structure and plantar pressure distribution suggested that overweight in preschool children led to anatomical changes and differences of plantar pressure distribution such as higher peak value of plantar pressure distribution, larger contact area of the arch and foot axis angle etc. [9, 11-14]. The most of previous studies on gait characteristics of obese children during walking showed that gait of obese children tended to be not favorable compared to non-obese children.

Walking, slow running (jogging) and fast running often occur in daily life, Physical Education Class, and Physical Fitness Test for children. Running is one of the most popular forms of exercise that contributes to sustained health and physical fitness [15]. Running consumes significantly more calories than walking, so obese children are encouraged to run whenever it is possible. As a form of running at a slow or leisurely pace, jogging is more often chosen for losing weight [16, 17] because of less effort and intensity than fast running. However, long-distance running led to the increased relative load and mean area under the MLA (medial longitudinal arch) that may alter lower limb loading and increase the risk of running-related injuries [18]. Nagel et al. found that long distance runners showed increased peak pressure of the metatarsal bones during running [19]. Van etc. also reported that the long distance runners were prone to sustain metatarsal stress fractures [20]. Jogging is also associated with increased risk of incurring lower limb injuries [21] and numerous overuse injuries have been reported in immature adolescent distance runners [22, 23]. Ho et al. examined the effect of changes in speed and incline slope on plantar pressure distribution of the foot during treadmill jogging for healthy young females, and found that the peak pressures of heel, the medial and lateral arch, central forefoot and lateral forefoot increased
significantly with the increase of speed. The maximum pressures of heel, the medial forefoot, and hallux and toes reduced significantly and the maximum pressures of lateral arch increased significantly as the jogging slope increased [24].

The most of previous studies focused on adults and adolescents, especially elite runners. Few studies were on regular primary school children. It is an important issue for obese children in primary schools to choose the appropriate form of exercise to fight obesity. The purpose of this study was to compare plantar pressure distribution characteristics of obese and non-obese children during natural walking, jogging and fast running, and evaluate biomechanical effects of those exercises on obese children.

### 2. Methods

#### 2.1 Participants

Forty children: 20 obese (mean ± standard deviation; age: 10.69±2.11 years; height: 1.51±0.11m; weight: 65.15±14.22 kg; BMI: 28.13±3.40kg/m²) and 20 non-obese (age: 11.02±1.01 years; height: 1.48±0.07m; weight: 38.57±6.09 kg; BMI: 17.44±1.57 kg/m²) from Yulin Primary School in Fengtai District, Beijing, China participated in the study. There were no significant differences for ages and heights between two groups (p=0.93, p=0.46). All subjects signed the informed consent form. The study was approved by the Ethics Committee of Capital Medical University and participants were not compensated.

Subjects were selected based on their age (7-13 years) and body mass index (BMI, kg/m²) as the inclusion criteria. Children with BMI ≥95% were defined as obese. Children with BMI <85% were defined as non-obese according to international standardization proposed by the National Center for Health Statistics (NCHS) [25].
Subjects with diseases associated with bones, muscles, motor nerves, hypertension, hyperlipidemia, and diabetes were excluded.

2.2 Experimental instrument

A 2-m footscan plantar pressure plate (RSscan International, Belgium) was used to collect the gait data with a sampling rate of 250 Hz. This plantar pressure plate has an area of 209.6cm×47.2cm with 16,384 resistive transducers. The size of a single sensor is 7.62mm×5.08mm. This system includes a force measurement plate, a 3-D collection box and corresponding software.

2.3 Gait test

Each participant’s height and body mass were measured using a calibrated stadiometer and calibrated Precision Medical Scale while the subjects stood motionless and wearing minimal clothing [9].

The platform was mounted on a firm and level surface and in the middle of a 10 m long rubber walkway. The platform was covered with a top-layer made from EVA material (hardness: Shore A 70; thickness: 2mm) to prevent subjects from adjusting their natural walking style when aiming at the plate [26].

Subjects passed the force plate in three movements: natural walking (the comfortable speed used in daily life), slower running (jogging, the most comfortable speed during warm-up in the Physical Education Class), and fast running (the fastest speed of 50 m race in the physical test) while barefoot. Children were asked to repeat trials until we collected three valid data. They began to walk or run 5 m ahead of the plate. After passing through the plate, two or more steps were required. In order to get familiar with the tests, subjects were asked to
complete at least two trials across the plate walkway prior to formal tests. The subjects were allowed to rest if they felt tired between trials for at least 2 minutes.

2.4 Parameters

Foot was divided into 10 anatomical regions by the footscan plantar pressure plate system. 10 anatomical regions are Toe 1 (T1), Toe 2 to Toe 5 (T2–T5), Metatarsal 1 (M1), Metatarsal 2 (M2), Metatarsal 3 (M3), Metatarsal 4 (M4), Metatarsal 5 (M5), Midfoot (MF), Heel medial (HM), Heel lateral (HL) [9].

The test parameters include sub-phases of support phase (heel strike, midstance and propulsion), the peak pressure of each region, arch index (AI), and angle of foot axis. Variables were explained in earlier study [9].

Heel strike covers the duration from the instance that the heel region (HM–HL) first contacts the plate to the instance that one of the metatarsal heads contacts the plate.

Midstance covers the duration between the instance when one of the metatarsal heads contacts the plate and the instance when the heel region loses contact with the plate.

Propulsion covers the duration from the instance that the heel region loses contact with the plate to the last moment of any contact.

Peak pressure of each region is the highest pressure applied to each region of the plantar surface.

Foot axis angle is the angle between foot axis direction and movement direction.

AI is a ratio of midfoot area to total foot contact area without the toes.

2.2.4. Statistical analysis

Average values of three valid trials were analyzed. Data was processed using SPSS (Version
19.0 for Windows), and presented as mean ± standard deviation. Followed by post-hoc analysis, statistical comparisons of different parameters between left and right foot for two groups were performed with paired t-test, and statistical comparisons between obese and non-obese children were performed with independent sample t-test. ANOVA was used for comparison of gait characteristics among three movements for two groups. p<0.05 was considered statistically significant. If there was no significant for any parameter between left and right foot, the data from right foot would be analyzed, otherwise data from both feet would be analyzed respectively.

3. Results

3.1 Comparison on plantar pressure distribution between obese and non-obese children during three movements

3.1.1 Subphases during foot-ground contact

There were no significant differences between left and right foot for subphases during three movements for both groups.

There were no significant differences in duration of the heel strike phase between the two groups during three movements (walking: p=0.92, jogging: p=0.12, running: p=0.71). Obese group showed significantly longer midstance phase (walking: 52.45%±10.22%, running: 49.88%±6.60%) and shorter propulsion phase (walking: 42.37%±8.26%, running: 47.82%±6.53%) than non-obese group (midstance: walking 46.11%±9.92%, running 44.98%±7.76%; propulsion: walking 48.17%±10.80, running 52.56%±8.32%) during walking (midstance: p=0.02, propulsion: p=0.02) and running (midstance: p=0.0005, propulsion: p=0.0008). There were no significant differences during jogging (midstance:
p=0.31, propulsion: p=0.98) although obese children intended to have shorter midstance phase (47.86% ± 7.65%) and longer propulsion phase (48.27% ± 5.16%) than non-obese group (midstance: 49.29% ± 6.66%, propulsion: 48.19% ± 7.91%).

3.1.2 Peak pressure of every plantar region

There were no significant differences between left and right foot for peak pressure of each plantar region during three movements for both groups.

Table 1 shows the peak pressures under each plantar region during three movements.

During natural walking, the peak pressures of other plantar regions except Toe II–V (T2-T5) for obese children were higher than those of non-obese children. The peak pressures of the metatarsal heads II–V (M2-M5) and midfoot (MF) were significantly higher than those of non-obese children (p=0.04, p=0.01, p=0.001, p=0.001, p=0.02).

During jogging, the peak pressures of other plantar regions except T2-T5 for obese children were higher than those of non-obese children. The peak pressures of M4-M5, MF, heel medial (HM) and heel lateral (HL) for obese children were significantly higher than those of non-obese children (p=0.003, p=0.01, p<0.001, p=0.002, p=0.002).

During fast running, the peak pressures of other plantar regions except T2-T5 and M2 for obese children were higher than those of non-obese children. The peak pressures of M4 and MF for obese children were significantly higher than those of non-obese children (p=0.02, p=0.001).

3.1.3 Foot axis angle

There were no significant differences for foot axis angle of two groups between left and right foot during walking (p>0.05). However, there were significant differences for two
groups during jogging and running (obese children: jogging p=0.01, running p=0.02; non-obese children: jogging p=0.02, running p=0.01).

During three movements, the angles of foot axis of obese children were larger than those of non-obese children (left foot: walking p=0.08, jogging p=0.09, running p=0.08; right foot: walking p=0.03, jogging p=0.04, running p=0.09). In particular, the angles of foot axis for the right foot of obese children (walking: 15.43±5.72; jogging: 16.80±6.91) were significantly larger than non-obese children (walking: 9.05±5.18; jogging: 12.44±6.95) during walking and jogging (p=0.03, p=0.04).

3.1.4 AI

There were significant differences for AI of obese children between left and right foot during three movements (walking: p=0.002, jogging: p<0.001, running: p<0.001). While there were all no significant differences during three movements for non-obese children (walking: p=0.05, jogging: p=0.18; running: p=0.18).

The AIs for the left foot of obese children (walking: 31.66±3.67; jogging: 33.54±2.99; running: 34.02±2.50) were significantly larger than those of non-obese children (walking: 27.52±3.12; jogging: 30.43±2.76; running: 30.63±2.50) during three movements (p=0.001, p=0.002, p<0.001). However AI for the right foot of obese children (28.50±2.96) was significantly greater than that of non-obese children (25.23±3.57) only during walking (p=0.004). Although AIs for the right foot of obese children (jogging: 29.86±1.89; running: 29.04±2.74) tended to be higher than those non-obese children (jogging: 28.32±3.41; running: 27.68±3.50) during jogging and running, there were no significant differences (p=0.09, p=0.18).
3.2 Changes of gait patterns from natural walking, jogging to fast running

Fig.1 shows the changes of subphases from natural walking, jogging to fast running for two groups. Heel strike duration decreased significantly for both obese children (p=0.002) and non-obese children (p=0.0004) as speed increased. Midstance duration had no significant changes for two groups (p=0.25, p=0.24). Propulsion duration of obese children increased significantly firstly and then decreased significantly from walking, jogging to running (p=0.02). However, propulsion phase duration of non-obese children changed insignificantly (p=0.22).

Fig. 2 shows the changes of peak pressures under 10 plantar regions from natural walking, jogging to fast running for two groups. Peak pressures under M4, M5, MF, HM and HL increased significantly firstly and then decreased significantly (p=0.005, p=0.003, p=0.004, p=0.03, p=0.01) and changes of peak pressures under other regions were not significant (T1: p=0.24, T2-T5: p=0.06, M1: p=0.08, M2: p=0.07, M3:p= 0.11) for obese children. For non-obese children, peak pressures under M1-M5 increased significantly (p=0.002, p=0.00006, p=0.00006, p=0.000003, p=0.0002) and changes of peak pressures under other regions were not significant (T1: p=0.14, T2-T5: p=0.13, MF: p=0.84, HM: p=0.32, HL: p= 0.28).

Fig.3 shows the changes of foot axis angles from natural walking, jogging to fast running for two groups. Only the foot axis angle of the right foot for non-obese children increased significantly. The angles of left foot for two groups and the right foot for obese children increased insignificantly (obese children: left foot: p=0.07, right foot, p=0.11; non-obese children: left foot: p=0.24, right foot: p=0.005).
Fig. 4 shows the changes of AI from natural walking, jogging to fast running for two groups. The changing trends were consistent for two groups and the values during jogging were the largest. (Obese children: left foot, p=0.04; right foot, p=0.25; non-obese children: left foot, p=0.001, right foot, p=0.02).

4. Discussion

This study investigated the characteristics of plantar pressure distribution for elementary students during their natural walking, jogging and running by using high frequency digital sampling technique for precise and comprehensive measurements. It has been reported that a detailed registration and analysis of foot-to-ground interaction could produce a detailed pressure image of the entire foot sole through high frequency digital sampling techniques [26].

The longer midstance phase duration is an indication of a safer and more tentative ambulation, and the shorter propulsion phase duration indicates the possible instability for movement [18]. Our results showed reduced stability during walking and running, suggesting a balance adaptation for better stability by obese children, which was similar to the findings in previous studies [7, 9]. Interestingly, the changing trends of midstance and propulsion between two groups were opposite from walking, jogging to running. For obese children, the midstance phase during jogging was the shortest among three movements, which showed the poorest stability for obese children during jogging. At the same time, the propulsion phase during jogging was the longest among three movements. It is speculated that obese children may try to increase ground reaction impulse through extending the propulsion duration when jogging, which increases the risk of foot/ankle injury. Therefore, obese children perhaps
should not jog for the long period of time.

Obesity leads to changes in the distribution of plantar pressure. The excess fat tissue that obese children have to carry makes their lower limbs and especially their feet suffering greater overload [27]. The high foot pressure values for obese children can increase the risk of developing pain, discomfort, and foot pathologies, especially considering children’s developing feet [13, 28]. In the present study, the differences of peak pressures between two groups during walking are similar with the results from previous studies [7, 9]. Significantly higher peak pressures under M2-M5 and MF for obese children resulted in the force concentrating on the lateral forefoot, which would probably lead to the damage on their plantar lateral forefoot region and subsequent forefoot supination for the longer period of time. During jogging and running, peak pressures under M4, M5, MF, HM and HL increased significantly firstly and then decreased significantly from natural walking, jogging to running for obese children. So the peak pressures under lateral forefoot, midfoot and rearfoot during jogging for obese children were the highest among three movements, which indicates that jogging may be more harmful to their lower limbs than walking and fast running because of higher peak pressure [29]. Therefore, obese children should aware that there are potential problems jogging may cause during exercise. For non-obese children, peak pressures under M1-M5 increased significantly from walking, jogging to running and this changing trend fits to the study by Munro et al [30]. Merely the results of their study showed that the maximum force during running was almost two times of natural walking, which are different from the value change in our study. From the present study, we infer that running modes between the two groups are perhaps different or obesity modifies the plantar surfaces [30] and redistribute
the forces and pressures on the plantar surfaces [27].

The angles of foot axis of obese children were larger than that of non-obese children during three movements. The angles are increasing with movement speeds because obese children maintain balance through increasing the angle of foot axis and the contact area with the ground. Thus, obese children are easier to have toe-out foot and get injury of foot and lower extremity [9].

AIs for obese children during three movements are significantly greater compared to non-obese children, and AIs during jogging for two groups were the largest among three movements. Larger AIs of the obese children may be caused by the flatter foot structure and makes them often to get fatigue [9]. The flatter foot is caused by a lowering of the longitudinal arch, and this structural changes adversely affect the functional capacity of the medial longitudinal arch and may be exacerbated if excessive weight bearing continue [10]. The increased AI of obese children during movement may also simply be due to the continued presence of a fatter pad in this foot region of the obese children [13]. AM Dowling et al. suggested that further studies pertaining to the causes of increased midfoot contact areas during movement in obese children was recommended as the mechanism of this increased midfoot contact area is purely speculative [13]. Regardless the reason, our results suggest that jogging would increase the possibility of plantar abrasion and tiredness of children.

In addition, the changing trends of foot axis angle and AI between left foot and right foot for obese children are asymmetry, increasing their gait abnormality. So, excessive jogging should be prevented to avoid the possible plantar injury for the obese children.

Conclusions
In conclusion, the plantar pressure distribution during three movements changed differently between two groups. The peak pressures under most plantar regions and AIs for obese children during jogging are the largest among three movements. Because jogging causes more biomechanical burden on the feet of obese children compared with walking and running, obese children perhaps should not consider jogging as regular exercise in order to avoid possible lower extremity injury in the long-term.

Conflict of interest

The authors have no financial and personal relationships with other people or organizations that could inappropriately influence (bias) their work.

Fund support: Beijing Natural Science Foundation (Grant 7152018) of China, The Importation and Development of High-Caliber Talents Project of Beijing Municipal Institutions (Grant CIT&TD201404177) of China, The major project of Beijing Municipal Science and Technology Commission of China (Grant Z151100003715001), Natural Science Foundation Program and Scientific Research Key Program of Beijing Municipal Commission of Education (Grant KZ201310025010) of China and Research Fund for the Doctoral Program of Higher Education of China (Grant 20121107110018)

Acknowledgment

The authors would like to thank for financial support provided by the Beijing Natural Science Foundation of China, The major project of Beijing Municipal Science and Technology Commission of China, The Importation and Development of High-Caliber Talents Project of Beijing Municipal Institutions of China, Natural Science Foundation Program and Scientific Research Key Program of Beijing Municipal Commission of Education of China and Research Fund for the Doctoral Program of Higher Education of
China. We would like to thank the subjects participating in this study and the teachers, especially Liang Xiuqiao, director in YuLin elementary school, District Fengtai, Beijing, providing us support and help.

References


Figure 1 Changes of subphase duration from natural walking, jogging to fast running for children

(a) heel strike phase; (b) midstance phase; (c) propulsion phase
Figure 2 Changes of peak pressures under 10 plantar regions from natural walking, jogging to fast running for children (a) Obese children; (b) non-obese children.

Figure 3 Changes of foot axis angle values from natural walking, jogging to fast running for children.
Figure 4 Changes of AIs from natural walking, jogging to fast running for children
Table 1 Peak Pressure under every plantar region of obese children and non-obese children during natural walking, jogging and fast running (N/cm²)

Note: *express P<0.05

<table>
<thead>
<tr>
<th>Plantar Region</th>
<th>Natural walking</th>
<th>Jogging</th>
<th>Fast running</th>
</tr>
</thead>
<tbody>
<tr>
<td>T1</td>
<td>5.60±2.60</td>
<td>5.17±1.88</td>
<td>0.56</td>
</tr>
<tr>
<td>T2-T5</td>
<td>1.42±1.39</td>
<td>1.71±1.04</td>
<td>0.46</td>
</tr>
<tr>
<td>M1</td>
<td>9.66±3.69</td>
<td>7.44±3.43</td>
<td>0.07</td>
</tr>
<tr>
<td>M2</td>
<td>15.04±6.73*</td>
<td>11.41±3.48</td>
<td>0.04</td>
</tr>
<tr>
<td>M3</td>
<td>16.40±9.49*</td>
<td>11.48±3.06</td>
<td>0.01</td>
</tr>
<tr>
<td>M4</td>
<td>11.37±4.11*</td>
<td>7.15±2.66</td>
<td>0.001</td>
</tr>
<tr>
<td>M5</td>
<td>5.76±1.57*</td>
<td>3.18±1.60</td>
<td>0.001</td>
</tr>
<tr>
<td>MF</td>
<td>4.19±1.24*</td>
<td>3.02±1.71</td>
<td>0.02</td>
</tr>
<tr>
<td>HM</td>
<td>13.73±5.17</td>
<td>11.65±4.78</td>
<td>0.20</td>
</tr>
<tr>
<td>HL</td>
<td>11.66±4.32</td>
<td>10.33±3.65</td>
<td>0.30</td>
</tr>
</tbody>
</table>