**Gait and Postural Stability in Obese and Nonobese Prepubertal Boys**

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**Objective:** To examine differences in gait and postural stability of obese and nonobese prepubertal boys.

**Design:** Percentage of gait cycle in double support was examined to determine significant differences. Postural stability was compared using temporal and frequency measures of the center of pressure in static stance.

**Setting:** Gait was examined using videography on a 30-meter walkway. Postural stability was examined using a measurement platform.

**Participants:** Ten obese (>95th percentile in body mass index) and 10 nonobese (15th to 90th percentile in body mass index) prepubertal boys aged 8 to 10yrs.

**Intervention:** Participants were examined at three walking cadences as determined by preferred gait cadence. Full vision, darkness, and visually confused conditions were used to accentuate static postural stability differences.

**Main Outcome Measures:** In the presence of dynamic stability differences (gait), static stability measures further investigated stability differences.

**Results:** Obese boys spent significantly ($p < .02$) greater percentage of gait cycle in dual stance. Obese boys showed significantly ($p < .01$) greater sway areas, energy, and variability primarily in the medial/lateral direction.

**Conclusions:** Dual stance differences suggest diminished dynamic stability in obese boys. Greater sway areas in medial/lateral direction in obese boys and the absence of significant frequency measures suggest that the instability observed in obese boys is caused by excess weight rather than underlying postural instability.

**Key Words:** Postural stability; Obese; Prepubertal.

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Although not thoroughly examined, there is some evidence that increased body weight not only influences balance during the gait cycle but also affects postural stability and equilibrium during standing. In 1968, a group of Navy physicians attempted to identify factors that affect equilibrium (other than vestibular) as admission criteria for flight school. These authors correlated anthropometric measures and health history with results of clinical postural tests and identified 10 factors that were significantly related to the postural tests used. The most important factors in order of magnitude were abdominal circumference, endomorphy, and weight. They concluded that body size and shape had a great influence on measures of postural stability because of the displacement of center of gravity in overweight individuals.

In a more recent study, Ledin and Odkvist used posturography to observe the effects of a 20% body weight increase on balance. When participants wore a weighted shirt, they showed greater areas of sway during static stance and slower sway velocity when vision was excluded. It was concluded that increased inertial load (as in the shirt) deteriorated balance and slowed the individual’s ability to adjust to external perturbations in standing.

Although Ledin’s model describes the effects of artificial increases in body weight on equilibrium, it is not known what effects actual excess adiposity may have on postural stability. The purpose of this study was to examine differences in gait and postural stability of obese and nonobese prepupal boys. Results of this investigation may suggest a relationship between postural stability, gait, and body mass index (BMI) in prepuparal boys.

**METHODS**

**Subjects**

Twenty boys (8 to 10 yrs of age) were recruited from pediatricians, elementary schools, and Boy Scout troops. Ten obese boys were above the 95th percentile in BMI; 10 nonobese boys were between the 15th and 90th percentile in BMI for age and race. Obese boys were slightly taller (obese, 1.14 ± 0.05m; nonobese, 1.3 ± 0.04m) and weighed substantially more than nonobese boys (obese, 59.58 ± 17.23kg; nonobese, 30.93 ± 3.29kg) (table 1).

Only male subjects were studied to eliminate possible gender differences in postural stability and gait characteristics. Parents of subjects were administered a health history questionnaire designed to identify factors that might affect postural stability (eg, recent lower limb injuries or inner ear surgical implants). The questionnaire also included subjective questions such as “Would you describe your son as clumsy?” and “Does your son fall frequently?” Participants and their parents signed an informed consent before participation in the study. The study design was approved by the institutional review board.

**Experimental Protocol**

Gait variables were calculated from the average of three strides at each of three gait cadences: normal, slow, and fast. Normal cadence was the subject’s preferred gait pattern and was determined by calculating the time taken to complete 20 strides; this was subsequently converted to cycles per minute. In determining normal cadence, instructions were standardized for all subjects. Slow and fast conditions were calculated as a percentage of the normal cadence (slow = 10% < normal cadence; fast = 30% > normal cadence), and a hand-held metronome was used for pacing. Subjects were videotaped from their dominant side (determined by the leg used to kick a ball) as they walked barefoot at each cadence through the middle 10m of a 30-m walkway. Time in double support and swing phases were converted to a percentage of the total cycle time to standardize performance.

Stability was analyzed from ground reaction forces obtained from two trials (26.5 sec) of quiet standing in each of two standardized foot positions, normal (heels together, feet externally rotated 10°) and tandem (dominant foot forward, heel to toe) during three experimental conditions (full vision, dark, and visual conflict). Participants were asked to stand as still and quiet as possible with hands at the sides. In the full vision condition, visual feedback was available and a reliable source for visual reference. In the dark condition, visual feedback was eliminated, forcing the subject to rely on other sensory feedback sources (eg, vestibular and proprioceptive information). The visual conflict condition was achieved through the use of a domed headpiece. The dome completely encircles the head, preventing the wearer from viewing anything but the interior of the dome. The headpiece moves with the subject’s sway, thereby providing conflicting visual feedback to the subject. Data were collected without shoes to eliminate the effects of shoe condition and heel height. Foot placement was standardized between trials, and trials were repeated if the participant lost balance (ie, stepped to regain balance) during data collection.

**Instrumentation**

Gait variables were collected using a level video camera (60Hz) positioned perpendicular to the plane of ambulation. Time in double support, stance, and swing were determined from the video provided by the PEAK Motus Video Analysis System. When an event such as heel strike fell between two video frames, the initial frame was used in the analysis.

Postural data were collected from a Kistler measurement platform. Ground reaction forces in the vertical (f v ), medial-lateral (f ml ), and anterior-posterior (f ap ) directions were used for the analysis of postural variables. Analogue output of the amplifiers was interfaced (20Hz) to a laboratory computer through a 12 bit A/D converter.

**Statistical Analysis**

Data collected included gait variables and measures of postural stability. Gait variables included in this investigation were (1) preferred (normal) cadence reported as cycles per minute, and (2) swing period, stance period, and double-support period reported as a percentage of total gait cycle at slow, normal, and fast cadences. Data were examined using an a priori null hypothesis that the mean percentages for swing, stance, and double support were the same for obese and nonobese subjects.

Postural sway was analyzed using both time and frequency measures calculated from the displacement of the center of pressure (COP) in the anterior-posterior and medial-lateral directions. Temporal measures included maximum displacement of the COP, total energy of the displacement vector, peak velocity of the COP, and root mean square (RMS) of COP displacement. These measures of postural control have been used extensively to quantify postural stability.
Analysis of the frequency composition of the force vectors (spectral analysis) was used to further determine whether there were differences in postural control between obese and nonobese boys. Spectral analysis has been used to identify impaired stability in the elderly. A Fast Fourier Transform (FFT) was used to quantify the frequency composition of the force vectors \((f_{\text{ällt}}, f_{\text{ap}})\). Frequency variables included measures of central tendency; mean spectral frequency \((f_{\text{mean}})\), median spectral frequency \((f_{\text{median}})\), mode spectral frequency \((f_{\text{mode}})\); and a measure of spectral dispersion \((f_{\text{sd}})\).

Gait and stability data were analyzed separately using repeated measures analysis of variance (ANOVA). Significance for gait data comparisons was held at a Bonferroni’s alpha level of .02 for the 2 group by 3 condition ANOVA. Stability measures were considered significant when \(p\) values were less than or equal to a Bonferroni’s alpha level of .01 for the 2 group by 6 condition ANOVA.

RESULTS

Health History Questionnaire
Two of the 10 parents of obese boys described their children as clumsy or unstable, whereas none of the parents of nonobese boys suggested problems with postural stability. One boy in each group reported inner ear tube implants at a young age because of frequent infections.

Gait Characteristics
Normal cadence (cycles/min) selected by subjects was based on the same protocol and standardized instructions for obese and nonobese subjects. The mean preferred cadence for nonobese boys (70.4 ± 6.7 cycles/min) was higher \((F = 2.37, p = .1412)\) than for obese boys (65.3 ± 8.1 cycles/min). Obese boys spent a significantly greater percentage of time in double support and stance than did nonobese boys at all walking cadences. Similarly, the swing phase of obese boys contributed significantly less to the gait cycle than was true of nonobese boys at each cadence (fig 1).

Postural Characteristics
Of the two groups, obese and nonobese, only one participant was unable to complete all the postural stability trials without falling. This participant was in the obese group and had a BMI of 32kg/m². The harmonic mean of the obese group was used in falling. This participant was in the obese group and had a BMI was unable to complete all the postural stability trials without falling. This participant was in the obese group and had a BMI.

Maximum displacement, energy, and RMS of COP\(_{\text{ap}}\) tended to be greater for obese boys across all conditions. Significant differences \((F = 7.27, p = .0147)\) between obese and nonobese boys were found for energy of COP\(_{\text{ap}}\) in full \((p = .0056)\) and dark \((p = .0020)\) tandem conditions. The RMS of COP\(_{\text{ap}}\) was significantly greater \((F = 7.26, p = .1484)\) for the obese subjects under full \((p = .0057)\) and dark \((p = .0009)\) tandem conditions and the dark \((p = .0090)\) condition in normal stance (fig 2).

Maximum displacement of COP\(_{\text{ml}}\) tended to be greater for obese boys under all experimental conditions. Significant differences \((F = 5.29, p = .0337)\) were observed in the dark (normal \([p = .0026]\) and tandem \([p = .0094]\)). A similar trend was observed in the energy of COP\(_{\text{ml}}\), with significantly greater \((F = 8.02, p = .0111)\) energy observed in obese boys when the postural control system was challenged in both the dark (normal \([p = .0001]\); tandem \([p = .0050]\)) and conflict (normal \([p = .0020]\); tandem \([p = .0013]\)) conditions. The RMS of COP\(_{\text{ml}}\) was similarly greater in obese than nonobese boys in all conditions, with dark (normal \([p = .0001]\); tandem \([p = .0030]\)) and visual conflict conditions (normal \([p = .0088]\); tandem \([p = .0089]\)) being significantly greater \((F = 7.68, p = .126)\) (fig 3).

Maximum velocity of COP was not different between the obese and nonobese boys. The tandem foot position presented a greater challenge to stability than did the normal foot position in both groups, whereas foot position did not appear to influence the maximum velocity of COP between groups.

Of the frequency measures, significant differences were observed only in the visual conflict tandem condition in the anterior-posterior direction. Frequency dispersion of \(f_{\text{ap}}\) \((F = 6.94, p = .0168)\) was significantly greater in the obese than nonobese groups \((p = .0004)\). Mean spectral frequency of \(f_{\text{ap}}\) \((F = 4.96, p = .0389)\) was significantly lower in obese than nonobese boys \((p = .0005)\).

Within-group comparisons were made between each of the full visual conditions (ie, normal and tandem stance) and the remaining conditions (ie, dark and confused). No significant differences were found in the anterior-posterior direction. In the medial-lateral direction, however, obese subjects showed increased instability on most of the variables when the postural control system was challenged by either modifying the visual system only or when both vision and base of support were changed. In contrast, nonobese children showed increased instability only when both the visual system and the base of support were challenged (table 2).

DISCUSSION

The purpose of this study was to examine selected gait and postural stability characteristics of obese and nonobese prepu-
bertal boys, possibly providing an explanation for decreased physical activity observed in obese children.

Gait Characteristics

A primary objective of this study was to determine whether the gait characteristics of obese boys were different from those of non-obese boys. Hills and Parker examined the gait characteristics of 10 obese and 10 non-obese children and observed that non-obese children showed a faster preferred gait cadence (133 steps/min) than obese children (125 steps/min). This investigation also found that non-obese boys, when asked to walk at their preferred walking speed (140 steps/min), showed a faster gait cadence than obese boys (130 steps/min).

Analysis of selected gait variables in this study point to significant differences between obese and non-obese boys in double support, stance, and swing phases of the gait cycle at each of three walking cadences. Obese boys spent a significantly greater percentage of the gait cycle in double support and stance, and less time in the swing phase than did non-obese boys. This is in agreement with Hills and Parker, who also reported significantly longer periods of support and shorter periods of swing in obese than in non-obese children. They suggested that the extended periods of support seen in obese children were indicative of underlying postural instability.

Postural Characteristics

Significant differences were observed in measures of postural stability in both anterior-posterior and medial-lateral directions; however, results of this investigation point to greater differences in medial-lateral stability than anterior-posterior stability in obese and non-obese boys. In the medial-lateral direction, significant differences between obese and non-obese boys included maximum displacement of COP, total energy of the displacement vector, and a measure of variability (RMS) during both foot positions in the dark condition. Modification of both the visual system and the base of support appeared to challenge medial-lateral postural stability in both subject groups. However, modification of visual cues alone did not appear to influence the postural control of non-obese subjects. The stability of obese boys appeared to be more influenced by challenges to the visual system than was the stability of non-obese boys; this suggests that changes to visual cues effectively challenged the postural control system and accentuated the differences in

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**Table 2: Within Group Comparisons in the Medial-Lateral Direction**

<table>
<thead>
<tr>
<th>Group</th>
<th>Full N vs Dark N</th>
<th>Full T vs Dark T</th>
<th>Full N vs Confused N</th>
<th>Full T vs Confused T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Obese</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Displacement</td>
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<td>.0001*</td>
<td>.2105</td>
<td>.0012*</td>
</tr>
<tr>
<td>Total Energy</td>
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<td>.0001*</td>
<td>.0002*</td>
<td>.0001*</td>
</tr>
<tr>
<td>RMS</td>
<td>.0001*</td>
<td>.0001*</td>
<td>.0018*</td>
<td>.0001*</td>
</tr>
<tr>
<td>Nonobese</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum Displacement</td>
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<td>.0013*</td>
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</tr>
<tr>
<td>RMS</td>
<td>.9628</td>
<td>.0002*</td>
<td>.1890</td>
<td>.0004*</td>
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</tbody>
</table>

Abbreviations: N, normal stance; T, tandem stance; RMS, root mean square. * Significant Bonferoni's p value < .0033.
postural stability between the two groups. In the visual conflict condition, total energy and variability (RMS) of the displacement vector were greater in obese than in nonobese boys in both foot positions. Within-group comparisons of the full vision condition (normal and tandem foot position) with the visual conflict conditions indicated that visually erroneous information created a greater challenge to stability in obese than in nonobese boys. The significant response in obese boys to the elimination of vision and to visual confusion suggests that the stability of obese boys is more dependent on vision than is true for nonobese boys.

Although there are no similar reports of decreased medial-lateral stability of obese children, a similar observation has been noted in studies investigating changes in postural control with aging. McClenaghan and associates found significant differences in measures of medial-lateral stability in a study of postural control of young adults and elderly individuals. Maki and coworkers reported similar results in a study designed to evaluate the relationship between postural stability and falls. It has been suggested that different postural control strategies are used to maintain medial-lateral versus anterior-posterior stability and thus may be influenced in different ways by the addition of noncontributory mass to the system. Anterior-posterior stability is maintained through muscular adjustments of the ankle and, to a lesser degree, the knee and hip. Maki suggested that the primary stabilizing response to perturbations in the medial-lateral direction occurs at the hip. The greater number of degrees of freedom available to maintain anterior-posterior stability provides the individual with alternative strategies to adjust stability and compensate for additional mass and external perturbations.

Mizrahi and Susak observed differences in the strategy used to apply ground reaction forces in the anterior-posterior and medial-lateral directions. Anterior-posterior adjustments in postural stability were applied to the support surface using the feet and ankle concurrently, whereas medial-lateral adjustments resulted from foot forces applied in opposition. This result suggests that during dynamic standing a different strategy, ankle rotation versus lateral weight shift, is used to maintain anterior-posterior versus medial-lateral stability. Therefore, the addition of noncontributory mass to the system would have a greater influence on the ability to shift weight laterally and thus, maintain medial-lateral stability. The gait cycle itself forces a narrowing of the base of support and places an inherent challenge on medial-lateral stability. The increased time in dual stance observed in the gait cycle of obese boys in this investigation may be the result of decreased medial-lateral stability caused by excess mass.

There were no differences between obese and nonobese boys in frequency characteristics of the force vectors. Although two isolated frequency measures were significant, no trend or relationship was observed. It has been suggested that frequency measures may describe the regularity in a system and may indicate potential underlying impairments to the postural control mechanism. The lack of significant differences in frequency measures suggest that the decreased stability showed by obese boys in this investigation was probably not caused by an underlying impairment of the postural control system but more by the increased noncontributory mass added to the system.

In general, experimental conditions designed to challenge the postural control system (ie, visual conflict and dark conditions) showed the greatest differences between obese and nonobese children. Activities of daily living and playing (eg, standing, walking, running, and jumping) place a considerable demand on the postural control system to maintain stability in the medial-lateral direction. It may be that the excess of noncontributory weight in obese boys lends itself to decreased medial-lateral stability, possibly affecting the obese child’s willingness to participate in strenuous physical activities that further challenge the postural control system. The obese child may feel less confident and thereby decrease the level of physical activity engaged in; this in turn results in a lower daily caloric expenditure. A limitation of this investigation is that it does not examine the relationship between stability or instability and physical activity levels. Data from this study only hint at a possible relationship; further research using activity monitors and physical activity questionnaires is needed to explore this potential relationship more closely.

Whether obesity results in reduced stability, or instability contributes to increased adiposity, requires additional investigation. Results from this study suggest that instability observed in obese boys may be caused by excess noncontributory mass and not an underlying impairment in the postural control system. If so, then obesity interventions may not benefit from special balance and stability activities, because the best treatment for the postural instability observed in obese children may be the ultimate goal of obesity intervention itself, decreased adiposity.

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