The Influence of Gender and Somatotype on Single-Leg Upright Standing Postural Stability in Children

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The purpose of this study was to investigate the influence of gender and somatotypes on single-leg upright standing postural stability in children. A total of 709 healthy children from different schools were recruited to measure the anthropometric somatotypes and the mean radius of center of pressure (COP) on a force platform with their eyes open and eyes closed. The results were that (a) girls revealed significantly smaller mean radius of COP distribution than boys, both in the eyes open and eyes closed conditions, and (b) the mesomorphic, muscular children had significantly smaller mean radius of COP distribution than the endomorphic, fatty children and the ectomorphic, linear children during the eyes closed condition. The explanation for gender differences might be due to the larger body weight in boys. The explanation for somatotype differences might be due to the significantly lower body height and higher portion of muscular profile in the mesomorphic children.

Key Words: body type, postural balance, static balance, upright stance

Postural stability has been defined as the ability to maintain an upright posture and to keep the center of gravity (COG) within the limits of the base of support (Jonsson et al., 2004; Karlsson & Frykberg, 2000; Kirshenbaum et al., 2001; Mochizuki, et al., 2006). The center of pressure (COP) is the application point of the resultant of the ground reaction forces and can be calculated from the ground reaction forces projected from the body, which are easily recorded with a force platform (Caron et al., 2000; Karlsson & Frykberg, 2000; Le Clair & Riach, 1996). It reflects the trajectory of the body center of mass and the amount of torque applied at the support surface to control body-mass acceleration (Chiari et al., 2002; Hertel et al., 2006). Postural stability has traditionally been examined by spatial measures of the COP, where larger amounts of COP distributions are considered signs of postural instability (Haddad et al., 2006).

Somatotype is an overview of the total physique characteristics of the human body, which is independent of body size, and can provide valuable information for understanding growth and maturity (Carter & Heath, 1990). The somatotype is rated in three components, namely, endomorphy (fatness), mesomorphy (musculature), and ectomorphy (linearity), according to the measurements of anthropometry. In general, nutrition, exercise, health habits, disease, and the timing of biological maturation might influence the somatotype. Body size and structure were both reported to affect physi-
cal performance in sports (Aitken & Jenkins, 1998; Santos et al., 2003; Van Someren & Palmer, 2003). One study also demonstrated the clinical practice of simple anthropometry to identify relationships between body composition and health risks (Janssen et al., 2002).

Adolescence is a period of dynamic physical and biological change (Baxter-Jones et al., 2005). Morphologic somatotypes are related to standing postural equilibrium in able-bodied subjects (Allard et al., 2001). The decrease in standing posture stability of the ectomorphic subjects is attributed to a relatively low muscle component, a high height-to-weight ratio, and an elevated position of the body center of mass. Moreover, thinner subjects have been found to have larger horizontal displacements of the COG than normal subjects (Farenc et al., 2003). However, one study reported no statistically significant correlation between sway parameters and developmental factors (body height, weight, and age) in two legs standing in children aged 7 to 18 years (Lebiedowska & Syczewska, 2000). In addition, poor correlations also have been reported between the composite equilibrium score and height, weight, and body mass index (Peterson et al., 2006).

The development of balance control in humans during their life span (Assaiante & Amblard, 1995; Kirshenbaum et al., 2001) and the difference of sensory inputs and motor activities between children and adults (Assaiante, 1998; Hatzitaki et al., 2002) have been reported previously. Limited studies have demonstrated that endomorphs have better postural control abilities than ectomorphs in adults (Allard et al., 2001; Chiari et al., 2002; Farenc et al., 2003).

Anthropometry and Somatotype Measurement

Body weight and height were measured with the subjects wearing no shoes and only light clothing. The body mass index (BMI), weight divided by height squared (kg/m²), was calculated according to the individual body height and weight. The height-to-weight ratio (HWR), height divided by the cube root of weight, was used in somatotyping. The somatotype of each subject was determined by the method described by Carter and Heath (1990). It consisted of 10 anthropometric parameters (height, weight, four skinfolds, two girths, and two breadths) and was measured according to the protocol recommended by the International Society for the Advancement of Kinesiology. The skinfolds (triceps, subscapular, supraspinal, and medial calf), girths (upper arm and calf), and breadths (humerus and femur) were measured on the right side of the body.

The anthropometric somatotype was calculated from the following equations: Endomorphy = −0.7182 + (0.1451 × X) − (0.00068 × X²) + (0.0000014 × X³), where X = (sum of triceps, subscapular, and supraspinal) × (170.18/height, cm). Mesomorphy = (0.858 × humerus breadth) + (0.601 × femur breadth) + (0.188 × corrected arm girth) +

Methods

Subjects

A total of 709 children (344 girls and 365 boys) recruited from different primary schools participated in this study. These children were healthy and had no known musculoskeletal impairments or neurological disorders that might have affected their sense of balance. The main selection criteria were being in good health and aged between 9 and 11 years. Subjects with any abnormal musculoskeletal diseases or any other signs of postural, orthopedic, or neurological disorders were excluded from the study. The mean age of the subjects was 9.61 ± 0.68 years and their height and weight were 134.23 ± 7.10 cm and 32.62 ± 8.04 kg, respectively. Subjects were first measured to determine their somatotype and then measured on their postural stability by force plate on the same day. Written informed consent was approved by the institutional human subjects ethics board and obtained from the parent(s) before the study, and the data of all children were collected and finished within 20 days.
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(0.161 × corrected calf girth) − (height × 0.131) + 4.5, where corrected arm and calf circumferences are the respective limb circumferences minus the triceps and medial calf skinfolds, respectively. Three equations were used to calculate ectomorphy according to the HWR: If HWR is ≥40.75 then ectomorphy = (0.732 × HWR) − 28.58; if HWR is less than 40.75 but greater than 38.25, then ectomorphy = (0.463 × HWR) − 17.63; if HWR ≤38.25, then ectomorphy = 0.1 (Carter and Heath, 1990).

Skinfold thicknesses were measured using the Lange skinfold caliper. Other anthropometrical parameters were measured using the Centurion Kit instrumentation (Rosscraft, Surrey, BC, Canada). Three series of anthropometrical measurements were taken and the means were used. Each subject was described by three numbers determining their morphological structure. These refer respectively to the endomorphic, mesomorphic, and ectomorphic components of the somatotype. Afterward, all subjects were divided into three groups based on the value of the dominant (the highest value) somatotype component (Allard et al., 2001).

Postural Stability Assessment

Subjects stood barefoot in a comfortable upright posture with their eyes open or closed for single-leg standing test on a force platform (Advanced Mechanical Technologies Inc, Waltham MA). The force platform was linked via a 16-bit analog-to-digital converter (MP100, BIOPAC System Inc, Goleta CA) to an IBM-compatible PC loaded with AcqKnowledge (Version 3.8) for data collection and analysis. Subjects were instructed to lift the limb that was not being tested by flexing 90° at the hip and knee joints with both arms hanging relaxed at the sides. The subjects were asked to stand as motionless as possible, looking straight ahead at a point on the wall 65 cm away. The displacements of the COP were recorded at a frequency of 100 Hz and filtered with a 10-Hz low-pass cutoff frequency. The mean radius of the COP (the mean excursion of the COP in any direction) was used as balance parameters to describe the subjects’ balance stability. It was demonstrated that the tests of single-leg standing balance had moderate-to-excellent group reliability and therefore could be used to compare the balance performance of various subject groups (Birmingham, 2000).

Once the subjects were in this position and stated that they were ready, data collection began. All the subjects performed three trials of 10 s in duration. It was reported that a testing duration of 10 s is reliable when assessing postural stability in single-leg stance (Le Clair & Riach, 1996). After several practice trials, subjects were asked to perform the single-leg standing test for both “eyes open” and “eye closed” alternately on left and right limb. Four testing conditions were performed and the test orders were randomized. In order to collect comprehensive information and as a representative index for the assessment of postural stability in children, we averaged the COP data from both limbs during eyes open (EO) and eyes closed (EC) testing conditions.

Statistical Analysis

The data were analyzed using SPSS 10.0 Statistical Package (SPSS Inc, Chicago, IL). A two-way gender (boys vs. girls) × somatotype group (endomorphs, mesomorphs, ectomorphs) ANOVA was performed on anthropometric and postural stability parameters. Post hoc LSD tests were carried out to identify the groups that were statistically different from each other. The level of significance for statistical analysis was set at \( p < 0.05 \).

Results

Table 1 details the basic anthropometric measurements, somatotype components, and the postural stability parameters for all subjects and for each group. The mean somatotype component for our subjects was 4.08-4.56-2.56. Since the mesomorphic components (4.56) and the endomorphic (4.08) did not differ by more than one-half unit, but both were higher than the ectomorphic component (2.56), the group was described as mesomorphic-endomorphic. The mean somatotype component for boys was 4.10-4.85-2.38. Since the mesomorphic component (4.85) was higher than the endomorphic (4.10) and the ectomorphic components (2.38) by at least one-half unit, the boys, as a group, were described as mesomorphic-endomorphic. The mean somatotype component for the girls was 4.05-4.26-2.76. The girls as a group, therefore, were classified as mesomorphic-endomorphic.

Statistical analysis revealed that the boys had significant higher values than girls in body weight \( (F = 7.27, p < 0.05) \), BMI \( (F = 7.99, p < 0.05) \), mean radius of COP in EO condition \( (F = 14.84, p < 0.05) \), and mean radius of COP in EC condition \( (F = 20.20, p < 0.05) \). In addition, girls had significant higher
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values than boys in HWR ($F = 5.14, p < 0.05$) and ectomorphic component ($F = 5.67, p < 0.05$) only. All other differences were not statistically significant.

All subjects were grouped according to the somatotype component with the highest value. There were 174 children in the endomorphic group, 349 children in the mesomorphic group and 186 children in the ectomorphic group. In somatotype components, the value of the dominant somatotype component was well above 4 and significantly larger ($F = 70.94 \sim 257.65, p < 0.05$) than the other two, clearly indicating a dominant somatotype.

In anthropometric measures, body weights in endomorphs were significantly heavier ($F = \ldots$)

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### Table 1  Anthropometric Measurements, Somatotype Components, and the Postural Stability Parameters for Boys and Girls

<table>
<thead>
<tr>
<th>Parameters</th>
<th>All children ($N = 709$)</th>
<th>Endomorphs ($N = 174$)</th>
<th>Mesomorphs ($N = 349$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boys ($N = 365$)</td>
<td>Girls ($N = 344$)</td>
<td>Boys ($N = 64$)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>9.58 ± 0.66</td>
<td>9.63 ± 0.69</td>
<td>9.61 ± 0.63</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>134.30 ± 6.87</td>
<td>134.17 ± 7.34</td>
<td>137.64 ± 6.94</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>33.38 ± 8.42</td>
<td>31.80 ± 7.54</td>
<td>37.57 ± 8.57</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>18.32 ± 3.36</td>
<td>17.51 ± 3.02</td>
<td>20.18 ± 3.24</td>
</tr>
<tr>
<td>HWR</td>
<td>42.12 ± 2.34</td>
<td>42.69 ± 2.09</td>
<td>41.06 ± 1.95</td>
</tr>
<tr>
<td>Endomorphic</td>
<td>4.10 ± 2.05</td>
<td>4.05 ± 1.64</td>
<td>5.20 ± 1.47</td>
</tr>
<tr>
<td>Mesomorphic</td>
<td>4.85 ± 2.36</td>
<td>4.26 ± 3.18</td>
<td>4.18 ± 1.53</td>
</tr>
<tr>
<td>Ectomorphic</td>
<td>2.38 ± 1.50</td>
<td>2.76 ± 1.34</td>
<td>2.15 ± 1.11</td>
</tr>
<tr>
<td>EO (cm)</td>
<td>4.80 ± 3.92</td>
<td>3.94 ± 2.84</td>
<td>5.46 ± 3.10</td>
</tr>
<tr>
<td>EC (cm)</td>
<td>11.97 ± 0.03</td>
<td>9.37 ± 7.33</td>
<td>13.67 ± 9.44</td>
</tr>
</tbody>
</table>

Note. BMI: body mass index; HWR: height-weight ratio; EO: mean radius of COP in eyes open, single-leg standing test; EC: mean radius of COP in eyes closed, single-leg standing test.
*Represents $p < 0.05$.
†Represents significant larger value in boys than girls.
‡Represents significant larger value in girls than boys.
*Significant differences between endomorphs and mesomorphs, ectomorphs.
†Significant differences between mesomorphs and endomorphs, ectomorphs.
‡Significant differences between ectomorphs and endomorphs, mesomorphs.

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### Table 1 (continued)

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Ectomorphs ($N = 186$)</th>
<th>Gender factor $F$ value</th>
<th>Somato factor $F$ value</th>
<th>Gender-by-somato interaction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Boys ($N = 79$)</td>
<td>Girls ($N = 107$)</td>
<td>Boys ($N = 219$)</td>
<td>Girls ($N = 130$)</td>
</tr>
<tr>
<td>Age (years)</td>
<td>9.62 ± 0.71</td>
<td>9.56 ± 0.66</td>
<td>9.57 ± 0.63</td>
<td>9.56 ± 0.65</td>
</tr>
<tr>
<td>Height (cm)</td>
<td>134.53 ± 5.95</td>
<td>135.16 ± 6.58</td>
<td>137.64 ± 6.94</td>
<td>135.46 ± 6.86</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>27.46 ± 4.04</td>
<td>27.88 ± 4.07</td>
<td>37.57 ± 8.57</td>
<td>35.77 ± 7.57</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>15.15 ± 1.40</td>
<td>15.18 ± 1.00</td>
<td>20.18 ± 3.24</td>
<td>18.79 ± 2.94</td>
</tr>
<tr>
<td>HWR</td>
<td>44.76 ± 2.00</td>
<td>44.68 ± 0.96</td>
<td>41.06 ± 1.95</td>
<td>41.80 ± 1.85</td>
</tr>
<tr>
<td>Endomorphic</td>
<td>2.43 ± 0.65</td>
<td>2.72 ± 0.49</td>
<td>2.15 ± 1.11</td>
<td>2.15 ± 1.06</td>
</tr>
<tr>
<td>Mesomorphic</td>
<td>2.93 ± 0.66</td>
<td>2.63 ± 0.73</td>
<td>1.93</td>
<td>70.94</td>
</tr>
<tr>
<td>Ectomorphic</td>
<td>4.18 ± 1.47</td>
<td>4.13 ± 0.70</td>
<td>5.67</td>
<td>257.65</td>
</tr>
<tr>
<td>EO (cm)</td>
<td>5.12 ± 3.75</td>
<td>4.83 ± 2.60</td>
<td>14.84</td>
<td>5.68</td>
</tr>
<tr>
<td>EC (cm)</td>
<td>13.45 ± 10.05</td>
<td>10.44 ± 9.72</td>
<td>20.20</td>
<td>6.10</td>
</tr>
</tbody>
</table>

Note. BMI: body mass index; HWR: height-weight ratio; EO: mean radius of COP in eyes open, single-leg standing test; EC: mean radius of COP in eyes closed, single-leg standing test.
*Represents $p < 0.05$.
†Represents significant larger value in boys than girls.
‡Represents significant larger value in girls than boys.
*Significant differences between endomorphs and mesomorphs, ectomorphs.
†Significant differences between mesomorphs and endomorphs, ectomorphs.
‡Significant differences between ectomorphs and endomorphs, mesomorphs.
66.03, $p < 0.05$) and body height in mesomorphs was significantly lower ($F = 16.62, p < 0.05$) than others, but ectomorphs had significant smaller BMI values ($F = 128.61, p < 0.05$) and larger HWR value ($F = 207.89, p < 0.05$) than endomorphs and mesomorphs. In postural stability, the mean radius of COP in the EO and EC conditions were both significantly smaller ($F = 5.68, F = 6.10; p < 0.05$, respectively) in mesomorphs than in the other two groups. Nevertheless, the gender-by-somatotype interaction was significant in the age, weight and endomorphic.

**Discussion**

To our knowledge, this study was the first to examine the effects of gender and somatotype components on single-leg stance postural control in children. In this study, a large sample of children recruited from different school districts and classified into three groups according to the highest value of the predominant morphologic somatotype component should provide more insight than a small sample, single anthropometric parameter methodology.

The single-leg upright stance is a particular challenging part of human locomotion, not only because the entire body mass is placed on one leg, but also because this process requires keeping the center of body mass within the small area of the support. The single-leg upright stance position is a fundamental of human locomotion (Richardson et al., 1996) and also offers the advantage of evaluating steadiness in a situation that challenges the postural control system (Bryant et al., 2005). This stance reduces the base of support compared with the bipedal stance and requires the postural control system to make more corrective movements in order to maintain balance (Hertel et al., 2006; Palmieri et al., 2002).

The integration of visual, vestibular, and somatosensory inputs is needed for single-leg stance to plan and execute motor commands for maintaining balance (Chiari et al., 2002; Hertel et al., 2006). Le Clair and Riach (1996) reported that vision is important in the Romberg stance and subjects were more destabilizing at short test durations (10 s) than at long test durations in EC condition. The results of this study revealed that postural stability in EC conditions was significantly poorer than in EO conditions when comparing different gender and somatotypes. Visual inputs provide exteroceptive information about the environment and are the most reliable sources of perceptual information for balance control, especially in children (Assaianote & Amblard, 1995). However, the ability to interpret and use visual inputs is associated with increasing accuracy and consistency of eye movements, which is acquired with age and is not achievable in children (Hatzitaki et al., 2002).

Several studies have examined gender differences in balance performance that reported women having better balance than men (Bryant et al., 2005; Farenc et al., 2003). Furthermore, several studies also reported that there are no gender differences after normalizing (the subject’s height) the balance performance in elders or adults (Bryant et al., 2005; Era et al., 2002). The results of this study revealed that boys have significantly larger mean radius of COP distributions than girls during the EO and EC conditions. After dividing each result by the height of the children (Bryant et al., 2005), the girls still have smaller mean radius of COP distributions than boys (EO $t = 3.23, p < 0.05$; EC $t = 3.77, p < 0.05$). Because the subjects in this study were younger than those in other studies and their development of postural instability differed from the adults or elderly (Rival et al., 2005), this may account for the discrepancies.

In bipedal stance, fractional Brownian motion (fBm) modeling demonstrated that women have better control of the COP trajectories than men under both EO and EC conditions (Farenc et al., 2003) because the moment of body inertia, larger for men, and natural body frequency, higher for women, can also be used to explain the differences observed according to gender. In addition, another possible explanation for gender differences might be the intrinsic differences of anthropometric characteristics between subjects (Chiari et al., 2002), because boys in this study also revealed significant greater body weight and BMI value than girls.

The results of this present study revealed that the endomorphs (more relative fatness of the body) displayed significant larger mean radius of COP excursion than the mesomorphs (more relative musculature of the body). This was different from other studies, which reported that endomorphs had better postural stability than ectomorphs, but the ectomorphs had the worst postural stability among older children and adults (Allard et al., 2001; Farenc et al., 2003). Our results revealed that the children in the endomorph
category had significantly higher body weight and BMI values than the ectomorph group, which might be the reason for the discrepancy found in this study. In addition, a previous study also reported that the amount of oscillation in upright standing posture was strongly dependent on height and in part on weight (Chiari et al., 2002).

To the best of our knowledge, two studies evaluate the relationship between morphologic somatotypes and bipedal upright standing posture equilibrium. In one study, the ectomorphs had the largest and statistically different sway area covered by the time displacement of the COP than the other two somatotypes (Allard et al., 2001). Also, another recent study reported that thinner subjects had larger horizontal displacements of the COG than normal subjects (Farenc et al., 2003). These results highlight the fact that either in bipedal stance or single-leg stance, the somatotype and body characteristics indeed influence postural stability in able-bodied subjects.

Interestingly, the results of this study revealed that the mesomorphs had better postural stability than endomorphs and ectomorphs during the EO condition ($F = 5.68$, $p < 0.05$) and the EC condition ($F = 6.10$, $p < 0.05$). It is believed that humans use different sensory input for postural control during the EO and EC conditions (Assaiante & Amblard, 1995; Hatzitaki et al., 2002; Nakagawa et al., 1993) and the control of single-limb standing also requires both biomechanical properties and neuromuscular control (Le Clair & Riach, 1996, Winter et al., 2003).

Significantly better postural stability in the mesomorphs might be due to a relatively higher proportion of musculature in the body when compared with the endomorphs and the ectomorphs in both the EO and EC conditions. Because muscles that act on the lower limb complex contract in an effort to control a stable upright posture, proper muscular strength and architecture might be beneficial for joint stability and postural control (Heitkamp et al., 2001). Although some physiological differences might also play a certain role in this finding, as suggested by Farenc et al. (2003), it is important to acknowledge that perhaps muscle architectural properties might also have significant implications with respect to postural stability differences observed in this study. Alternatively, the difficulties in maintaining static postural stability in the elderly, unlike children, seem to be dependent on decreased muscle strength and endurance (Jonsson et al., 2004).

Surprisingly, the ectomorphs did not demonstrate significantly poorer postural stability than the endomorphs or the mesomorphs in this study. Previous studies reported that ectomorphs had relatively small muscle mass and greater height-to-weight ratio (increase the height of center of mass), making it more difficult to maintain their postural stability (Allard et al., 2001; Farenc et al., 2003). The ectomorphs in this study indeed had significantly higher HWR values ($F = 207.89$, $p < 0.05$) than the endomorphs and the ectomorphs; however, they also had significantly smaller BMI value ($F = 128.61$, $p < 0.05$), and this might be the explanation for the discrepancy with other studies.

The results of this study highlight the fact that gender and somatotype components indeed influence postural stability in children and this finding significantly differs from that reported for adults. These differences might be attributed to morphological characteristics and physiological functions, such as muscular strength and neuromuscular development in childhood. With respect to gender differences, boys have significantly poorer single-leg postural stability than girls, and this may be due to the larger body weight and the moment of inertia for the boys. In terms of somatotype differences, the mesomorphic children had significantly better single-leg postural stability than endomorphic and ectomorphic children. This finding might be due to the significantly lower body height and higher portion of muscular profile in the mesomorphic children.

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