Gait Characteristics of Obese Children

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- The gait patterns of ten obese and ten normal-weight, prepubertal children were evaluated to provide objective data for a weight status comparison. Temporal and kinematic analyses were conducted on representative gait cycles at three speeds of walking: slow, normal, and fast. Subjects were filmed by two phase locked cameras, one each in the sagittal and frontal planes, operating at a speed of 50 frames per second while the subjects traversed a 10-m walkway in one direction. Obese subjects displayed longer cycle duration ($p < .001$), lower cadence ($p < .001$), lower relative velocity (statures/set, $p < .001$), and longer stance period (sec, $p < .001$) than normal-weight subjects at all speeds. Other temporal differences included gait asymmetry and greater stride width for the obese, all pointing to a slower, more tentative normal speed and problems encountered when walking at speeds other than normal. Greatest instability was evidenced at the slow speed of walking. Joint angle displacement data showed a largely invariant pattern among speeds for most joints studied and similar patterns for both study groups. Normal-weight subjects displayed more consistent patterns of rotation at all joints and speeds, and for the hip and knee joints, there was greater total excursion that favored increased flexion. Obese subjects displayed a more flat-footed weight acceptance period in early stance and a greater external rotation (out-toeing) of the foot at all phases of the gait cycle.

KEY WORDS: Gait; Obese; Temporal

Specific stages of development and characteristics of walking patterns have been identified for normal-weight subjects, but no such data exist for obese prepubertal children. Knowledge regarding the nature of walking in obese children is limited to subjective comments about the quality of their movement patterns. Subjective observations highlight the difficulty that obese individuals experience in executing what may be described as simple everyday tasks. This difficulty is not unexpected because obesity presents a distinct disadvantage in movement due to a large proportion of body weight which does not contribute to performance, but does need to be moved at a specific cost in terms of energy. Nevertheless, no earlier studies have tested these assumptions in relation to walking characteristics of obese children.

An important contribution to the understanding of the movement capabilities of obese children can be provided via gait analysis. Walking is a fundamental locomotor task, a complex interrelationship of genetic, neuromuscular, and environmental factors. Behaviors displayed in movement tasks, such as walking, may not only provide a quantification of differences between obese and normal-weight populations, but they may also distinguish features of movement capacity that have a bearing on desire for, and subsequent involvement in, physical activity tasks.

This investigation was designed to define the temporal and kinematic parameters of walking in obese prepubertal children and, specifically, to determine the ability of obese children to accommodate changes in walking velocity above and below their normal pace. Results for the obese group were compared with normal-weight children of the same age.

METHODS

A group of ten obese and ten normal-weight subjects of similar age and socioeconomic status comprised the study group. All subjects were classified as prepubertal by a medical practitioner, and written consent was obtained from each child's parent or guardian before the study. Obese subjects were above the 95th percentile in weight for their age and had a body mass index greater than 25. The average age of the total group was 10.5 years (range = 8.5 to 10.9 years).

Subjects were filmed as they walked barefoot in one direction on the level surface of a 10-m gait track. Subjects were filmed by two phase locked Photosonics cameras operating at a film speed of 50 frames/sec, with the shutter angle at 160°. Phase locking ensured that both sagittal and frontal cameras maintained frame-for-frame synchrony, enabling accurate identification of events during subsequent film analyses. The sagittal camera was fitted with a fixed Angenieux f2.2 lens and mounted on a tripod and movable trolley that was propelled along metal tracks, following the subject's mean gait speed and filming the right side of the body. The frontal camera, with an Angenieux f3.5 zoom lens, was mounted on a tripod at the end of the walkway.

Kinematic and temporal data were obtained from three walking speeds: slow, normal, and fast. A small, portable electronic device, equipped with frequency dial, speaker, and both audio and visual feedback, was used to regulate the subject's walking pace. The beeper tone was used as a guide to speed for both slow and fast trials.

The slow speed was set 10% slower than the subject's natural walking speed, while the faster speed was 30% faster than the normal, free speed of walking. After the observation of a large number of children in pilot studies, these speeds were
Table 1: Body Characteristics of Subjects

<table>
<thead>
<tr>
<th>Variable</th>
<th>Obese (n = 10)</th>
<th>Normal weight (n = 10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height (cm)</td>
<td>145.8 ± 5.6</td>
<td>151.0 ± 2.1</td>
</tr>
<tr>
<td>Weight (kg)</td>
<td>51.3 ± 4.6</td>
<td>27.3 ± 0.8</td>
</tr>
<tr>
<td>Body Mass Index (BMI)</td>
<td>26.0 ± 1.6</td>
<td>16.0 ± 0.7</td>
</tr>
<tr>
<td>Triceps skinfold (mm)</td>
<td>22.3 ± 4.6</td>
<td>9.8 ± 1.4</td>
</tr>
<tr>
<td>Subscapular skinfold (mm)</td>
<td>25.2 ± 6.7</td>
<td>6.0 ± 1.3</td>
</tr>
<tr>
<td>Biceps skinfold (mm)</td>
<td>15.4 ± 4.0</td>
<td>4.2 ± 1.3</td>
</tr>
<tr>
<td>Suprailiac skinfold (mm)</td>
<td>28.4 ± 6.6</td>
<td>6.9 ± 2.7</td>
</tr>
<tr>
<td>Sum of 4 skinfolds</td>
<td>92.3 ± 10.6</td>
<td>27.9 ± 4.9</td>
</tr>
</tbody>
</table>

Table 2 shows the mean temporal data for both groups. At each walking speed, cycle duration was longer in the obese (p < .001), with the mean cycle duration (seconds) decreasing progressively as the speed of walking increased. Analysis of other temporal components suggests a trend toward a slower walking gait in obese subjects compared to normal-weight children that were peculiar to the weight status of individuals. There were no significant differences in functional leg length for any of the subjects tested.

RESULTS

Temporal Components

Mean morphologic and body composition data for each group are presented in table 1. Analysis of temporal and kinematic gait parameters revealed a number of differences in obese vs normal-weight children that were peculiar to the weight status of individuals. There were no significant differences in functional leg length for any of the subjects tested.

Table 2 shows the mean temporal data for both groups. At each walking speed, cycle duration was longer in the obese (p < .001), with the mean cycle duration (seconds) decreasing progressively as the speed of walking increased. Analysis of other temporal components suggests a trend toward a slower and more tentative gait in the heavier subjects, even though they were taller than their nonobese counterparts. The height discrepancy resulted in a longer stride length at each speed for the obese children, but correction for height saw a lower relative stride length in the obese. Cadence (p < .001) and relative velocity (p < .001) were also lower for the obese at all speeds. Results of the present investigation confirm the subjective reference to a slower walking gait in obese subjects compared to normal-weight subjects.

The figure displays the percentage of the walking cycle occupied by stance (support) and swing (nonsupport) phases for both study groups and other reference data. A comparable

that a subject is covering 80% of height in overground distance per second.

In our study, the characteristics of each limb during walking, and hence the degree of symmetry displayed, were gained by observing the raw data for left and right step length, plus calculation of the normalized parameters—relative step length (left and right) and step factor (left and right). In each case, matched readings for opposing limbs were gained, and statistical analyses (student t-test) of differences were completed. The computer program used in conjunction with digitizing and reduction of film data enabled calculation of temporal characteristics of both left and right limbs.
GAIT OF OBESE CHILDREN, Hills

COMPARATIVE STANCE & SWING PERCENTAGES ACROSS 3 SPEEDS OF WALKING.

Percentage allocation by both groups was evident at the normal speed, but at slow and fast speeds there was a tendency for obese children to spend more time in stance (support). Similarly, obese subjects showed a consistently higher mean value for the double stance period at each speed of walking.

Obese subjects showed a significant degree of asymmetry in comparisons of left and right limbs. Step length showed greater readings at all speeds for the right limb as opposed to left limb—slow speed (p < .001), normal speed (p < .01), and fast speed (p < .05)—whereas the only trend to asymmetry in normal-weight subjects was a mean difference at the slow speed. Other symmetry indicators, relative step length (number of left and right statures) and step factor, also displayed a walking pattern in obese subjects which favored the right limb. Both limb length and hand dominance were recorded in this study. There were no examples of unequal limb length, but each of the subjects was right-handed.

JOINT ANGLE DISPLACEMENT PATTERNS

Comparisons of joint angle displacement showed relatively invariant patterns across the three speeds of walking and similar joint characteristics for each group. For the temporal parameters, some important differences were found in the gait of obese vs normal-weight children. Rotation of the hip and knee joints in the sagittal plane showed both a greater total excursion and increased flexion for normal-weight subjects, irrespective of walking speed.

At all joints studied, normal-weight subjects were able to ambulate with a minimal alteration in joint characteristics among the speeds. Speed differences in this group were limited to thigh rotation (less thigh adduction as measured in the frontal plane) at the normal speed (p < .038). For obese subjects, hip rotation was significantly greater at the normal speed (p < .014) and knee rotation at the fast speed (p < .040).

At the normal walking speed, both groups showed a more sustained major knee flexion period than for other speeds. At fast and slow speeds, this same flexion period was more protracted for obese children and indicative of a more rigid and extended limb position. Knee flexion continued well into the swing phase for normal-weight subjects, while extension was initiated close to right toe-off for the obese. This effectively contributed to a reduced toe clearance in the heavier subjects.

As for the hip and knee joints, ankle rotation was also generally comparable between groups, except for the following differences. Plantar flexion from right heel strike to full foot contact occurred more rapidly at each speed in the obese, and, in a number of cases, feet at right heel strike were already in a more extended (flatter) position. At both normal and fast speeds for both groups, the propulsive plantar flexion period of stance began earlier than at the slow speed. Peak extension at the normal speed occurred after right toe-off and at right toe-off for the fast speed.

The foot contact patterns of obese subjects were quite varied while all normal-weight subjects displayed the normal heel-to-foot flat toe pattern. Some of the obese children did not have this normal pattern; they walked with a relatively flat foot at the initial contact point of the gait cycle. This, combined with reduced knee flexion at right toe-off, meant that toe clearance during swing was minimal in the obese group. A relatively flat-footed gait was present at each speed for subjects who displayed this tendency.

Decreased ankle dorsiflexion in some obese subjects did not result in toe drag at any speed, although the obese group showed greater external rotation of the foot (out-toeing) at all speeds and points with the gait cycle. This could be a factor that contributes to both stability during stance and ease of foot clearance in swing.

DISCUSSION

TEMPORAL COMPONENTS

Beck and colleagues calculated that regardless of age, stride length expressed as a percentage of a child's height at a speed of 1.04m/sec was 76%. The increased speed of walking in this study contributed to much greater values: 85%, 85%, and 94% for the obese subjects and 87%, 89%, and 92% in normal-weight subjects.

Weight bearing stability during the stance phase is identifiable from the relationship between the single and double stance. Individuals with reduced stability display a lengthened
double stance period and a decreased single stance period, such was the case in this study with obese subjects who showed a consistently higher double stance period at each walking speed. It is difficult to make conclusive comparisons between studies due to deficiencies in reporting speeds other than the normal pace and the possibility of variation in slow and fast speeds.

Parker and associates, in a study of obese Down syndrome children, reported a higher than normal percentage of the gait cycle spent in support. For obese subjects in our study and those reported in the study above, the greater support time is indicative of a safer and more tentative ambulation that reduces the nonsupport period and, hence, the possibility of instability. Comparisons with the adult data of Winter showed stance percentages that exceed those of all subjects in our study and, similarly, the often-quoted normal speed standards of Murray (stance 60% and swing 40%). These differences suggest that considerable variability exists in both the childhood and adult populations.

Relatively few attempts have been made to identify the normal variability of symmetry in gait, with most gait studies assuming consistency of characteristics for both limbs. Reasons that have been suggested for differences in symmetry in previous studies have included unequal limb length, hand dominance, asymmetric hip musculature, and unequal maturation of brain hemispheres. In studies by Hannah and Morrison and Minford and coworkers, a high degree of temporal and kinematic symmetry in able-bodied individuals has been reported.

The asymmetry displayed by obese children may be related to their body composition and affected by their speed of walking. Greatest difficulty was noticed at speeds other than normal pace, particularly at the slow speed. The slow speed trial was only 10% slower than the normal speed in our study, but this was enough to cause a pronounced alteration in gait. The additional body weight may further complicate such walking in the obese individual.

Taylor and colleagues suggested that at velocities less than 0.7 to 2.0 m/sec, there is a disruption of normal gait pattern that may be due to a neural control mechanism sensitive to momentum that controls motor performance. Walking velocity at the slow speed in the present investigation was, in fact, toward the upper end of the range reported by Taylor, which suggests that instability for the obese occurs at a faster walking velocity.

Even though some researchers have equated normal speed and natural cadence with maximum efficiency, Winter qualifies such statements by reporting that evidence is still limited and confounded by the variability in and lack of consensus regarding the biomechanical definition of work efficiency. The temporal data seem to suggest a reduced difficulty while ambulating within the narrow framework of the free and comfortable normal speed.

The specific cadence value representative of supposed maximum efficiency in adult walking approximates 109 steps per minute. The cadence of normal-weight subjects was considerably higher at 118 steps per minute, for obese subjects, it was lower at 100 steps per minute. The lower cadence of older normal-weight children reported by Statham and Murray is indicative of a progressively more stable gait in which the need for increased lateral stability is reduced. Such differences are a further indication in the obese of the instability that threatens to make deviations in gait speed from the normal and the added precaution of increased stride width.

Kinematics

In agreement with Winter, each of the sagittal plane views of the three joints studied showed a relatively invariant pattern across the three speeds of walking. The reduction in the major hip flexion phase outside the limits of the normal walking speed motor pattern may mean that obese children lack the muscular strength and neuromuscular control required to sustain greater flexion at both hip and knee joints. For the normal children, flexion continued during the swing phase, decreasing the moment of inertia and increasing the angular velocity of the forward-swinging limb.

The distinct boundaries for ankle plantar flexion at the slow speed were the major events of left heel strike and right toe-off. This variability in component parts of the ankle rotation pattern is not present in adults. Winter reported that with the exception of minor variations in amplitude, the timing of flexion and extension patterns remains constant irrespective of walking speed.

The reduction in knee flexion at right toe-off, combined with a relatively flat foot at contact, contributed to minimal toe clearance during swing for the obese group. A similar situation was reported with obese Down syndrome children.

The requirement of a wider base of support for the obese children was more pronounced at the slow and normal speeds, with greatest similarity between groups at the fast speed. As for foot rotation, thigh rotation in the frontal plane was almost identical between groups at the fast speed. Joint angle displacement curves for normal-weight subjects were similar, irrespective of speed, while the obese group showed greatest variability at slow and normal speeds.

CONCLUSION

The walking gait of obese children at their normal walking speed may be described as slow and tentative compared to normal-weight children. Results of this study demonstrate difficulty for obese children in accommodating changes in gait velocity from the normal speed, with greatest instability at the slow speed of walking. Obese individuals may be more disadvantaged than normal-weight individuals when attempting to move at speeds other than their optimal walking speed.

Joint angle displacement characteristics of obese children were within normal ranges, but some mean differences in aspects of joint data at specific points in the gait cycle were found. These included a more flat-footed weight acceptance period in the stance phase and greater out-toeing of the foot in the gait cycle of obese children.

References


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