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BRIEF REPORT

Influence of Weight Classification on Children Stepping over Obstacles

ABSTRACT

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The objective of this study was to evaluate how weight classification relates to meeting task constraints. Using a cross-sectional design, three-dimensional motion data were collected while children crossed obstacles of various heights. Twelve normal-weight (≥5th and <85th percentile on growth charts) and 12 overweight or obese (≥85th percentile on growth charts) 4- to 13-yr-olds participated. During obstacle crossing, children who were overweight or obese took longer to reach maximum knee height and to achieve foot contact (all $P = 0.04$). Normal-weight children landed flat-footed after obstacle crossing whereas overweight and obese children landed heel first ($P = 0.04$). Children had higher coefficients of variation for ankle position at heel contact after crossing medium obstacles ($P = 0.02$). Slower rates of obstacle crossing and landing heel first after crossing obstacles could be behind higher risks of falls for children who are overweight or obese.

Key Words: Body Mass Index, Psychologic Adaptation, Pediatrics, Safety

Obesity is prevalent among children; rates of obesity are as high as 10% for 2- to 5-yr-olds, 20% for 6- to 11-yr-olds, and 18% for 12- to 19-yr-olds.[1] Children who are overweight and obese have walking impairments.[2–4] Compared with their normal-weight counterparts, overweight and obese children demonstrate impairments in their spatial and temporal walking parameters with wider step widths, shorter step lengths, slower walking velocities, shorter single-limb support times, shorter swing times, and longer double-limb support times.[2,3,5] These characteristics of walking in overweight and obese children create difficulty in maintaining stability and recovering balance after stability has been lost.[4] Their walking impairments are also reflected during gross motor activities; they have slower velocities when walking on a balance beam and while walking on a line.[4,6] Although the literature shows that weight classification is linked to impaired walking, there is limited information on how children who are overweight or obese alter their gait to meet task constraints.

The purpose of this study was to examine how weight classification relates to children's ability to meet a task constraint: crossing obstacles of various heights. Specifically, we examined two factors that have been related to changes in motor actions in overweight and obese children: increased movement time and variability in motor actions.[5] In the present study, we tested whether weight classification was associated with increased movement time and variations in strategies used to meet task constraints.

METHODS

Participants

The participants were volunteers from a children's summer camp at Queens College, NY. Inclusion criteria were being free of intellectual diagnoses or physical conditions that precluded independent walking based on parents' reports and experimenters' observations and being between 4 and 13 yrs old. Overweight and obese classifications for 2- to 19-yr-old children were based on a comparison between body mass index (BMI) and the Centers for Disease Control and Prevention weight-for-recumbent length growth charts.[7] Children at or above the 5th and below the 85th percentile were considered to be normal weight, those who were at or above the 85th percentile and below the 95th percentile were classified as being overweight, and those who were above the 95th percentile were deemed to be obese. Twenty-four children were divided into two groups. Twelve had BMI scores in the reference range, and twelve had BMI scores that were classified as overweight or obese (Table 1).

Apparatus, Room Setup, and Procedure

Three-dimensional motion data were collected at 120 Hz using a Vicon Nexus Model 1.4 motion capture system. After parents provided informed consent and children provided assent, anthropometric measurements were taken to ensure accurate motion capture calibration. Participants were then outfitted with 41 reflective markers placed on the anterior and posterior portions of the head, between the clavicles, on the sternum, on the anterior and posterior superior iliac spines, on C7, on T10, on the arms (seven per segment), on the legs (three per segment), and on the feet (lateral malleoli, fifth metatarsal, first metatarsal, and the posterior aspects of the calcanei).

Obstacles were created using two 25 cm–high wooden towers with three holes. An 81-cm dowel was inserted into holes on each tower so that the dowel served as an obstacle. The dowel could be moved to create low (4 cm), medium (11 cm), and high (16 cm) obstacles in the bottom, middle, and

TABLE 1 Demographic information

Participant	Age, yrs	Body Mass Index, kg/m^2	Percentile	Sex
Children with normal body mass index				
1	12	18.26	48	Female
2	8.5	16.83	72	Female
3	9	18.35	84	Female
4	5	13.61	16	Male
5	5	13.86	12	Male
6	13	18.18	55	Male
7	4	13.64	13	Male
8	13	18.29	63	Male
9	12	17.40	44	Female
10	4.5	11.65	5	Female
11	6	14.26	21	Female
12	9	15.87	49	Male
Mean (SE)	8.42 (1.00)	15.85 (0.68)	N/A	N/A
Children with high body mass index (overweight or obese)				
1	9	18.92	85	Female
2	10	19.91	89	Male
3	6	19.51	95	Female
4	13	31.23	95	Male
5	9	22.36	95	Male
6	7	18.03	93	Male
7	7	29.56	95	Male
8	8	19.48	95	Male
9	5	17.65	95	Female
10	6	16.67	95	Male
11	11	21.63	95	Female
12	12	22.04	89	Female
Mean (SE)	8.58 (0.73)	21.41 (1.31)	N/A	N/A

TABLE 2 Average total times at baseline trials, mean (SE)

	Normal Body Mass Index	Overweight or Obese Body Mass Index
Initial baseline, secs	0.23 (0.02)	0.27 (0.02)
Final baseline, secs	0.25 (0.01)	0.27 (0.01)

top holes of each tower. Each obstacle height represented the height of an everyday environmental constraint: a door threshold (4 cm), a small step (11 cm), and a tall step (16 cm).

Participants first walked once over a 406 cm–long path on flat ground with no obstacle (initial baseline). Afterward, in a counterbalanced order, they walked and stepped over low, medium, and high obstacles five times. At the end, they walked one final time on the 406 cm–long path with no obstacle (final baseline). All trials were completed at a self-selected pace. The protocol was approved by the institutional review board.

Data Processing

The x- (anterior/posterior), y- (medial/lateral), and z- (up/down) coordinates from the motion data were read into a custom-built program, which allowed users to view a point-light display of participants as they walked. Trials were clipped to include only one step before and after children crossed obstacles.

Means and standard errors for both groups were computed for the dependent variables. For measures of movement time when crossing obstacles, we measured the time from lifting the foot off of the ground to maximum knee height and the time from maximum knee height to foot contact. We also computed maximum knee height for both groups. To assess strategies used to meet the task constraint, we measured ankle angles at foot contact to determine neutral (angles near 90 degrees) or dorsiflexed ankle positions (angles less than 90 degrees)[8] and sagittal knee and ankle angles at maximum knee height. Lastly, we estimated variability in ankle positions at foot contact by calculating the coefficient of variation (standard deviation/mean).

Analyses

All statistical analyses were conducted using SPSS 16.0 statistical software. The results were presented as means and standard errors. Separate 2 (BMI group) × 3 (low, medium, high obstacles) repeated measures (RM) analyses of variance (ANOVAs) were run on the time it took children to achieve maximum knee height when stepping over obstacles, the time from maximum knee height to foot contact, ankle position at foot contact, sagittal knee and ankle angles at maximum knee height, and variability of the ankle angle at foot contact. We also conducted 2 (BMI group) × 2 (initial and final baseline condition) RM ANOVAs on ankle angle at foot contact and the variability of ankle angle at foot contact. Post hoc analyses for the RM ANOVAs included pairwise comparisons. Independent *t* tests were conducted on baseline trials for total time. All tests were subjected to Bonferroni corrections to reduce experiment-wise errors.

RESULTS

Baseline Comparisons

No differences were found in the total time for initial ($t[20] = -1.35$, $P = 0.19$, $d = 0.72$) and final ($t[19] = -1.18$, $P = 0.25$, $d = 0.49$) baseline comparisons between groups. Participants who were normal weight and were overweight or obese took similar amounts of time to walk during normal overground walking (Table 2).

Obstacle Stepping

Movement Time

On average, overweight or obese children took longer to achieve maximum knee height when stepping over high obstacles. A 2 (BMI group) × 3 (low, medium, high obstacles) RM ANOVA on the time taken to achieve maximum knee height revealed a two-way interaction between group and obstacle height ($F[2, 21] = 3.98$, $P = 0.04$). Post hoc analyses revealed more time on high obstacles for the overweight and obese group *vs.* the normal weight group ($P = 0.04$, $d = 3.00$), but there were no differences for low ($P = 0.41$, $d = 1.00$) or medium ($P = 0.31$, $d = 1.00$) obstacles (Table 3). We

TABLE 3 Average (SE) time to achieve maximum knee height at each obstacle

	Normal Body Mass Index	Overweight or Obese Body Mass Index
Low, secs	0.09 (0.03)	0.12 (0.03)
Medium, secs	0.10 (0.01)	0.09 (0.01)
High, secs	0.08 (0.01)	0.11 (0.01)

examined whether this result was caused by larger maximum knee heights in overweight and obese children in comparison with children with normal weight. However, this was not the case. A 2 (BMI group) × 3 (low, medium, high obstacles) RM ANOVA on the *z*-value of maximum knee height showed no group differences (*F*[2, 21] = 0.34, *P* = 0.57) and no interaction between groups and obstacle height (*F*[2, 21] = 0.09, *P* = 0.77).

A 2 (BMI group) × 3 (low, medium, high obstacles) RM ANOVA on the time from maximum knee height to foot contact revealed a two-way interaction between BMI group and obstacle height (*F*[2, 21] = 4.16, *P* = 0.02). Follow-up analyses for the two-way interaction revealed that children who were overweight or obese took less time to step down, compared with children with normal weight, from high obstacles (*P* = 0.04, *d* = 0.63) but not on low (*P* = 0.13, *d* = 0.65) or medium (*P* = 0.96, *d* = 0.22) obstacles (Table 4).

Strategies and Variability

We measured the children's ankle position after crossing obstacles by conducting a 2 (BMI group) × 3 (low, medium, high obstacles) RM ANOVA on ankle angles at foot contact. The results showed a two-way interaction between group and obstacle (*F*[2, 21] = 3.14, *P* = 0.04). Post hoc analyses demonstrated that children who were overweight or obese exhibited more dorsiflexion at foot contact on low obstacles compared with children with normal weight (*P* = 0.04, *d* = 3.13), but it showed only a trend on medium obstacles (*P* = 0.07, *d* = 2.68) and no difference on high obstacles (*P* = 0.89, *d* = 0.21). Table 5 shows ankle angles at each obstacle height for both groups. To test whether children used a similar ankle strategy during the baseline trials, we ran the same analyses on children's ankle position at foot contact at baseline. We found no differences for initial *vs.* final baselines (*F*[1, 22] = 1.76, *P* = 0.20), group (*F*[1, 22] = 0.08, *P* = 0.78), or baseline conditions by group (*F*[1, 22] = 0.34, *P* = 0.57). We also assessed children's joint kinematics by conducting separate 2 (BMI group) × 3 (low, medium, high obstacles) RM ANOVAs on sagittal knee and ankle angles at maximum knee height. The analyses produced no significant findings for knee angles for obstacle (*F*[2, 21] = 1.39, *P* = 0.26), group (*F*[2, 21] = 0.21, *P* = 0.65), or obstacle and group (*F*[2, 21] = 0.48, *P* = 0.62). Results for sagittal ankle angles showed no main effects for obstacle (*F*[2, 21] = 2.25, *P* = 0.12) or group (*F*[1, 21] = 0.18, *P* = 0.68) and no interaction between obstacle and group (*F*[2, 21] = 0.15, *P* = 0.87).

TABLE 4 Average (SE) time from maximum knee height to foot contact at each obstacle

	Normal Body Mass Index	Overweight or Obese Body Mass Index
Low, secs	0.0006 (0.0006)	0.0011 (0.0009)
Medium, secs	0.0005 (0.0005)	0.0006 (0.0004)
High, secs	0.0011 (0.001)	0.0006 (0.0005)

TABLE 5 Average (SE) ankle angles at each obstacle height for both groups

	Normal Body Mass Index	Overweight or Obese Body Mass Index
Low, degrees	99.24 (6.18)	79.90 (6.18)
Medium, degrees	97.18 (6.33)	80.19 (6.33)
High, degrees	88.05 (7.46)	89.58 (7.46)

We then examined the variability of children's ankle position with a 2 (BMI group) × 3 (low, medium, high obstacles) RM ANOVA on the coefficient of variation of ankle angles at foot contact. The ANOVA revealed a main effect for obstacle (*F*[2, 21] = 5.19, *P* = 0.02). Post hoc analyses showed that children were more variable on medium obstacles compared with low obstacles (*P* = 0.01, *d* = 2.75). The comparison between the coefficient of variation for ankle angles at foot contact on low and high obstacles was not significant (*P* = 0.08, *d* = 1.90). Table 6 shows means and standard errors for the coefficients of variation. To examine the variability of children's ankle position at baseline, we conducted the same analyses on their baseline trials. The findings revealed a main effect for initial *vs.* final baselines (*F*[1, 19] = 5.64, *P* = 0.03). Children had more variable ankle positions at the final baseline compared with the initial baseline (*P* = 0.03, *d* = −1.60). Effects for group (*F*[1, 19] = 0.09,

TABLE 6 Coefficients of variation and standard errors for average ankle angles at each obstacle height

Low	Medium	High
0.08 (0.02)	0.15 (0.03)	0.14 (0.04)

$P = 0.77$) and baseline conditions by group ($F[1, 19] = 0.14$, $P = 0.71$) were not significant.

DISCUSSION

The main purpose of this study was to evaluate the relationship between weight classification and changes in movement time and strategies to meet a task constraint: crossing obstacles of various heights. In comparison with children with normal weight, when crossing high obstacles, overweight and obese children took longer to achieve maximum knee height and less time to contact their feet with the floor after crossing. Strategies used to cross obstacles differed between the two groups; the normal weight group exhibited a neutral ankle position after crossing medium obstacles whereas the overweight and obese group landed with the ankle dorsiflexed. Overall, children demonstrated more variability in ankle position after crossing medium obstacles.

Our findings showed that analyzing segments of the movement involved in obstacle crossing (i.e., the time until maximum knee height and the time taken to achieve foot contact) can reveal information about how weight classification relates to increased movement time. Studies with normal-weight children have shown that more cautious obstacle crossing is expressed by increasing movement time during toe clearance, essentially the beginning phase of crossing the obstacle.[9] Therefore, it would seem that increasing movement time during the beginning phase of obstacle crossing would be most important in preventing a fall caused by tripping. Overweight and obese children did indeed increase movement time in the beginning phase of obstacle crossing. However, they increased time more than children in the normal weight group. This result was not caused by group differences in maximum knee height. Instead, the result may be caused by musculoskeletal difficulties associated with being overweight or obese such as heavier lower limbs[10]; perhaps, it took more time for overweight and obese children to raise their legs to cross the high obstacle because of heavier legs.

Part of our primary question also included asking whether weight classification influenced the use of variable strategies to complete task constraints. Generally, children who are experienced and unimpaired walkers use a heel-toe strategy in which they contact the ground with the heel before the toe.[11] This seemingly contradicts our findings because normal-weight children landed with neutral ankle positions (i.e., flat feet) after obstacle crossing whereas overweight and obese children landed in dorsiflexion (i.e., heel-first). However, other studies have also shown that strategies indicative of skilled walking are not always useful when it is necessary to meet a constraint; skilled infant walking is associated with longer step lengths, but infants who are experienced walkers decrease step length when descending steep slanted surfaces.[12] Therefore, the most useful strategy for obstacle crossing may have been for normal-weight children to land flat-footed to increase stability. In contrast, overweight and obese children landed heel-first, which is less stable. Obesity is associated with impairments that create safety risks for children,[13] and walking impairments put obese children at risk of injuries.[14] For example, children who are obese are more likely to sustain lower-limb injuries such as fractures and sprains compared with children who are nonobese.[15] Decreased stability may be behind the increase in safety risks for overweight and obese children. More research is needed to determine whether differences in rates of obstacle crossing and strategies may lead to an avenue of intervention for children who are overweight or obese.

CONCLUSIONS

The current study examined how weight classification related to movement time and strategies during obstacle crossing. We found that overweight and obese children showed no differences in movement time during the baseline trials but showed differences in time while stepping over obstacles. During obstacle crossing, children who were overweight or obese took longer to cross obstacles and had a dorsiflexed ankle position when landing. We also found that children demonstrated high variability in ankle position when crossing medium obstacles and during the final baseline trials.

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