Research in Developmental Disabilities 35 (2014) 46–53

Contents lists available at ScienceDirect

Research in Developmental Disabilities

Effects of overweight and obese body mass on motor planning and motor skills during obstacle crossing in children

Simone V. Gill [a,*], Ya-Ching Hung [b]

[a] Department of Occupational Therapy, Boston University, College of Health and Rehabilitation Sciences: Sargent College, 635 Commonwealth Avenue, Boston, MA 02215, USA
[b] Department of Family, Nutrition, and Exercise Sciences, Queens College, City University of New York, 65-30 Kissena Boulevard, Flushing, NY 11367, USA

ARTICLE INFO

Article history:
Received 30 August 2013
Received in revised form 17 October 2013
Accepted 21 October 2013
Available online 12 November 2013

Keywords:
Obesity
Motor planning
Children
Motor skills

ABSTRACT

Little is known about how obesity relates to motor planning and skills during functional tasks. We collected 3-D kinematics and kinetics as normal weight ($n = 10$) and overweight/obese ($n = 12$) children walked on flat ground and as they crossed low, medium, and high obstacles. We investigated if motor planning and motor skill impairments were evident during obstacle crossing. Baseline conditions showed no group differences (all $ps > .05$). Increased toe clearance was found on low obstacles ($p = .01$) for the overweight/obese group and on high obstacles ($p = .01$) for the normal weight group. With the crossing leg, the overweight/obese group had larger hip abduction angles ($p = .01$) and medial ground reaction forces ($p = .006$) on high obstacles and high anterior ground reaction forces on low obstacles ($p = .001$). With the trailing leg, overweight/obese children had higher vertical ground reaction forces on high obstacles ($p = .005$) and higher knee angles ($p = .01$) and anterior acceleration in the center of mass ($p = .01$) on low obstacles. These findings suggest that differences in motor planning and skills in overweight/obese children may be more apparent during functional activities.

1. Introduction

Obesity, now classified as a disease by the American Medical Association (AMA, 2013), is at 16% for children in the United States (Ogden, Carroll, Kit, & Flegal, 2012) and has led to a call for increased physical activity for children. Current recommendations are for children to participate in a minimum of 60 min of daily physical activity (DHHS, 2008). Unfortunately, these recommendations are not being met (Hills, Andersen, & Byrne, 2011) and are instead concurrent with increases in sedentary activities (Vandewater, Shim, & Caplovitz, 2004).

Differences in motor planning and motor skills may thwart efforts to increase physical activity for children who are overweight and obese. There is evidence that obesity has a negative impact on the cognitive processing needed to adequately plan movements. Obese children and adolescents perform worse on tasks of visuospatial organization, global executive functioning, and tasks of executive function involving planning and mental flexibility (Boeka & Lokken, 2008). A diversity of activities has been shown to improve executive functioning needed for motor planning (Diamond & Lee, 2011), however children who are overweight and obese engage in limited physical activity thereby increasing chances for poor motor planning. Impairments in these components of cognitive processing weaken the ability to plan movements leading to poor

* Corresponding author at: Boston University Department of Occupational Therapy, 635 Commonwealth Avenue, Boston, MA 02215, USA. Tel.: +1 617 353 7513; fax: +1 617 353 2629.
E-mail address: simvgill@bu.edu (S.V. Gill).

0891-4222/$ – see front matter
http://dx.doi.org/10.1016/j.ridd.2013.10.024

motor planning and decreased motor performance on tasks (Wolpert & Miall, 1996). For example, when walking on flat ground, adolescents with obese body mass index (BMI) scores demonstrate poor motor planning via slower velocities in their center of mass during gait initiation: the phase between standing still and steady-state walking (Colne, Frelut, Peres, & Thoumie, 2008). Children who are overweight and obese have higher rates of falls compared to normal-weight children (Bazelmans et al., 2004). Difficulty with motor planning can increase their predisposition to falls and injuries. Although research suggests that there is a relationship between obesity and motor planning difficulties, few studies have examined how motor planning affects motor skills and motor performance in this population.

In addition to motor planning, motor skills are affected by obesity, particularly skills related to walking (Gill, 2011; Shultz, Browning, Schutz, Maffeis, & Hills, 2011). In comparison to their normal-weight counterparts, overweight and obese children walk more slowly, take shorter steps, spend less time supporting their weight with one leg, walk with their feet farther apart, and keep both feet on the ground for longer periods of time (Deforche et al., 2009; McGraw, McClenaghan, Williams, Dickerson, & Ward, 2000; Wearing, Hennig, Byrne, Steele, & Hills, 2006). They also demonstrate altered hip and knee mechanics like larger joint powers during weight acceptance (Shultz, Hills, Sitler, & Hillstrom, 2010), higher peak pressures under the feet during walking (Yan, Zhang, Tan, Yang, & Liu, 2013), and less knee flexion (i.e., straighter knees) at initial foot contact (McMillan, Phillips, Collier, & Blaise Williams, 2010). Excess weight also makes it difficult to accelerate the center of mass during walking because of the metabolic cost and the amount of mechanical work required (Peyrot et al., 2010). Common interventions for childhood obesity involve increased physical activity via walking (Wing & Phelan, 2005). However, walking characteristics of overweight and obese children may hinder efforts to encourage increased walking.

While the walking characteristics discussed above may increase stabilization in overweight and obese children to counteract poor balance (Singh, Park, Levy, & Jung, 2009), these characteristics are positively correlated with difficulty recovering balance once it has been lost leaving them susceptible to falls and injuries (Deforche et al., 2009). These walking characteristics combined with motor planning difficulties amplify the risk of injuries in overweight and obese children (Gill, 2011). Most research on differences in motor planning and motor skills in the overweight and obese population has focused on activities that have few imposed task constraints (i.e., walking over flat ground) (Wearing, Hennig, Byrne, Steele, & Hills, 2006). However, the propensity for increased injuries for overweight and obese children is most evident during functional activities, which typically involve higher task constraints (e.g., stair climbing) (D'Hondt et al., 2013; D'Hondt et al., 2011; Hung, Gill, & Meredith, 2013; Strutzenberger, Richter, Schneider, Mundermann, & Schwameder, 2011). For example, when crossing obstacles with heights similar to everyday environmental obstacles like door thresholds and steps, overweight and obese children demonstrate slower movement times and decreased stability due to landing heel-first after obstacle crossing (Gill & Hung, 2012; Hung, Gill, & Meredith, 2013). Therefore, while it is useful to know how walking differs between overweight and obese children compared to normal-weight controls, understanding walking differences with little imposed task constraints may not reveal deficits in motor planning and motor skills that correlate with fall risks. Little work has been done to investigate how the motor planning and motor skills of overweight and obese children translate into performance during activities that are more similar to everyday functional activities with higher task constraints (Gill & Hung, 2012; Strutzenberger, Richter, Schneider, Mundermann, & Schwameder, 2011).

The purpose of the present study was to examine whether body mass index would influence the ability of 4- to 13-year olds to plan and coordinate their movements to cross obstacles of various heights. Our aims were: (1) to examine whether a task beyond flat ground walking would be more sensitive to problems with motor planning and motor skills in children with overweight and obese BMI scores and (2) to investigate if difficulty with motor skills would influence lower extremity movements and the acceleration of the center of mass during obstacle crossing. For children with overweight and obese BMI scores, we predicted that obstacle crossing will better detect differences in motor planning and motor skills and that both lower extremity movements and the acceleration of the center of mass will be affected during obstacle crossing.

2. Methods

2.1. Participants

Twenty-two children (9 girls, 13 boys, *M* age = 8.62; *SD* = 0.93) who were volunteers from a children's summer camp participated. Inclusion criteria consisted of having normal cognitive abilities, no known physical conditions that would preclude independent walking, and being between 4 and 13 years old. These criteria were confirmed via parent reports and experimenters' observations. BMI classification was based on BMI and on weight-for-recumbent length growth charts from the Centers for Disease Control and Prevention (Kuczmarski, 2000). BMI classifications were as follows: normal weight (between the 5th and 85th percentile), overweight (at or above the 85th percentile and below the 95th percentile), and obese (at or above the 95th percentile). Based on this, children were divided into two groups: 10 normal weight (*M* BMI = 15.85; *SD* = 0.68, *Minimum* = 5th, *Maximum* = 84th) and 12 overweight/obese (*M* BMI = 21.85; *SD* = 0.50, *Minimum* = 85th, *Maximum* = 95th).

2.2. Procedure and experimental setup

Following an auditory go signal, children crossed obstacles at a self-selected pace on a 4.06-m-long path with two AMTI OR6-6 force platforms (each 46 cm × 50 cm) located in the center of the path. There were five conditions: initial baseline, low obstacles, medium obstacles, high obstacles, and final baseline. During the initial and final baseline conditions, children walked along the path with no obstacles. During low, medium, and high obstacle conditions, children crossed obstacles that were created with an 81-cm-long wooden dowel inserted into two 25-cm-high wooden towers at 4 cm (low obstacle), 11 cm (medium obstacle), and 16 cm (high obstacle). Each height reflected obstacles that would be encountered in everyday life: a door threshold (4 cm), a small step (11 cm), and a tall step (16 cm). Trials ended when children walked to a stop line at the end of the walking path. Children received 3 practice trials to become familiarized with the task. All conditions included 5 trials each for a total of 25 trials. Averages for all trials were computed per child for further analysis. Informed consent was obtained from all participants and their caregivers, and the study was approved by the University Institutional Review Board.

2.3. Data acquisition

Three-dimensional kinematic data were collected with the whole body plug-in-gait model of VICON Nexus 1.51 with seven infrared cameras. Collecting anthropometric measurements for each child prior to data acquisition ensured proper calibration. Forty-one reflective markers positioned bilaterally captured motion with *x*- (anterior/posterior), *y*- (medial/lateral), and *z*- (up/down) coordinates from the anterior and posterior portions of the head, the shoulders (acromion process), the elbows (lateral epicondyle), the wrists (radio and ulnar styloid processes), the hands (index metacarpophalangeal joint), the upper arms, the forearms, the anterior and posterior superior iliac spines, the lateral thighs, the knee joints, each tibia, the ankle joints, the heels and the big toes. Markers were also placed between the clavicles, on the sternum, on C7, on T10, and on the right scapula. All markers were digitized at a rate of 120 Hz with VICON Nexus 1.51. All digitized signals were processed with a low pass digital filter with a cutoff frequency of 6 Hz. Kinetic data from both force plates were processed and synchronized with the kinematic data at a rate of 1200 Hz with VICON Nexus 1.51.

Joint angles created with the *x*, *y*, and *z* coordinates from the motion data were read into a custom-built Java program, which produced a point-light display of participants as they walked. Obstacle crossing trials were clipped to include only one step before and after children crossed obstacles. Baseline trials were clipped to only include the same portion of the walking path analyzed for obstacle crossing.

2.4. Analyses

SPSS 16.0 software was used to conduct analyses with data presented as means and standard errors. Independent *t*-tests with BMI classification as the independent variable were run on lower extremity dependent variables (i.e., hip and knee angles for each leg), vertical, anterior/posterior, and medial/lateral ground reaction forces normalized by weight (i.e., normalized ground reaction forces), and vertical, anterior/posterior, and medial/lateral acceleration of the center of mass for the baseline conditions. To examine motor planning, repeated measures (RM) analysis of variance (ANOVAs) with two independent variables, BMI classification and obstacle height, were conducted on the maximum toe height for each leg during obstacle crossing. For each leg, separate 2 (BMI classification) $\times$ 3 (obstacle height) RM ANOVAs were conducted on children's lower extremity movements (i.e., hip and knee angles), normalized vertical, anterior/posterior, and medial/lateral ground reaction forces, and vertical, anterior/posterior, and medial/lateral acceleration of the center of mass. Specifically, for both the crossing leg (i.e., the leg used to cross the obstacle) and for the trailing leg (i.e., the leg trailing behind) at maximum knee height during obstacle crossing, analyses were done on children's sagittal plane hip angle, frontal plane hip angle, sagittal plane knee angle, normalized vertical, anterior/posterior, and medial/lateral ground reaction forces, and vertical, anterior/posterior, and medial/lateral acceleration of the center of mass. Post hoc analyses for RM ANOVAs consisted of pairwise comparisons. To reduce experiment-wise errors, the Tukey procedure was used for all tests. We used Cohen's *d* after each *p*-value as a measure of effect sizes for follow up pairwise comparisons (Cohen, 1988). Interpreting effect size is based on the absolute value of Cohen's *d*. Absolute values of Cohen's *d* are interpreted as small, medium, or large: absolute values of Cohen's $d \geq 0.2$ = small effects, ≥ 0.5 = medium effects, and ≥ 0.8 = large effects.

3. Results

3.1. Baseline comparisons

Baseline comparisons showed no differences between normal weight and overweight/obese groups at either the initial or final baseline conditions for hip angles, knee angles, normalized vertical, anterior/posterior, and medial/lateral ground reaction forces, and acceleration of the center of mass in the vertical, anterior/posterior, and medial/lateral positions; all $ps > .05$.

3.2. Motor planning: toe clearance from obstacles for crossing and trailing legs

To assess motor planning, we examined the maximum toe height of the first leg to cross obstacles (i.e., crossing leg) for each trial (Table 1). The RM ANOVA revealed no significant main effects for obstacle or BMI classification and no interaction between the two (all $ps > .05$). Motor planning for the second leg to cross the obstacle (i.e., trailing leg) was quantified for each trial (Table 1). No significant main effects were found for obstacle height or BMI group (all $ps > .05$). There was a

Table 1
Average toe height for first (crossing leg) and second legs (trailing leg) to cross low, medium, and high obstacles for children in each group and standard errors (SE).

Group	Obstacle	Crossing leg toe height in centimeters (SE)	Trailing leg toe height in centimeters (SE)
Normal weight group	Low	17.26 (1.53)	13.73 (1.47)*
	Medium	15.40 (1.60)	16.28 (1.53)
	High	16.06 (1.54)	18.38 (1.53)*
Overweight/obese group	Low	20.57 (1.60)	23.13 (1.53)*
	Medium	22.41 (1.55)	21.18 (1.60)
	High	17.57 (1.62)	16.76 (1.59)*

* Interaction between BMI classification and obstacle height with $p < .05$.

Table 2
Average hip and knee angles at maximum knee height for crossing and trailing legs for condition and standard errors (SE).

Group	Obstacle	Crossing leg sagittal hip angles in degrees (SE)	Crossing leg frontal hip angles in degrees (SE)	Trailing leg sagittal hip angles in degrees (SE)	Trailing leg frontal hip angles in degrees (SE)	Crossing leg sagittal knees angles in degrees (SE)	Trailing leg sagittal knees angles in degrees (SE)
Normal weight	Low	21.61 (2.45)	39.42 (1.20)	15.99 (0.90)	41.57 (0.48)+	4.62 (1.22)	6.99 (0.66)+,*
	Medium	19.94 (0.95)	36.60 (0.33)	8.58 (0.94)	37.46 (0.31)+	5.54 (0.57)	3.55 (0.79)+
	High	18.79 (1.20)	35.44 (0.52)	6.75 (0.85)	37.32 (0.45)+	15.32 (0.68)	4.64 (0.64)*
Overweight/ obese	Low	18.49 (1.78)	47.28 (0.47)*	8.77 (1.24)	40.36 (0.42)+	9.40 (1.07)	11.09 (1.16)+,*
	Medium	23.94 (1.42)	50.28 (0.52)*	13.24 (1.23)	37.84 (0.33)+	10.29 (0.83)	6.06 (1.38)+
	High	22.84 (1.52)	66.75 (0.57)*	10.58 (1.82)	35.56 (0.45)+	20.10 (2.59)	12.02 (1.05)*

* Interaction between BMI classification and obstacle height with $p < .05$.
+ Main effects for obstacle height with $p < .01$.

significant interaction between obstacle height and BMI classification ($F(2,46) = 4.91$, $p = .02$) for trailing leg toe clearance. Children with normal weight had higher toe clearances on high versus low obstacles ($p = .01$; $d = -0.90$). In contrast, children with overweight/obese BMI scores demonstrated higher toe clearance values on low versus high obstacles ($p = .01$; $d = 1.18$).

3.3. Lower extremity movements

3.3.1. Hip angles at maximum knee height

For the crossing leg, as shown in Table 2, in the sagittal plane, no significant differences were found for hip angles based on condition, BMI classification, or the interaction between condition and BMI classification (all $ps > .05$). Analyses on hip angles in the frontal plane also showed no main effects for obstacle height or BMI classification (all $ps > .05$). A significant interaction was revealed between obstacle height and BMI classification, however ($F(2,44) = 4.25$, $p = .02$). Follow up comparisons showed that children in the overweight/obese group had the largest abduction angles at the highest obstacle compared to low ($p = .01$; $d = -10.77$) and medium ($p = .02$; $d = -1.75$) obstacles. With the trailing leg, children's hip angles varied based on obstacle height ($F(2,32) = 16.21$, $p = .0001$). Children exhibited more hip abduction after crossing low compared to medium obstacles ($p = .0001$; $d = 1.17$) and low compared to high obstacles ($p = .001$; $d = 0.97$).

3.3.2. Knee angles at maximum knee height

Table 2 illustrates average knee angles for the crossing leg at maximum knee height. The RM ANOVA showed no main effects or interaction for obstacle heights or BMI classifications (all $ps > .05$). Children's knee angles for the trailing leg differed according to obstacle height ($F(2,32) = 3.72$, $p = .04$). Follow up analyses on the main effect for condition showed that children's knee angles were larger after crossing low versus medium obstacles ($p = .049$; $d = 0.63$). The RM ANOVA also revealed an interaction between obstacle height and BMI classification ($F(4,32) = 2.90$, $p = .04$) for the trailing leg. After crossing low obstacles, children with BMI scores in the overweight and obese range had larger knee angles than children with normal-range BMI scores ($p = .01$; $d = 1.01$). We found same results on high obstacles. Children who were overweight/obese had larger knee angles compared to normal weight children at heel contact on high obstacles ($p = .01$; $d = 1.15$).

3.3.3. Normalized anterior/posterior ground reaction forces

At maximum knee height for the crossing leg, we found no main effects for BMI classification or obstacle height (all $ps > 05$) for anterior/posterior ground reaction forces on the trailing leg; Table 3. However, there was a significant interaction between BMI classification and obstacle height ($F(2,44) = 21.94$, $p = .001$). Follow up analyses showed that children with normal weight exerted the largest normalized ground reaction forces on high versus low ($p = .01$; $d = -1.00$) and medium

Table 3
Average group normalized anterior/posterior (A/P), medial/lateral (M/L), and vertical ground reaction forces for trailing leg at time of maximum knee height of crossing leg (TrCr) and for crossing leg at time of maximum knee height of trailing leg (CrTr) and standard errors (SE).

Group	Obstacle	TrCr Normalized A/P GRF in N/kg (SE)	CrTr Normalized A/P GRF in N/kg (SE)	TrCr Normalized M/L GRF in N/kg (SE)	CrTr Normalized M/L GRF in N/kg (SE)	TrCr Normalized vertical GRF in N/kg (SE)	CrTr Normalized vertical GRF in N/kg (SE)
Normal weight	Low	0.17 (0.06)*	0.32 (0.05)	0.13 (0.08)	0.13 (0.01)	1.38 (0.27)*	2.31 (0.24)
	Medium	0.29 (0.03)*	0.28 (0.08)	0.19 (0.06)	0.09 (0.05)	2.14 (0.22)*	2.27 (0.23)
	High	0.33 (0.04)*	0.31 (0.17)	0.12 (0.07)	0.10 (0.05)	1.92 (0.26)	1.75 (0.24)
Overweight/obese	Low	0.66 (0.02)*	0.23 (0.09)	0.11 (0.06)	0.08 (0.07)	1.99 (0.19)	1.88 (0.23)
	Medium	0.18 (0.08)*	0.27 (0.05)	0.04 (0.02)*	0.08 (0.04)	1.58 (0.29)*	1.74 (0.24)
	High	0.33 (0.12)*	0.25 (0.09)	0.19 (0.05)*	0.12 (0.03)	2.23 (0.24)*	1.96 (0.22)

* Interaction between BMI classification and obstacle height with $p < .05$.

Table 4
Average group anterior/posterior (A/P), medial/lateral (M/L), and vertical acceleration of the center of mass (COM) at time maximum knee height of crossing and trailing legs and standard errors (SE).

Group	Obstacle	Crossing A/P acceleration in COM (SE)	Trailing A/P acceleration in COM (SE)	Crossing M/L acceleration in COM (SE)	Trailing M/L acceleration in COM (SE)	Crossing vertical acceleration in COM (SE)	Trailing vertical acceleration in COM (SE)
Normal weight	Low	0.63 (0.08)*	0.66 (0.12)*	1.35 (0.27)	2.44 (0.31)+	2.25 (0.24)	2.76 (0.26)+
	Medium	0.78 (0.06)	0.83 (0.06)	1.35 (0.25)	1.58 (0.31)	2.16 (0.23)	1.85 (0.17)+
	High	0.84 (0.04)	0.73 (0.09)	1.38 (0.28)	1.28 (0.10)+	2.19 (0.24)	1.68 (0.25)+
Overweight/obese	Low	1.05 (0.05)*	1.02 (0.12)*	1.26 (0.26)	1.32 (0.31)+	2.07 (0.24)	2.32 (0.27)+
	Medium	0.75 (0.04)	0.70 (0.06)*	1.41 (0.22)	1.63 (0.31)	2.19 (0.21)	2.10 (0.18)+
	High	0.75 (0.07)	0.56 (0.09)*	1.53 (0.27)	0.96 (0.10)+	2.16 (0.21)	1.75 (0.26)+

* Interaction between BMI classification and obstacle height with $p < .05$.
\+ Main effects.

($p = .01$; $d = -0.75$) obstacles. In contrast, children in the overweight/obese group had larger ground reaction forces at low versus medium ($p = .001$; $d = 2.67$) and high ($p = .002$; $d = 1.32$) obstacles. At maximum knee height for the trailing leg, children showed no differences in normalized anterior/posterior ground reaction forces for the crossing leg (all $ps > .05$).

3.3.4. Normalized medial/lateral ground reaction forces

At the time of maximum knee height for the crossing leg, analyses on medial/lateral ground reaction forces for the trailing leg showed no main effects (all $ps > .05$); Table 3. There was a significant interaction ($F(2,44) = 3.61$, $p = .04$), which showed that children in the overweight/obese group had larger ground reaction forces in the medial direction at high versus medium obstacles ($p = .006$; $d = -1.25$). No significant effects were found at maximum knee height for the trailing leg in normalized medial/lateral ground reaction forces for the crossing leg (all $ps > .05$).

3.3.5. Normalized vertical ground reaction forces

Analyses on normalized vertical ground reaction forces at maximum knee height of the crossing leg, showed no main effects for the trailing leg (all $ps > .05$). However, there was a significant interaction between BMI classification and obstacle height ($F(2,44) = 10.87$, $p = .001$). Children with normal weight BMI scores had larger vertical ground reaction forces at medium versus low obstacles ($p = .005$; $d = 0.89$), but children with overweight/obese BMI scores had larger vertical ground reaction forces at high versus medium obstacles ($p = .005$; $d = -0.71$); Table 3. No significant effects were found at maximum knee height for the trailing leg in normalized vertical ground reaction forces for the crossing leg (all $ps > .05$).

3.4. Center of mass acceleration

3.4.1. Anterior/posterior acceleration of the center of mass

As shown in Table 4, there no were no main effects for the anterior/posterior acceleration of children's center of mass at maximum knee height of the crossing leg (all $ps > .05$). But, there was a significant interaction ($F(2,44) = 6.26$, $p = .006$); follow up comparisons showed that at low obstacles children with overweight/obese BMI scores exhibited more anterior acceleration in the center of mass than children with normal BMI scores ($p = .01$; $d = -1.83$). At maximum knee height of the trailing leg, the RM ANOVA on the acceleration of children's center of mass in the anterior/posterior direction revealed a significant interaction between BMI classification and obstacle height ($F(2,40) = 5.24$, $p = .01$). Children with overweight/obese BMI scores had more anterior acceleration when crossing low versus medium obstacles ($p = .01$, $d = 1.14$) and when crossing low versus high obstacles ($p = .005$, $d = 1.39$). Children in the overweight/obese group also had higher anterior/posterior acceleration in their center of mass on low obstacles compared to children in the normal weight group ($p = .04$, $d = 0.53$).

3.4.2. Medial/lateral acceleration of the center of mass

Table 4 shows average accelerations for the center of mass in the medial/lateral direction for both groups. We found no effects for group or condition and no interactions (all $ps > .05$). The RM ANOVA for the time of maximum knee height of the trailing leg showed a main effect for condition ($F(2,40) = 4.95$, $p = .01$); children had greater acceleration values on low compared to high obstacles ($p = .001$, $d = 1.12$). The RM ANOVA also showed a trend for the interaction between BMI classification and obstacle height ($F(2,40) = 2.94$, $p = .06$).

3.4.3. Vertical acceleration of the center of mass

We found no significant effects for vertical acceleration of the center of mass at the time of maximum knee height for the crossing leg (Table 4); all $ps > .05$. However, at the time of trailing leg maximum knee height, results from the RM ANOVA revealed a main effect for condition ($F(2,40) = 16.33$, $p = .001$). Follow up comparisons showed that children had higher vertical acceleration in their center of mass when crossing low versus high obstacles ($p = .001$, $d = 0.97$). Vertical acceleration values were also higher on low versus medium obstacles ($p = .022$, $d = 0.77$). The RM ANOVA also showed a trend for the interaction between BMI classification and obstacle height ($F(2,40) = 2.92$, $p = .06$).

4. Discussion

In the current study, we tested children with varying BMI classifications to investigate if an obstacle crossing task would detect deficits in motor planning better than flat ground walking and if trouble with motor skills via lower extremity movements and acceleration in the center of mass would be evident during obstacle crossing. Results showed no baseline differences between groups. However, children with overweight and obese BMI scores had higher toe clearance when crossing low versus high obstacles whereas children with normal weight did the reverse. Children with overweight and obese BMI scores also had higher hip abduction angles with the crossing leg on high versus low obstacles and higher knee angles than normal weight children with the trailing leg on low and high obstacles. When using the trailing leg to support weight during obstacle crossing, the overweight/obese group had the highest normalized anterior/posterior ground reaction forces on low obstacles and higher normalized medial ground reaction forces on high versus low obstacles. When using the crossing leg to support weight, overweight/obese children had higher normalized vertical ground reaction forces on high versus medium obstacles and the highest acceleration in their center of mass on low obstacles.

4.1. Baseline movement control

We found no group differences for baseline conditions. Although previous research shows that overweight/obese children demonstrate differences in motor skills related to walking compared to normal weight children on flat ground (Hills & Parker, 1991; Wearing et al., 2006), our results only showed differences during obstacle crossing. Differences during flat walking may present themselves more when comparing normal weight children to obese children (i.e., without including overweight children); wider disparities between groups in terms of weight may accentuate differences in motor skills.

4.2. Motor planning

Our findings showed that the normal weight and overweight/obese groups used opposite strategies when crossing high and low obstacles; the normal weight group had higher toe clearance on high versus low obstacles, but the overweight/obese group higher toe clearance on low versus high obstacles. Recent work shows that overweight/obese children demonstrate different strategies when crossing low obstacles compared to normal weight children by landing heel first: a strategy leaving them prone to increased instability after obstacle crossing (Gill & Hung, 2012). Similarly, in the present study, overweight/obese children's difficulty with motor planning may have contributed to the use of a less effective strategy when crossing high obstacles. As previously shown with other medical populations (Said, Galea, & Lythgo, 2013), differences in motor skills and strategies used during obstacle crossing can increase the risk of injury; less toe clearance on high obstacles increases the chance of tripping and falling.

The mechanism responsible for the relationship between obesity and motor planning is still unclear, but several causes could underlie the phenomena. For instance, impaired metabolic processing that affects brain areas involved in planning and organization (e.g., the cerebellum) could be responsible; physical inactivity decreases oxygen flow to the brain in obese individuals, which could lead to the impairments in spatial reasoning needed to motor plan (Wolpert & Miall, 1996). More research needs to be conducted to understand the mechanism that causes deficits in motor planning in overweight and obese children.

4.3. Lower extremity movement control

Results matched our prediction that lower extremity movements (i.e., hip and knee angles and ground reaction forces) and acceleration in the center of mass would differ between normal and overweight/obese children during obstacle crossing. Children in the overweight and obese group demonstrated differences in motor skills compared to the normal weight group that appeared to be compensatory strategies: possibly needed to counteract for challenges with motor planning. When crossing high versus low obstacles, children with overweight and obese BMI scores demonstrated more hip abduction. Also, when using the crossing leg to support weight, overweight/obese children had higher normalized vertical ground reaction forces on high versus medium obstacles and higher normalized medial ground reaction forces on high versus low obstacles. Although modifying motor skills to cross the highest obstacle might be best for this task, children in the overweight and obese group altered their movements in ways that may increase their risk of injuries. For example, already existing balance problems (Singh, Park, Levy, & Jung, 2009) and musculoskeletal disorders (Wearing et al., 2006) may be exacerbated by large hip abduction angles and high vertical and medial ground reaction forces, particularly when crossing high obstacles. Modifying hip and vertical ground reaction forces on high obstacles may work in opposition to children's efforts to maintain stability by instead making it difficult to regain stabilization after losing balance (Deforche et al., 2009).

Compared to the normal weight group, our results showed that children in the overweight/obese group had higher knee angles with the trailing leg on low and high obstacles. This finding matches other findings in the literature stating that overweight/obese children tend to demonstrate less knee flexion during functional tasks (McMillan, Phillips, Collier, & Blaise Williams, 2010). Decreasing knee flexion could be an attempt to increase stability by stiffening the joints (McMillan et al., 2010). Limiting range of motion is demonstrative of movement patterns evident during early skill acquisition in which individuals freeze degrees of freedom by voluntarily increasing joint rigidity to prevent falls (Bernstein, 1967). But, stiffening joints can lead to an increased risk of injuries (Chaudhari & Andriacchi, 2006).

Interestingly, some differences in lower extremity movement control in the overweight/obese group were evident on low obstacles. Findings showed that children with overweight and obese BMI scores had large anterior/posterior normalized ground reaction forces on low obstacles. They also had higher values for the acceleration in their center of mass compared to the normal weight group on low obstacles at the time of maximum knee height with both the crossing and trailing legs. Therefore, some of the differences in movement strategies between normal weight and overweight/obese children may reveal themselves during activities that appear to be less challenging. This highlights the importance of assessing motor performance not only on challenging tasks, but also on tasks that are scaled both below and above a child's abilities (Gill, Adolph, & Vereijken, 2009). Higher acceleration of the center of mass anteriorly in the overweight/obese group may have reflected difficulty controlling the forward acceleration of their bodies while crossing obstacles regardless of their height. This highlights both the effects of BMI on meeting task constraints and the added mechanical work required to control acceleration in the center of mass with excess weight (Gill, May-Benson, Teasdale, & Munsell, 2013; Peyrot et al., 2010).

4.4. Limitations

The current task had fixed obstacle heights rather than heights that reflected a percentage of children's leg lengths, which did not allow for scaling the task to each child's body dimensions. However, the study was designed to test children's abilities on obstacles similar to the height of environmental obstacles, which are not individualized to each person. In addition, factors that could contribute to the current findings were not measured including spatial and visual perception. Future studies will investigate how these contribute to motor planning and motor skills in children with overweight and obese BMI scores.

5. Conclusion

The current study illustrates differences in children's motor planning and motor skills with imposed higher task constraints. Assessing the impact of BMI classification on motor planning and motor skills may be most useful in the presence of imposed higher task constraints because this approximates functional, everyday activities. Differences in motor planning and motor skills between normal weight and overweight/obese children during obstacle crossing may reflect movement patterns evident during early skill acquisition in which children attempt to freeze degrees of freedom, difficulty planning and controlling their movements with excess adiposity, or unknown mechanisms responsible for motor planning and motor skill abilities that are specific to this population (e.g., metabolic processing affecting executive functioning). A few studies suggest that training may improve motor skills in children with overweight and obese BMI scores (Cliff et al., 2011; Logan, Robinson, Wilson, & Lucas, 2012; Matvienko & Ahrabi-Fard, 2010). Future studies need to investigate the underlying mechanisms of how obesity influences motor planning and motor skills.

Acknowledgments

This work was supported by Boston University start-up funds.

References

AMA.. (2013). *Recognition of obesity as a disease* Retrieved June 19, 2013,from: http://media.npr.org/documents/2013/jun/ama-resolution-obesity.pdf.

Bazelmans, C., Coppieters, Y., Godin, E., Parent, F., Berghmans, L., & Dramaix, A. (2004). Is obesity associated with injuries among young people? *European Journal of Epidemiology, 19*, 1037–1042.

Bernstein, N. (1967). *The coordination and regulation of movements*. Oxford: Pergamon Press.

Boeka, A. G., & Lokken, K. L. (2008). Neuropsychological performance of a clinical sample of extremely obese individuals. *Archives of Clinical Neuropsychology, 23*, 467–474.

Chaudhari, A. M., & Andriacchi, T. P. (2006). The mechanical consequences of dynamic frontal plane limb alignment for non-contact ACL injury. *Journal of Biomechanics, 39*, 330–338.

Cliff, D. P., Okely, A. D., Morgan, P. J., Steele, J. R., Jones, R. A., Colyvas, K., et al. (2011). Movement skills and physical activity in obese children: Randomized controlled trial. *Medicine & Science in Sports& Exercise, 43*, 90–100.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences*. New Jersey: Lawrence Erlbaum.

Colne, P., Frelut, M. L., Peres, G., & Thoumie, P. (2008). Postural control in obese adolescents assessed by limits of stability and gait initiation. *Gait & Posture, 28*, 164–169.

Deforche, B. I., Hills, A. P., Worringham, C. J., Davies, P. S., Murphy, A. J., Bouckaert, J. J., et al. (2009). Balance and postural skills in normal-weight and overweight prepubertal boys. *International Journal of Pediatric Obesity, 4*, 175–182.

DHHS.. (2008). *Physical activity guidelines for Americans* Retrieved March, 12, 2013, from: http://www.health.gov/paguidelines.

D'Hondt, E., Deforche, B., Gentier, I., De Bourdeaudhuij, I., Vaeyens, R., Philippaerts, R., et al. (2013). A longitudinal analysis of gross motor coordination in overweight and obese children versus normal-weight peers. *International Journal of Obesity, 37*, 61–67.

D'Hondt, E., Deforche, B., Vaeyens, R., Vandorpe, B., Vandendriessche, J., Pion, J., et al. (2011). Gross motor coordination in relation to weight status and age in 5- to 12-year-old boys and girls: A cross-sectional study. *International Journal of Pediatric Obesity, 6*, e556–e564.

Diamond, A., & Lee, K. (2011). Interventions shown to aid executive function development in children 4–12 years old. *Science, 333*, 959–964.

Gill, S. V. (2011). Optimising motor adaptation in childhood obesity. *Australian Occupational Therapy Journal, 58*, 386–389.

Gill, S. V., Adolph, K. E., & Vereijken, B. (2009). Change in action: How infants learn to walk down slopes. *Developmental Science, 12*, 888–902.

Gill, S. V., & Hung, Y. C. (2012). Influence of weight classification on children stepping over obstacles. *American Journal of Physical Medicine and Rehabilitation, 91*, 625–630.

Gill, S. V., May-Benson, T. A., Teasdale, A., & Munsell, E. G. (2013). Birth and developmental correlates of birth weight in a sample of children with potential sensory processing disorder. *BMC Pediatrics, 13*, 13–29.

Hills, A. P., Andersen, L. B., & Byrne, N. M. (2011). Physical activity and obesity in children. *British Journal of Sports Medicine, 45*, 866–870.

Hills, A. P., & Parker, A. W. (1991). Gait characteristics of obese children. *Archives of Physical Medicine and Rehabilitation, 72*, 403–407.

Hung, Y., Gill, S. V., & Meredith, G. S. (2013). Influence of dual task constraints on whole body organization during walking in overweight and obese children. *American Journal of Physical Medicine and Rehabilitation, 92*, 461–467.

Kuczmarski, R. J. (2000). *CDC growth charts: United States, advance data from vital and health statistics; no. 314*. Hyattsville, MD: National Center for Health Statistics.

Logan, S. W., Robinson, L. E., Wilson, A. E., & Lucas, W. A. (2012). Getting the fundamentals of movement: A meta-analysis of the effectiveness of motor skill interventions in children. *Child: Care, Health, and Development, 38*, 305–315.

Matvienko, O., & Ahrabi-Fard, I. (2010). The effects of a 4-week after-school program on motor skills and fitness of kindergarten and first-grade students. *American Journal of Health Promotion, 24*, 299–303.

McGraw, B., McClenaghan, B. A., Williams, H. G., Dickerson, J., & Ward, D. S. (2000). Gait and postural stability in obese and nonobese prepubertal boys. *Archives of Physical Medicine and Rehabilitation, 81*, 484–489.

McMillan, A. G., Phillips, K. A., Collier, D. N., & Blaise Williams, D. S. (2010). Frontal and sagittal plane biomechanics during drop jump landing in boys who are obese. *Pediatric Physical Therapy, 22*, 34–41.

Ogden, C. L., Carroll, M. D., Kit, B. K., & Flegal, K. M. (2012). Prevalence of obesity and trends in body mass index among US children and adolescents, 1999–2010. *JAMA, 307*, 483–490.

Peyrot, N., Morin, J. B., Thivel, D., Isacco, L., Taillardat, M., Belli, A., et al. (2010). Mechanical work and metabolic cost of walking after weight loss in obese adolescents. *Medicine & Science in Sports & Exercise, 42*, 1914–1922.

Said, C. M., Galea, M. P., & Lythgo, N. (2013). People with stroke who fail an obstacle crossing task have a higher incidence of falls and utilize different gait patterns compared with people who pass the task. *Physical Therapy, 93*, 334–344.

Shultz, S. P., Browning, R. C., Schutz, Y., Maffeis, C., & Hills, A. P. (2011). Childhood obesity and walking: Guidelines and challenges. *International Journal of Pediatric Obesity, 6*, 332–341.

Shultz, S. P., Hills, A. P., Sitler, M. R., & Hillstrom, H. J. (2010). Body size and walking cadence affect lower extremity joint power in children's gait. *Gait & Posture, 32*, 248–252.

Singh, D., Park, W., Levy, M. S., & Jung, E. S. (2009). The effects of obesity and standing time on postural sway during prolonged quiet standing. *Ergonomics, 52*, 977–986.

Strutzenberger, G., Richter, A., Schneider, M., Mundermann, A., & Schwameder, H. (2011). Effects of obesity on the biomechanics of stair-walking in children. *Gait & Posture, 34*, 119–125.

Vandewater, E. A., Shim, M., & Caplovitz, A. G. (2004). Linking obesity and activity level with children's television and video game use. *Journal of Adolescence, 27*, 71–85.

Wearing, S. C., Hennig, E. M., Byrne, N. M., Steele, J. R., & Hills, A. P. (2006). The impact of childhood obesity on musculoskeletal form. *Obesity Review, 7*, 209–218.

Wing, R. R., & Phelan, S. (2005). Long-term weight loss maintenance. *American Journal of Clinical Nutrition, 82*, 222S–225S.

Wolpert, D. M., & Miall, R. C. (1996). Forward models for physiological motor control. *Neural Networks, 9*, 1265–1279.

Yan, S. H., Zhang, K., Tan, G. Q., Yang, J., & Liu, Z. C. (2013). Effects of obesity on dynamic plantar pressure distribution in Chinese prepubescent children during walking. *Gait & Posture, 37*, 37–42.