Impact Characteristics of Female Children Running in Adult Versus Youth Shoes of the Same Size

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The purpose of this study was to determine if ground reaction forces were influenced by shoe design (adult vs. youth) for female children when running. Subjects (n = 10, 12.0 ± 1.1 years old; 154 ± 4.9 cm; 46.2 ± 14.3 kg; shoe size 3.5–7 youth) were fit with a shoe model available in youth and adult sizes. Subjects ran 10 trials per shoe condition across a force platform placed in the middle of a 9-m runway. Impact force, second maximum force, loading rate, stance time and average vertical ground reaction forces were recorded for each trial. Shoes underwent a mechanical impact test with peak force, peak acceleration, and percent energy returned recorded. Each variable was compared between shoe conditions. From the impact testing, it was determined that peak force, peak acceleration and percent energy return were 7.1%, 7.1%, and 18.9% greater, respectively, for the youth vs. adult shoe (p < .001). From the running tests, it was determined that loading rate was different (p = .009) between shoe conditions whereas impact force, second maximum force, average force and stance time were not different between shoes (p > .01). Young girls had a greater loading rate when running in youth vs. adult shoes even though the shoe size was the same.

Keywords: ground reaction force, exercise, speed

The popularity of organized sports for children is evident by about 30 million children participating in some sport (Adirim, & Cheng, 2003; Marsh, & Daigneault, 1999). Along with this, there has been a parallel increase in the number of injuries children experience related to sport participation (Flynn, Lou, & Ganley, 2002; Junge, Cheung, Edwards, & Dvorak, 2004; Kennedy, Knowles, Dolan, & Bohne, 2005; Watkins & Peabody, 1996). Running is a large component of many sports and is an activity associated with overuse injuries (e.g., Hreljac, Marshall, & Hume, 2000; James, Bates, & Osternig, 1978), and children are just as susceptible to overuse injuries as adults (Hawkins, & Metheny, 2001; Roberts, 2007). For example, Rauh and colleagues (2006) observed that 38.5% of high-school aged runners had some type of overuse injury during an 11-week cross-country season. This rate of injury is similar to what has been observed in adult runners (Hreljac, Marshall, & Hume, 2000), with women being at a greater risk than men for overuse injuries such as stress fractures (Milner, Ferber, Pollard, Hamill, & Davis, 2006).

Although there are many factors that ultimately explain an overuse injury, the main cause is the repetitive loading nature of running. When children participate in endurance running it makes sense to select an appropriate shoe for the child to minimize the risk of overuse injury even though it is not clear how (or whether) the shoe influences risk of injury. Given the wide range of shoe models available, parents and children are often faced with the daunting task of picking the right shoe. A characteristic to consider when purchasing children’s shoes is the fit of the running shoe and it has been reported that only 46.7% of children wear shoes with a proper fit (Walther et al., 2008). An improperly fit shoe may lead to discomfort and the possibility of an injury due to lack of appropriate movement of the foot within the shoe or if the footwear is stiff and tight (Staheli, 1991; Wolf et al., 2008). Thus, a properly fit shoe should help reduce the chance of developing a running injury due to constrained or excessive movement of the foot within the shoe.

To complicate the process of choosing an appropriate shoe, children’s feet often reach the size where either an “adult” or “youth” size shoe can be worn. However, even though the child can be properly fitted into a youth or adult shoe size, the construction of the shoe may be different between the youth and adult shoe. There is likely the temptation to purchase which ever shoe is least expensive vs. which shoe may be best for the child even though there is little to no information on whether either shoe is appropriate for the child.

There is a wealth of research on the influence of shoe design on running mechanics; however, there is no research on any ground reaction force parameter for children running in a youth vs. adult shoes (of the same model). Since overuse injuries are hypothesized to be

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linked to ground reaction forces (Hreljac et al. 2000; James, Bates, & Osternig, 1978; Nigg, 1997) and there is evidence linking overuse injuries to impact characteristics in female runners (Milner et al., 2006), it makes sense to determine if specific aspects of the ground reaction forces are influenced by the shoe used by the child. Previous studies have suggested that the risk of overuse injury to runners is lower when loading rate is lower in magnitude (Hreljac et al. 2000; Nigg, 1997) and Milner et al. (2006) determined that females with a history of tibial stress fracture had higher loading rates than those without history of injury. Therefore, the purpose of this study was to determine if ground reaction forces are influenced by shoe design (adult vs. youth, same model) for children runners. We hypothesized that loading rate during running would be influenced by adult vs. youth shoe design because we suspected the youth shoe was not as effective at absorbing impact energy. We included mechanical impact testing of shoes to determine if the shock absorbing performance of the youth and adult shoes was similar or different. Furthermore, in addition to examining loading rate, we analyzed impact force, maximum force, and average force since these parameters are often used to describe vertical ground reaction forces during running when evaluating shoe performance. It was suspected that the difference in shoe construction would lead to different shock absorbing capabilities of the shoes and therefore differences in ground reaction force parameters.

Methods

Subjects

Subjects were 10 healthy girls (age: 12.0 ± 1.1 years; height: 154 ± 4.9 cm; mass: 46.2 ± 14.3 kg). The study was not funded by external sources but internal funds were available to purchase a limited number of shoes. Because of this and because there is limited research on the female adolescent runner, we elected to purchase female shoes only. Participants had to be able to wear a youth shoe size between 3.5 and 7.0, be comfortable running for 20 min, and have no current injury that interfered with running. Subjects granted assent and their parents gave written informed consent before youth participation. The study was approved by the institutional review board of the university.

Instrumentation

The running shoes used in this study were of the same model: (1) Nike Air Pegasus +25 (Figure 1a) and (2) Child Nike Air Pegasus +25 (Figure 1b). Both the adult and youth Nike Air Pegasus +25 are classified in the retail market as neutral cushioning shoes (vs. stability or motion control running shoes that each provide more support to control over pronation). Both shoes both have a full-length Nike Air-sole unit and a polyurethane footbed to provide cushioning. Polyurethane is a heavy material that is dense, durable and stable. It is designed to provide protection from impact. Both shoes also have a lightweight phylon midsole to provide cushioning and impact protection. Phylon is composed of heated and molded ethyl vinyl acetate foam pellets or sheets and is very lightweight and responsive. The shoes also have a de-coupled and articulated crash pad to absorb the initial shock of impact. The shoes differ in that there is no midfoot shank in the children’s shoe. In the adult shoe, there is a midfoot shank under the medial arch to support the foot and provide lateral support and stability while also allowing some natural torsional rotation. The shoes also differ in that the youth shoe upper (i.e., the top part of the shoe that encases the foot) and outsole (i.e., the bottom part of the shoe that provides traction) contains more durable components than the adult model in order for the shoe to last long.

A mechanical impact tester (Exeter Research Inc., Brentwood, NH) interfaced to Impact Plus (version 3.0) software was used to impact test shoes. Material testing using the Impact Testing System (3000 Hz) occurred before subject data collection. One youth and one adult shoe of equivalent size were tested. Since adult and youth sizes are on different scales, sizes 4.5 youth and 6.0 women’s for this shoe model were selected as equivalent absolute sizes. The shoes were rear-foot tested for midsole hardness following a modified American Standard for Testing Materials (ASTM) Standard Test Method for Shock Attenuating Properties of Material Systems for Athletic Footwear procedure (ASTM F1614–99). The test involves repeated dropping of a weighted missile on the rear foot portion of the shoe. ASTM F1614–99 protocol involves 5 preloading and test impacts but we elected to...
use 10 preloading impacts (no data collected) followed by 10 impacts (data collected). Using this protocol, the maximum and minimum values were removed and the remaining 8 impacts represent the sample size per shoe. These modifications have been used to minimize the influence of noise in the data set. The test yields the parameters of peak acceleration, peak force, and percent energy return that describe the shock absorbing capabilities of the rear foot portion of the running shoe. Lower peak acceleration and peak force indicate that more impact energy was absorbed by the shoe. Higher percent energy return indicates the level of elasticity of the shoe that would cause the missile head to rebound. Although this parameter does not directly describe impact absorbing capability of a shoe, it is a typical parameter to include in mechanical shoe evaluation.

In addition to mechanical testing of shoe shock absorbing capability, our experiment required subjects to run in the shoes. A force platform (Kistler Model 9281C) was used to collect ground reaction force data and stance time (sample frequency of 1000 Hz). The force platform was mounted flush with the surrounding tile floor. The force platform was located halfway between the total length of a 9-m runway. Running velocity was monitored with two pair of photocell timing lights (Lafayette Instruments, Model 63501 IR). The height of the timing lights was level with the shoulder of the subject and the timing lights were positioned 3.66 m apart with the force platform located at the midpoint between the timing lights.

**Procedures**

Subjects were unaware of the difference (i.e., adult vs. youth model) between two shoe conditions and were kept naïve as to which shoe model was the adult and which was the youth shoe model. Subjects were allowed to randomly select which pair of shoes to use first. Subjects ran practice trials to become comfortable with running in the laboratory and striking the force platform in a natural manner. Running velocity for the last 3 practice trials was recorded and averaged and used as the test speed for both shoe conditions. Subjects completed 10 successful running trials per shoe that were within ±10% of the test speed and characterized by striking the force platform in a natural manner (e.g., did not stutter step, skip, hop, or look down when striking the force platform). Up to 20 attempts were allowed to capture the 10 trials used for analysis.

**Data Reduction**

Vertical ground reaction force data were processed using custom laboratory software (Matlab, The Mathworks, version 13) written to extract the dependent variables from each data set. Stance time was determined to be the time between when the vertical ground reaction force was greater than 20 N at contact and less than 20 N at toe off. Ground reaction force data were further reduced to yield the following variables: Impact force, second maximum force, loading rate, and average vertical ground reaction force (Figure 2). Impact force was determined as the first maximum force that occurred within 50 ms after ground contact. In trials where no impact force was observed, that trial was not used to calculate the mean impact force for that condition. It was determined post hoc that 87% of the trials contained an impact force. The second maximum force was represented as the second peak that occurred at about 50% of midstance. The average ground reaction force was determined by calculating the average force

![Figure 2](image.png) — Illustration of an example vertical ground reaction profile during running and parameters analyzed in the study (impact force, second maximum force, and average force). Loading rate was calculated as the slope between ground contact and impact force. Stance time was determined as the time between contact and toe off.
during contact. Loading rate was calculated by dividing impact force by the time to impact force. Each parameter was averaged across the 10 trials per subject-condition combination. Trials that did not have an impact force were not included in analysis of impact force or loading rate. All ground reaction force parameters were normalized to body weight.

**Statistical Analysis**

Shoe impact test data (peak acceleration, peak force, percent energy return) were compared between shoes using an independent $t$ test. The dependent variables from the running test (impact force, loading rate, second maximum force, average force, stance time) were compared between shoes using paired $t$ tests for each parameter using a Bonferroni correction ($\alpha = .017$).

**Results**

Through impact testing of shoes it was determined that peak acceleration, peak force and percent energy return were each greater (7.1%, 7.1%, 18.9%, respectively) in youth vs. adult shoes ($p < .001$; Table 1). In the running tests, there was no difference in running speed between shoes (youth: $3.25 \pm 0.62$ m·s$^{-1}$; adult: $3.21 \pm 0.56$ m·s$^{-1}$) ($p = .264$). From the run-conditions portion of the experiment, it was determined that impact force ($p = .033$), maximum force ($p = .174$), average force ($p = .840$) and stance time ($p = .139$) were not different between shoes (Table 2). However, loading rate was 32% greater during running in the youth vs. adult shoes ($p = .009$, Table 2).

<table>
<thead>
<tr>
<th>Table 1</th>
<th>Means and standard deviations for shoe impact test results</th>
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<tbody>
<tr>
<td></td>
<td>Youth Shoe</td>
</tr>
<tr>
<td>Peak Acceleration (g)</td>
<td>24.24 ± 0.004</td>
</tr>
<tr>
<td>Peak Force (N)</td>
<td>2020.77 ± 0.239</td>
</tr>
<tr>
<td>Energy Return (%)</td>
<td>47.64 ± 0.385</td>
</tr>
</tbody>
</table>

*Parameter was different between shoes ($p < .001$).

<table>
<thead>
<tr>
<th>Table 2</th>
<th>Ground reaction force characteristics during running in youth and adult shoes (means ± SD)</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Youth Shoe</td>
</tr>
<tr>
<td>Impact Force (BW)</td>
<td>2.46 ± 0.76</td>
</tr>
<tr>
<td>Maximum Force (BW)</td>
<td>3.42 ± 1.16</td>
</tr>
<tr>
<td>Average Force (BW)</td>
<td>2.03 ± 0.64</td>
</tr>
<tr>
<td>Stance time (s)</td>
<td>0.22 ± 0.03</td>
</tr>
<tr>
<td>Loading Rate (BW/s)</td>
<td>105.85 ± 52.31</td>
</tr>
</tbody>
</table>

Note. Impact force, maximum force, average force, and stance time were not different between shoes ($p > .017$).

*Loading rate was different between shoes ($p = .009$).
rates between studies is complicated by the calculation of loading rate. For example, Munro et al. (1987) calculated loading rate from the time the ground reaction force curve exceeded 50 N until it reached 50 N greater than 1 BW. In the current study, loading rate was calculated by dividing impact force over time of occurrence of this force event with ground contact being set to 0 s. Despite different calculation approaches, the results for an adult running in an adult shoe in Munro et al., (1987) exhibited similar loading rates for children running in an adult shoe.

We suspect that the difference in loading rate for the youth running in youth vs. adult shoe is likely related to the impact test result that the adult shoe was better at absorbing impact energy. However, we did consider that loading rate may have been influenced by a change in running style between shoes since running style influences ground reaction forces (Mercer et al., 2005). For example, impact forces are influenced by stride length regardless of running speed likely because the lower extremity alignment at impact changes with stride length (Mercer et al., 2005). Since kinematics were not measured in the current study, we do not know how running style may or may not have changed between shoe conditions. However, we did examine stance time and it was determined that there was no change in stance time between shoes.

The importance of understanding how shoes influence loading rate is emphasized by the results of Milner et al. (2006). In that study, female adult runners were grouped based upon whether there was a history of tibial stress fracture. Ground reaction forces were measured with each subject running the same speed (3.7 m/s). It was determined that subjects with the history of stress fracture had higher loading rates. While the exact mechanism of overuse injury is multifactorial, it is reasonable to recommend youth wear the adult shoe when it fits properly since our study identified that loading rate was greater during running in youth vs. adult shoes.

Loading rate is determined by impact force and time of occurrence of this force. Thus, we know that loading rate will change when 1) impact force increases for a given time, 2) time to impact force changes for a given impact force, or 3) both impact force and time to the impact force change concurrently. In the current study neither impact force nor the time of occurrence were significantly different between shoes but loading rate was greater for running in the youth vs. adult shoes. Therefore, loading rate was influenced by concurrent changes in impact force and time to impact force.

The magnitude of the impact force in the current study (2.46 ± 0.76 BW in the youth shoe and 2.09 ± 0.83 BW in the adult shoe) was similar or tended (p = .033, adjusted alpha level = .0017) to be higher in the youth vs. adult shoe (the reason for using an adjusted alpha level was to account for multiple dependent variables and to control for Type I error). Despite the lack of significant difference, the impact force during running in either shoe seemed to be higher than what would be expected for adults running at equivalent speeds. Impact forces are influenced by running speed (Cavanagh & Lafortune, 1980; Mercer, et al. 2005; Munro et al., 1987). In the current study, our children subjects ran at speeds of 3.25 ± 0.62 m·s–1 in the youth shoe and 3.21 ± 0.56 m·s –1 in the adult shoe and had corresponding impact forces of 2.46 ± 0.76 BW and 2.09 ± 0.83 BW. Munro et al. (1987) observed impact force magnitudes of 1.69 ± 0.21 BW for adults running at 3.25 m·s–1 and Mercer et al. (2005) developed a prediction equation that impact force would be 1.68 BW for running at 3.2 m·s–1. The difference between studies is that our experiment used children runners whereas Munro et al. (1987) and Mercer et al. (2005) used adult runners. Given these observations, even though the impact forces were within reasonable range (e.g., 2–3 BW), the magnitude of impact force for children running at these speeds tended to be higher than what would be expected if adults ran these same speeds. Likewise, the magnitudes of second maximum force in our study seem to be greater than what has been reported for adults running at equivalent speeds (e.g., Bates et al.,1983; Cavanagh & Lafortune, 1980; Clarke et al., 1983; Mercer et al., 2005; Munro et al., 1987). For example, using prediction equations of Mercer et al. (2005), the second maximum force would be expected to be 2.53 BW for running 3.2 m·s–1 (adult runners) whereas we observed magnitudes of 2.03 ± 0.64 BW and 1.97 ± 0.58 BW while running in the youth and adult shoes, respectively.

We suspect that the higher than expected forces for youth vs. adults running at the same speed is due to the differences in construction of shoes which we determined that the adult shoe had better shock absorbing performance than the youth shoe. However, we believe the higher than expected forces are also related to how children vs. adults absorb impact shock. Mercer et al. (2010) observed that children attenuated less shock than adults even though children were running at slower velocities. If less impact shock is attenuated, a greater impact force would be expected. Taken together, these observations suggest that children are not miniature adults and absorb impact shock differently than adults—which seems to highlight the importance of designing youth shoes for the child runner.

We decided to include female youth runners (12.03 ± 1.14 years) in this study. It is not clear if the results are generalizable to boys since Mercer et al. (2010) observed that shock absorption was different in boys and girls. Nevertheless, the observations made in this study highlight what we believe is the importance of designing the running shoe for the youth runner.

It was important in this experiment that the subjects ran with a comfortable, natural, unaltered gait and strike
the force platform similarly unencumbered. From a qualitative perspective, it is often hard to know what is the right way to say or give instructions to subjects to have them run using a comfortable, natural gait or if gait changes over time. Working with children complicates this and it is not known how instructions to children subjects influenced their choice of running style or speed or if fatigue during the protocol were confounding factors.

There are no standards for what materials or structures need to be built into a shoe—evidence of this is the wide variety of styles of shoes for adult runners. Furthermore, there is no consensus as to what elements of a shoe are important even though it has long been thought that it is important to select an appropriate running shoe to minimize the risk of overuse injury. Although we tested only one model of youth shoe and one model of adult shoe, the importance of this study is the idea that selecting a shoe for a youth runner should not be limited to considering youth shoe models only. Because a greater loading rate was observed while running in the children’s shoes, it is concluded that the lesser loading rate for the subject wearing the adult shoe may reduce risk of overuse injury and is the better shoe choice for girls aged 11–13 years old. However, even though loading rate was different between shoes, it is unclear whether one loading rate is more dangerous than the other. It might be that both loading rates are within a safe region to minimize the risk of overuse injury. Furthermore, there is no known research that has empirically determined that shoes reduce the chance of obtaining an overuse injury.

References


