Difference in the running biomechanics between preschoolers and adults

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Abstract

Purpose High vertical loading rate is associated with a series of running-related musculoskeletal injuries. There is evidence supporting that non-rearfoot footstrike pattern, greater cadence and shorter stride length may reduce the vertical loading rate. These features appear to be common among preschoolers, who seem to experience lower running injury incidence, leading to a debate whether adults should accordingly modify their running postures. This study sought to compare the running biomechanics between preschoolers and adults.

Method Ten preschoolers (4.2 ± 1.6 years) and ten adults (35.1 ± 9.5 years) were recruited and they ran overground with their usual shoes at a self-selected speed. Vertical average (VALR) and vertical instantaneous loading rate (VILR) were calculated based on the kinetic data. Footstrike pattern and spatiotemporal parameters were collected using a motion capture system.

Results There was no difference in normalized VALR (p=0.46), VILR (p=0.51), running speed (p=0.38), and footstrike pattern (p=0.29) between the two groups. Preschoolers demonstrated greater cadence (p<0.01, Cohen's d=4.13) and shorter normalized stride length (p=0.03, Cohen's d=-1.11).

Conclusion By comparing the kinetic and kinematic parameters between children and adults, our findings do not support the notion that adults should modify their running biomechanics according to the running characteristics in preschoolers for a lower injury risk.

Keywords: Children; Vertical loading rate; Footstrike pattern; Cadence; Spatiotemporal parameters

1. Introduction

Distance running is a globally popular sport and this bloom can be partially reflected by the increasing number of marathon finishers and major running events around the world [1]. In spite of potential cardiovascular and mental health benefits related to distance running [2], the incidence of running-related musculoskeletal injury is extremely high. According to previous epidemiological studies [3, 4], up to 79% of regular runners may incur an overuse injury in a given year. Thus, prevention of running-related musculoskeletal injuries has received a lot of attention over the past decades.

A series of retrospective studies have related high vertical impact loading, which is usually expressed as vertical average loading rate (VALR) and vertical instantaneous loading rate (VILR), with a series of running ailments, such as patellofemoral pain, tibial stress fracture, and plantar fasciitis [5-7]. Recent prospective studies also suggest that high VALR and VILR may be associated with the development of running injuries [8, 9]. Therefore, different strategies have been proposed to lower the vertical loading rates, including footstrike pattern modification [10] and cadence adjustment [11].

Specifically, runners exhibiting non-rearfoot strike, i.e. midfoot or forefoot strike, have been shown to experience lower VALR and VILR than rearfoot strikers [12, 13]. Such reduction in the impact loading can be explained by a lower effective mass during non-rearfoot strike [14]. As for spatial parameters, runners with greater cadence and shorter stride length have been reported to place the heel closer to the center of mass at initial contact, which results in a reduction in the braking impulse [15] and vertical loading rates [16]. Therefore, shortened strike length accompanied with increased cadence for a given velocity also contribute to the reduction of running injuries [11].

In view of the relationship between running-related musculoskeletal injuries and running biomechanics, a lot of runners attempt to adjust their running pattern so as to reduce the injury risk. Anecdotally, many runners believe that adults should mimic the running pattern of children [17], who are supposed to exhibit the most natural running gait [18] without being habitualized to any external device e.g., shoes [19]. Such belief in running biomechanics modification is mainly based on the assumption that children usually land with more non-rearfoot strikes, run with shorter stride length and higher cadence, when compared with adults [19].

Limited knowledge exists, however, with regard to the difference in running characteristics between children and adults. To our best knowledge, the majority of previous studies explored differences in walking biomechanics between the two groups. For example, Dusing and Thorpe reported higher cadence, shorter stride length, and slower self-selected walking velocity in children than adults [20]. Other studies suggested that spatiotemporal parameters during walking were similar in the two groups but the ankle power generation was lower in children [21, 22]. Such difference can be explained by children's age and the variables explored in each study. However, there is a lack of evidence showing the differences in the running biomechanics between children and adults.

Considering running kinetics [23], spatiotemporal parameters [24], and joint kinematics [22] become mature and more adult-like at approximately 7-8 years old, the present study compared the running biomechanics between preschoolers (i.e. age < 7) and adults. Kinetically, we hypothesized that preschoolers would present lower body weight normalized VALR and VILR than adults. We also expected preschoolers would exhibit more non-rearfoot strikes, greater cadence and longer normalized stride length than adults.

2. Materials and Methods

2.1 Subjects

A sample size estimation was carried out using the effect size extracted from a study comparing walking gait differences between school-aged children (5-13 years) and young adults (18-27 years) [24]. Normalized speed of children aged 5.7 years and young adults aged 19.6 years was extracted for calculating Cohens' *d*. A sample size of 9 subjects in each group was required for this present study, based on an effect size of 1.25, type I error of 5% and type II error of 20% (power: 80%).

Ten preschoolers (four males and six females) who were able to run independently and ten adults (six males and four females) were recruited in this study (**Table 1**). Subjects were excluded if they had any known developmental, neurological, or musculoskeletal conditions that may have affected their gait. The experimental procedures were reviewed and approved by the institutional ethical review board and all adult subjects and the parents of the toddler subjects provided written consents prior to the test.

2.2 Experimental procedures

We firmly affixed ten reflective markers onto specific body landmarks according to a previously established model [25]. FSA during standing was defined as the angle between the anteroposterior axis of the lab coordinate system and the line connecting markers at the calcaneus and metatarsal. After calibration, five anatomical markers were moved. FSA during running was the result of subtracting the original FSA from the angle of the foot at each footstrike. Each subject was then asked to run overground along a 10-meter runway with his/ her usual shoes at a self-selected speed for 10 successful trials, which were defined as a clean strike onto the force plate (Optima, AMTI, Watertown, MA, USA). In order to avoid fatigue, subjects were allowed to have 3-minute rest between each trial [26]. Kinematic data was collected using a 10-camera motion capturing system (Vicon, Oxford Metrics, Oxford, UK) at 120 Hz. Marker trajectories were filtered with a fourth order Butterworth low-pass filter at 12 Hz [27]. The initial contact was determined when the vertical ground reaction force exceeded 10 N [28].

The VALR and VILR were computed based on the method described in previous studies [28, 29]. In brief, VALR and VILR were the average and maximum slopes of the line from the 20% point to 80% point of the vertical impact peak respectively. If the vertical impact peak was indiscernible, the value at 13% of the total stance was used as a surrogate for time to the vertical impact peak [30]. Both VALR and VILR were normalized with body weight. We examined footstrike pattern by measuring the footstrike angle (FSA). FSA was calculated as the offset angle between the ground surface and the line virtually connecting the reflective markers at heel and metatarsal. The footstrike pattern was determined according to a validated method [25], such that a FSA lower than -1.6° indicated a forefoot strike (FFS); FSA higher than 8° indicated a rearfoot strike (RFS); and FSA between -1.6° and 8° indicated a midfoot strike (MFS). Cadence and stride length were calculated based on the time series data of the heel marker trajectory [27, 31]. Cadence was expressed as number of steps per minute and stride length was defined by the distance travelled by the heel marker between two consecutive heelstrikes. In view of the difference in the anthropometry between preschoolers and adults, stride length and running speed were normalized by body height, according to a previous study [32].

2.3 Statistical analysis

Sex, demographic data, and test running speed were compared between the two groups using Chi-square test and Wilcoxon rank sum test. Data normality of all selected biomechanical parameters was evaluated by Shapiro–Wilk test. In view of the small sample of the present study, Wilcoxon rank sum tests were used to compare normalized VALR, normalized VILR, FSA, cadence, and normalized stride length. Effect size in terms of *r* was also calculated to determine the quantitative strength of the between-group difference. Chi-square test was adopted to compare the footstrike pattern between the two groups. All statistical analysis was performed using SPSS 23.0 with priori alpha at 0.05.

3. Results

According to the results of Shapiro-Wilk test, the VILR of adult group was determined to be non-parametric (p=0.02), thus to support the use of non-parametric statistical test. There is no significant difference in the normalized running speed between the two groups (p=0.85, r=0.20). The VALR, VILR, footstrike angle and footstrike pattern, cadence, and stride length in preschoolers and adults are presented in **Table 2**. There was no significant difference in the VALR (*p*=0.48, *r*=0.18) and VILR (*p*=0.48, *r*=0.15) between preschoolers and adults. Preschoolers and adults also demonstrated no differences in the FSA (*p*=0.85, *r*=-0.02) and footstrike pattern (*p*=0.29). In terms of spatiotemporal parameters, preschoolers exhibited greater cadence (*p*<0.001, *r*=0.90) and shorter normalized stride length (*p*=0.01, *r*=-0.45) than adults.

4. Discussion

This study examined the difference in the running biomechanics between preschoolers and adults. There were no significant differences in the vertical loading rates and footstrike pattern between the two age groups. Post-hoc power for VALR, VIAR and FSA was found to be 75.4%, 72.8% and 86.5% respectively, which gives us a reasonable good confidence to confirm there was no between-group differences in these three main outcome measures. However, preschoolers demonstrated a statistically greater cadence and shorter stride length than adults.

In the present study, preschoolers presented similar VALR and VILR with adults. Originally, we expected that preschoolers might experience lower vertical loading rate during running than adults. Such hypothesis is largely based on two assumptions. First, preschoolers may have less influence from footwear habituation [18, 19]. A previous study suggested that children who had never worn shoes experienced lower vertical loading rates during running [14]. In the present study, however, most of the parents of our preschooler subjects reported that their children started to wear shoes on a daily basis since the acquisition of walking skill. In view of the normal developmental milestone of independent walking at approximately 12 months [33], and the mean age of our preschooler subjects i.e., 4.2 years, footwear habit for 3 years may be sufficient to alter the natural running pattern [34]. The second assumption relates to the expected lower running injury risk in preschoolers. Because of the strong association between vertical loading rate and running injury [8, 9], we originally hypothesized that a lower vertical loading rate would be presented in preschoolers, when compared with adults. A prospective study found that 38.5% of adolescent runners sustained at least one injury over a running season [35]. This injury rate is actually similar to the risk in adult runners reported by previous studies (i.e. 19-79%) [4, 36]. The comparable vertical loading rates between preschoolers and adults may reflect similar injury risk between preschoolers and adults.

We also expected that preschoolers would present more non-RFS than adults due to the time difference in the shod running experience between the two subject groups.

Similar to the findings on vertical loading rates, preschoolers demonstrated similar FSA and footstrike pattern when compared with adults. This finding is likely explained by the interaction of footstrike pattern and footwear. Modern footwear usually comprises thick and cushioned midsole, rigid heel counter and protective arch support [37]. Although footstrike pattern can be affected by other factors, such as running speed [38], these shoe features have shown to possibly lead to a RFS [14, 39]. This finding is consistent with a previous research investigating footstrike pattern in a group of preschool children [40]. In that particular study, shod running experience encouraged RFS landing in children who aged 3-6 years and the authors suggested that there may be a footstrike pattern transition from non-RFS to RFS due to the use of shoes [40].

Shod running has been reported to result in a reduction of cadence and an increase of stride length in preadolescent children [41]. In the present study, preschoolers exhibited greater cadence and shorter stride length than adults, in spite of similar vertical loading rate and footstrike pattern. This finding is in accordance with the findings reported by a previous study [42]. A plausible explanation is that the spatiotemporal parameters may be more inert to the shoe effect when compared with footstrike pattern [43].

Children in growing process may experience more changes in gait resulting from musculoskeletal growth and central nervous maturation [44]. It has been suggested that some body growth factors e.g., body mass and body stiffness, also affect cadence during running gait development [45]. Cadence is almost coincident with the natural frequency of human locomotion during lower-speed running, and the natural frequency is determined by both body mass (*m*) and body stiffness (*k*) with relation $f = (\sqrt{(k/m)})/2\pi$ [18]. For children from 2 to 12 years old, the natural frequency of locomotion decreases with age and it is mainly attributed to the reduction in the ratio between body stiffness and body mass [18, 46, 47]. The reduction in the ratio between *k/m* results in a reduction in both natural frequency and cadence. Cadence appears to be mature at the age of 12 years, as the ratio between *k/m* becomes constant due to the parallel increase in both *k* and *m* with age in the following years [18].

The greater cadence may imply shorter stride length in preschoolers given the linear and quadratic stride length-cadence relationship [48]. Additionally, lower ankle power generation in preschoolers, which is the consequential deficiency of motor control immaturity, may also partly explain the shorter stride length compared with adult. Running gait seems to require greater operating effort from the ankle than knee extensors [49]. However, preschoolers use their proximal muscles, i.e. hip muscles, more than distal muscles, i.e. ankle plantar flexors, for power generation because of the immaturity of neuromuscular control [44]. As ankle power is associated with stride length

[50], developing children, especially at a younger age, may therefore present shorter stride length compared with adults.

The two age groups in our study presented comparable loading rates, despite the preschoolers demonstrated higher cadence and shorter stride length, which are commonly considered as low-risk factors during running. Taken together these findings and the potential reasons that children demonstrated different spatiotemporal running gait from adults, simply imitating preschooler-like pattern to run may not be efficacious in decreasing musculoskeletal running injuries. Considering the individuality and complication in running pattern, laboratory-based test and retraining may be more appropriate and efficient in decreasing impact loading in every step.

It is very important to note several limitations in this study when interpreting our findings. Firstly, the present experiment adopted a cross-sectional design and the causal relationship cannot be determined. Therefore, the footwear effect on the locomotion development remains very much speculative and future prospective studies are highly warranted. Secondly, we did not control the testing shoes in the present study as we failed to find a running shoe model for both preschoolers and adults available in the market. Thirdly, we did not collect individual joint kinematics, thus leaving comprehensive analysis of difference in running postures between preschoolers and adults largely unknown. Fourthly, the sample in this study is not enough for subgroup analysis based the ages ranging from 3-6 years to further investigate the impact of time length of shoe wearing and running experience. Data from narrow age cohorts in further studies may minimize the influence of footwear and provide better understanding of the natural development of running gait. Finally, the present study was conducted in a laboratory environment, which may not fully reflect the actual gait biomechanics in a natural environment. With the recent advancement of sensor technology, measurement of running biomechanics in the wild using wearable body-worn sensors become possible [51]. Future investigations of gait biomechanics in a natural environment are therefore highly warranted.

5. Conclusions

Preschoolers in our study demonstrated greater cadence and shorter stride length compared with adults. However, these spatiotemporal performances did not contribute to more frequent non-RFS pattern nor decrease vertical loading rates during initial contact, which were found to be associated with decreased musculoskeletal injuries in running from literature. Therefore, our findings do not support the notion that adults should modify their running biomechanics according to preschoolers' running postures for a lower injury risk.

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Table 1 Demographics of the subjects.

	Adults	Preschoolers	*p*
Gender	6 males 4 females	4 males 6 females	0.37
Age (year)	35.10 ± 9.45	4.16 ± 1.63	<0.001*
Body weight (kg)	59.79 ± 10.20	15.31 ± 3.24	<0.001*
Body height (m)	1.70 ± 0.11	1.00 ± 0.11	<0.001*
Test speed (BH/s)	1.88 ± 0.15	2.03 ± 0.49	0.85

BH = body height; data are expressed as mean ± standard deviation (SD).

* Indicates $p < 0.05$.

Table 2 Comparison of running biomechanics between preschoolers and adults.

	Adults (mean ± SD)	Preschoolers (mean ± SD)	Mean difference (95% CI)	p
Kinetics				
VALR (BW/s)	52.84 ± 10.73	56.63 ± 11.70	3.79 (−6.76, 14.34)	0.48
VILR (BW/s)	59.39 ± 11.79	63.12 ± 12.88	3.72 (−7.88, 15.33)	0.48
FSA (degree)	9.37 ± 11.75	9.10 ± 4.80	−0.27 (−9.02, 8.48)	0.85
Footstrike pattern				
Rearfoot strike	5	5		0.29
Midfoot strike	3	5		
Forefoot strike	2	0		
Cadence (step/min)	169.33 ± 11.41	222.65 ± 14.24	53.32 (41.15, 65.48)	<0.001*
Normalized stride length (BH)	1.33 ± 0.14	1.13 ± 0.24	−0.20 (−0.39, −0.01)	0.01*

95% CI = 95% confidence interval of the difference; VALR = vertical average loading rate; VILR = vertical instantaneous loading rate; BW = body weight; FSA = footstrike angle; BH = body height.

* Indicates $p < 0.05$.

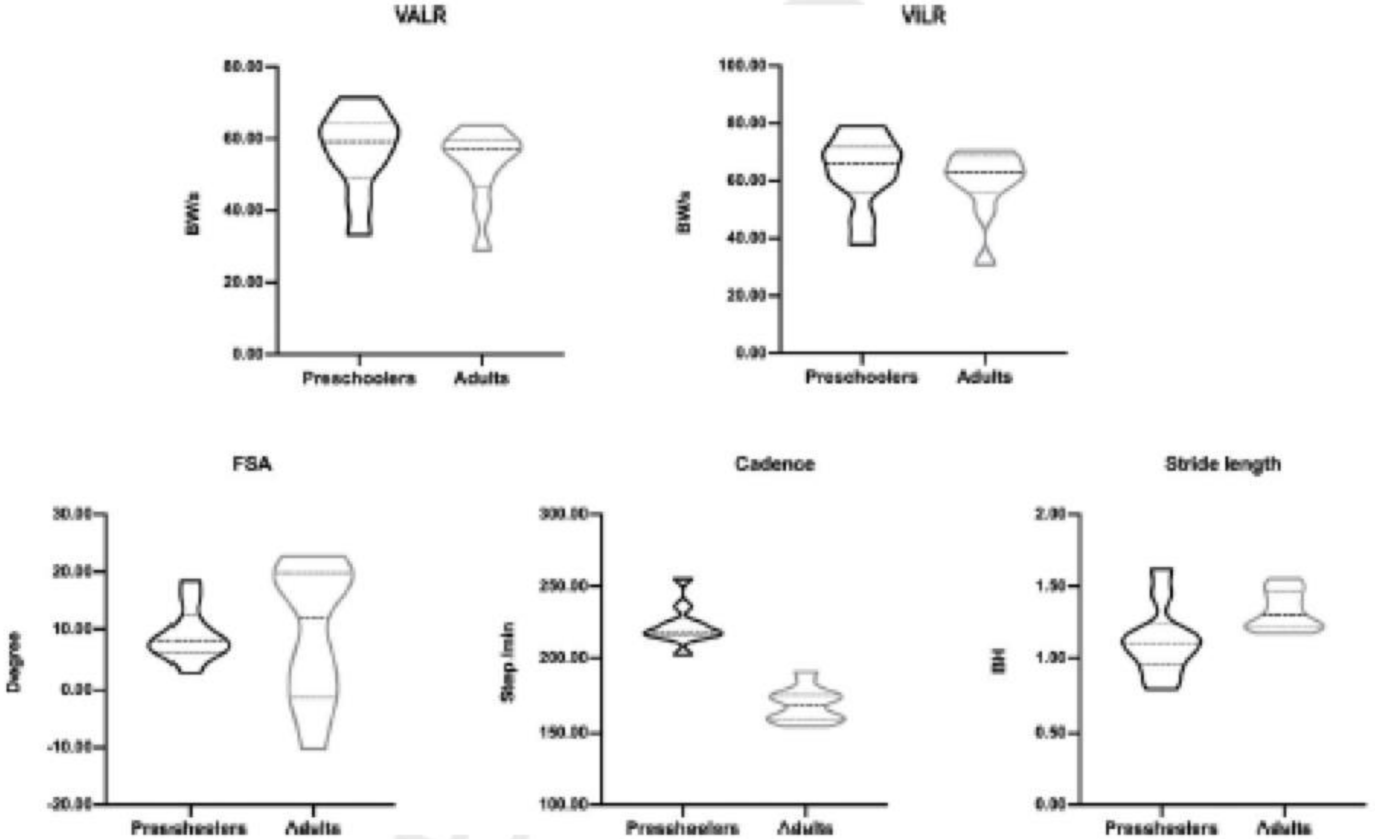

Figure 1 Violin plots, indicating medians (black dotted lines), quartiles (gray solid lines) and data distribution, to compare running biomechanics between preschoolers and adults.