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THE EFFECT OF BODY MASS INDEX ON CHILDREN'S GAIT PATTERNS WHILE WALKING ON FLAT AND SLOPED SURFACES

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ABSTRACT

Childhood obesity has been linked to numerous health problems that are typically associated with adult obesity. Previous studies have suggested that obesity is associated with gait pattern abnormalities, gait instability, the development of lower extremity joint injuries and musculoskeletal diseases, and long-term orthopedic complications. The purpose of this study was to investigate the relation between gait patterns and body size in children ages 3-5 years while walking on flat, inclined, and declined surfaces. More specifically, this study examined the association between cadence, walking velocity, and the variability in step width and step length between each walking trial with age and sex specific BMI percentiles. Data were analyzed using SPSS software. Bivariate correlations were used to measure the relation between BMI-for-age and sex percentiles and the variables of cadence, walking velocity, step width, and step length. The significance level was set at $p<0.05$. BMI-for-age-and sex percentiles were not associated with cadence, walking velocity, and gait variability (step length, step width) during all three conditions of walking. This pilot study does not suggest that children's body mass index is related to altered gait patterns while walking on flat and sloped surfaces in children ages 3-5 years. Future studies with larger samples and more direct measures of body composition would provide a more comprehensive view of the nature of early growth and body composition and the effects on locomotion.

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CHAPTER 1

LITERATURE REVIEW

Childhood Obesity in the United States

Obesity is a serious health problem that affects many children and adolescents in the United States. The high prevalence of this disease has caused it to become one of the more serious problems facing children and adolescents in today's society. The Centers for Disease Control and Prevention (CDC) attribute obesity to an imbalance between caloric intake and caloric expenditure (CDC, 2010). Predisposing factors for childhood obesity include genetics, excessive energy intake, sedentary behavior, decreased physical activity, prenatal and postnatal effects, and environmental influences (CDC, 2010; Vos,Welsh, 2010).

Body mass index (BMI), an index of weight relative to height (kg/m^2), is a measure that is commonly used to estimate adiposity levels within children and adolescents. BMI is widely used for the identification of overweight and obesity. However, it is not a direct indicator of adiposity due to its inability to distinguish between body fatness, muscle mass, and skeletal mass (Freedman, Sherry, 2011). When assessing body size in children, BMI percentiles are interpreted relative to the child's age and sex (CDC, 2010). According to the CDC, the term "overweight" is defined as a BMI-for-age-and sex at or above the 85th percentile and lower than the 95th percentile. In addition, the term "obesity" is defined as a BMI-for-age- and sex at or above the 95th percentile (CDC, 2010).

Within the past three decades, the childhood overweight and obesity rates have consistently increased within the United States, resulting in a childhood obesity epidemic (Mond et al., 2007). The most recent National Health and Nutrition Examination Survey (NHANES) conducted in 2007-2008 determined that 16.9% of children between the ages of 2 and 19 years were at or above the 95th percentile. Additionally, 31.7% of children between the same age ranges were at or above the 85th percentile (Odgen, Carroll, 2010).

While statistics now suggest that the rate of childhood obesity has begun to stabilize, NHANES surveys reveal that childhood overweight and obesity rates have increased drastically from 1970 to 1990 (Odgen, Carroll, 2010). Between the years of 1976-1980 and 2007-2008, the obesity rate for children ages 2-5 years increased from 5% to 10.4% (Odgen, Carroll, 2010). Within these same years, the obesity rate for children ages 6-11 years increased from 6.5% to 19.6% and the obesity rate for adolescents' ages 12-19 years increased from 5% to 18.1% (Odgen, Carroll, 2010). These obesity rates evident within the United States are particularly alarming due to the numerous ramifications and negative outcomes that can arise as early as childhood.

General Consequences

Children and adolescents who are overweight or obese are not only at risk for health problems during adulthood, but also are at risk during their younger years of life. Potential obesity related consequences are classified as either psychosocial or medical (Lee, 2009; Loke, 2002). Obesity can have a significant impact on the psychological and social aspects of a child. A child who is overweight or obese often has a negative self-image and poor self-esteem (Daniels, 2006). This frequently results in depression, body dissatisfaction, dietary restraint, and eating disorders (Daniels, 2006). Overweight and obese children tend to also have a difficult time forming relationships with others, suffer from discrimination and rejection from their peers, and often have fewer friends (Daniels, 2006).

Obesity related medical consequences are further divided into mechanical or metabolic complications; mechanical being associated with orthopedic disorders such as joint and skeletal complications as well as obstructive sleep apnoea (Lee, 2009; Loke, 2002). Metabolic problems that are associated with childhood obesity include glucose intolerance, dyslipidemia, hyperglycemia, hypertension, and type 2 diabetes mellitus. (Lee, 2009; Loke, 2002; Daniels, 2006). Psychosocial and medical consequences that arise during childhood can lead to a significantly lower quality of life as well as lead to complications and impairments in motor skill performance.

Motor Skill Consequences

Gross motor skills, the ability to perform a body movement using the larger muscles of the body, are affected by overweight and obesity. In a study examining the relation between obesity and skill attainment in children ages 2-3 years, obese males were less able to perform gross motor skills efficiently compared to normal weight children (Cawley, Spiess, 2008). Mond et al. (2007) reported similar findings in children between the ages of 4-9 years, with a higher prevalence of gross motor skill impairment in obese male children. Both studies established a relationship between high levels of adiposity and gross motor skill impairment within obese female children, but findings were not significant (Cawley, Spiess, 2008; Mond et al., 2007).

Postural balance also can be affected by body fatness. Postural balance is essential in the development of normal motor skill performance, requiring the even distribution of the body's center of mass relative to the force of gravity (Wearing et al., 2006). Goulding et al. (2003) demonstrated that when asked to perform a single leg stance while on a reduced base of support, obese boys between the ages of 10-21 years were less able to perform the balancing task compared to non-obese boys. All measures of adiposity (weight, BMI, fat mass, percentage fat, and waist circumference) were found to be directly related to poor performance on the balancing tasks (Goulding et al., 2003). It was hypothesized that postural balance was impaired due to a lack of muscular functioning and stability (Wearing et al. 2006). In a similar study, Deforche et al. (2009) reported that overweight boys between the ages of 8-10 years had difficulty maintaining balance while standing on one leg on a reduced base of support.

Overweight and obesity during childhood can also lead to complications and impairments in muscular strength and power, particularly in the lower limbs. Riddiford-Harland et al. (2006) found that lower limb functionality was significantly lower in obese children ages 8-9 years when performing lower limb strength and power tests. Obese children performed considerably poorer in both the vertical and standing long jump tests compared to nonobese children (Riddiford-Harland et al., 2006). However, obese children displayed significantly greater throwing abilities and performed better in tasks that required upper limb strength, suggesting that obese children possess greater upper limb strength and power compared to normal weight children (Riddiford-Harland et al., 2006).

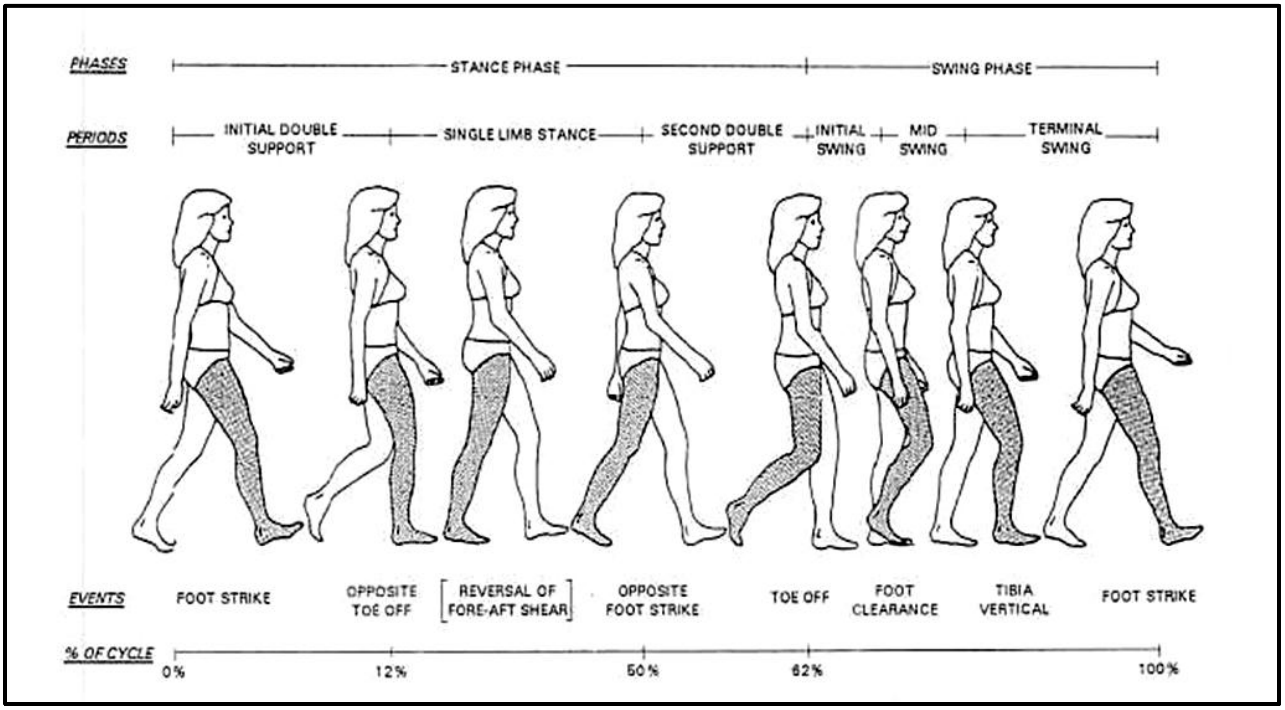
When performing the chair rising task, an exercise used to assess lower limb strength and functionality, obese children spend significantly more time in the transfer phase between sitting and standing, required additional assistance while performing the task, had a slower weight transfer, and exhibited a greater sway velocity compared to normal weight children (Riddiford-Harland et al., 2006; Deforche et al., 2009). In a study assessing the physical fitness of a random sample of Flemish schoolchildren, obese children performed significantly poorer in tasks that required them to lift their larger body mass against the force of gravity such as sit-ups, the standing-broad jump, bent-arm hand task, speed shuttle run, and endurance shuttle run (Deforche et al., 2003). The inability to perform gross motor skill tasks can further lead to complications in their locomotion or abilities, potentially becoming a major barrier to their primary form of physical activity.

Locomotion

Locomotion, which includes walking and running, is the most common form of human movement. It is one of the most essential forms of movement that a child will learn within their lifetime, beginning to emerge around the age of 1 year. Locomotion is an imperative task to acquire during childhood because it allows the movement from one place to another and is the child's first and primary form of physical activity. A normal gait cycle for a bipedal human being consists of 4 events (foot strike, opposite foot off, opposite foot strike, and foot off) and 2 phases (stance and swing) (Kaufman et al., 2006) (Fig.1.1). The stance phase, which constitutes 62% of the cycle, begins at foot strike (0%) and ends at opposite foot off (62%) (Kaufman et al., 2006). The swing phase, 38% of the cycle, begins at foot off (62%) and ends at ipsilateral foot strike (100%) (Kaufman et al., 2006).

Within a typical gait cycle, the body's center of mass is accelerated upward and downward as the individual ambulates forward (Davis, Kaufman 2006). During this time, vertical forces are being exerted up through the body called ground reaction forces. Based on Newton's Second Law of Motion (Force = Mass x Acceleration), a child who is overweight or obese will theoretically experience greater exerted ground reaction forces on their lower extremity joints due to their greater body mass compared to a normal weight child. This added stress placed on the lower extremities of the body can substantially lead to complications and irregularities in gait pattern formations as well as lead to injuries and disruptions in the joint biomechanics.

Figure 1.1: Normal Human Gait Cycle



Source: Sutherland DH, Kaufman KR, Moitoza JR. Kinematics of Normal Human Walking. *Human Walking*; 23-44.

Locomotion Consequences

Gait instability and control while walking can be compromised due to the effects of excessive weight placed on the body. Colne et al. (2008) reported that dynamic stability was reduced within 16 year old obese adolescents. In order to compensate for their instability while walking, obese adolescents adapted strategies in their gait formation to preserve center of mass equilibrium which in turn, decreased their forward walking velocity (Colne et al., 2008). McGraw et al. (2000) tested the stability differences between obese and non-obese boys’ from the ages of 8-10 years and found that obese boys exhibited a greater sway area and reduced stability in their gait compared to non-obese boys, suggesting a diminishment in dynamic stability. In addition, Deforche et al. (2009) reported that obese boys, ages 8-10 years, displayed a slower gait cycle while attempting to maintain balance when walking on a straight line.

The sustained load placed on the body can cause children and adolescents to develop complications and disruptions within the joint biomechanics of the lower extremities. These complications due to excessive body size can add stress to the joints of the lower extremities, potentially leading to injuries and the development of musculoskeletal diseases such as varus angular deformities and medial compartment osteoarthritis (Gushue et al., 2005). Altered joint biomechanics can additionally lead to long-term orthopedic complications. Therefore, researchers have recommended that overweight and obese children participate only in non-weight bearing activities in an attempt to relieve the stress placed on the lower extremity joints and avoid long-term injuries and complications (Shultz et al., 2009).

McMillan et al. (2009) examined frontal plane motions and moments during stance phase within fourteen overweight and healthy weight boys' between the ages of 10 and 12 years. Overweight boys had significantly different frontal plane motions and moments during stance phase of walking compared to healthy weight children (McMillan et al., 2009). These abnormal frontal plane motions and moments reveal that overweight boys over-compensate their body weight towards the medial and lateral directions while walking (McMillan et al., 2009). Overweight boys also had a collapsed hip adduction and knee valgus during stance phase due to the inability to support their body weight on one limb during single leg stance phase (McMillan et al., 2009).

In a more recent study, McMillan et al. (2010) examined the gait of 36 male and female adolescents, ages 12-17 years, within the sagittal and frontal planes. While in stance phase, obese children displayed considerably different joint mechanics within the sagittal and frontal planes compared to non-obese children; the most significant differences being found at the knee joint (McMillan et al., 2010). Within the sagittal plane, obese children displayed less knee flexion and lower knee flexion moments from initial contact to late stance phase (McMillan et al., 2010). Within the frontal plane, obese children exhibited knee abduction throughout the entire stance phase and had greater peak knee angles and moments (McMillan et al., 2010). Significant differences were also found at the hip joint in both the frontal and sagittal planes.

Gushue et al. (2005) studied the three-dimensional knee joint biomechanics during normal gait within obese children (11-12 years). Children who were obese walked with a significantly lower peak knee flexion angle and a higher peak internal knee abduction moment during early stance phase (Gushue et al., 2005). In a similar study, Shultz et al. (2009) examined the frontal, sagittal, and transvere planes as well as peak moments localized at the hip, knee, and ankle joints during preferred and fast walking cadences. Obese children between the ages of 8-12 years had an increased joint moment in all lower-extremity joints within the frontal, sagittal, and transverse planes during both preferred and fast walking cadences (Shultz et al., 2009). Obese children also exhibited greater peak ankle dorsiflexor moments (Shultz et al., 2009).

In addition to complications and irregularities in joint biomechanics of the lower extremities, obesity has also been shown to affect the gait characteristics of normal walking (McGraw et al., 2000; Hills et al., 1991; Hills et al., 1994). Hills & Parker (1991) found that obese pre-pubertal children, ages 8.5 to 10.9 years, showed greater asymmetry in their gait patterns compared to non-obese children. While walking, obese children significantly favored the right side of the body by bearing more weight on their right limb than their left limb (Hill, Parker, 1991). Obese children also displayed a greater step width while walking compared to the non-obese group (Hill, Parker, 1991).

Several temporal gait characteristics have also been shown to be notably different within obese children. For example, in a study conducted by Hills & Parker (1991), the gait patterns of ten obese and ten normal weight children (8.5 to 10.9 years) were evaluated using video gait analysis. Obese children displayed a significantly longer gait cycle duration, lower cadence, slower walking velocity, and a longer time spent in stance phase compared to non-obese children (Hills, Parker, 1991).

In support of the findings of Hills & Parker, Parker et al. (1995) reported that overweight children with Down's syndrome spent considerably more time in support phase. McGraw et al. (2000) found that obese boys between the ages of 8-10 years showed a decreased gait cadence and walking speed compared to non-obese boys. These results suggest that obese children exhibit significantly different temporal gait characteristics, resulting in a slower and more cautious gait compared to children of normal weight (Hills, Parker, 1991; Parker et al., 1995; McGraw et al., 2000).

Rationale for Investigating Body Size and Gait Patterns

Obesity is a health problem that can affect children during their younger years of life, potentially affecting their locomotion or abilities. Evidence suggests that obesity during childhood is linked to gait pattern abnormalities and instability as well as the development of lower extremity joint injuries, musculoskeletal diseases, and long-term orthopedic complications. In addition, childhood obesity has been associated to altered lower extremity joint biomechanics within the frontal, sagittal, and transverse planes and significant differences in temporal gait characteristics.

Locomotion is a child's primary form of physical activity and is the most essential type of movement for a child to acquire. Walking has the potential to improve overall health and well-being, enhance physical fitness levels, decrease sedentary lifestyles and rates of obesity, and set the stage for lifelong movement. Previous studies within the literature suggest that children who are obese suffer from numerous joint biomechanical complications and also display significant differences in their walking patterns. The excessive loads placed on the body may result in disruptions in their lower extremity joints, which has resulted in limitations in physical activity participation.

Obesity also may have an effect on the gait characteristics of normal walking, potentially causing a child to have a slower walking velocity, greater sway area, lower cadence, longer gait cycle duration, and longer time spent in stance phase These complications in their locomotion abilities may create an ongoing barrier to the main form of physical activity that these children perpetually engage in, thus, creating a snowball effect in terms of risks for obesity later in life as a teenager and an adult.

Therefore, the following study examined the relation between gait patterns and body size in children ages 3-5 years while walking on flat and sloped surfaces. More specifically, the study examined the association between cadence, walking velocity, and the variability in step width and step length between each walking trial with age and sex specific BMI percentiles. We hypothesized that as BMI-for-age-and sex percentiles increased, cadence and walking velocity would decrease while walking on flat, inclined, and declined surfaces. We also hypothesized that as BMI-for-age-and sex percentiles increased, step width and step length variability would increase between each trial while walking on each of the three surface conditions. To our knowledge it is the first study to investigate the relation between children's body size and gait patterns while locomoting on flat, inclined, and declined surfaces.

CHAPTER 2: JOURNAL MANUSCRIPT

THE EFFECT OF BODY MASS INDEX ON CHILDREN'S GAIT PATTERNS WHILE WALKING ON FLAT AND SLOPED SURFACES

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ABSTRACT

Background: Childhood obesity has been linked to numerous health problems that are typically associated with adult obesity. Previous studies have suggested that obesity is associated with gait pattern abnormalities, gait instability, the development of lower extremity joint injuries and musculoskeletal diseases, and long-term orthopedic complications.

Purpose: The purpose of this study was to investigate the relation between gait patterns and body size in children ages 3-5 years while walking on flat, inclined, and declined surfaces. More specifically, this study examined the association between cadence, walking velocity, and the variability in step width and step length between each walking trial with age and sex specific BMI percentiles.

Methods: A convenience sample of 30 children (17 male, 13 female) between the ages 3 and 5 were recruited from two university-based preschools. Children completed 5-7 trials while walking on three surface conditions: level, 15-degrees uphill, and 15-degrees downhill. Gait variables were measured using a 425 cm GAITRite Electronic Walkway (GAITRite System, 2006). Cadence was measured as the frequency or number of steps taken within each condition and walking velocity was measured as the distance traveled over the time elapsed. Gait variability was analyzed by examining the variability or dispersion in step width and step length for each child between walking trials. Step width was measured as the distance from the midline of one foot to the midline of the opposite foot, and step length was measured as the line between the heel points of two consecutive footprints of the same foot (GAITRite System, 2006). Step width and step length standard deviations were formulated for each surface condition in order to assess the gait variability between each trial while walking on the three surface conditions.

Results: Data was analyzed using SPSS software. Bivariate correlations were used to measure the relation between BMI-for-age and sex percentiles and the variables of cadence, walking velocity, step width, and step length. The significance level was set at $p<0.05$. Results indicate that BMI-for-age and sex percentiles were not associated with differences in cadence and walking velocity ($p>0.05$). In addition, no relation was found between BMI-for-age and sex percentiles and variability in step length or step width for each child between trials ($p>0.05$).

Conclusions: This pilot study does not suggest that children's body mass index is related to altered gait patterns while walking on flat and sloped surfaces in children ages 3-5 years. Future studies with larger samples and more direct measures of body composition would provide a more comprehensive view of the nature of early growth and body composition and the effects on locomotion.

Introduction

Within the past three decades, the childhood obesity rate has steadily increased within the United States, resulting in a childhood obesity epidemic (Mond et al., 2007) The most recent National Health and Nutrition Examination Survey (NHANES) conducted in 2007-2008 estimated that 16.9% of children and adolescents between the ages of 2-19 years were at or above the 95th percentile for BMI-for-age and 31.7% were at or above the 85th percentile for BMI-for-age (Odgen, Carroll 2010). These obesity rates evident within the United States are particularly alarming due to the numerous ramifications and negative outcomes that can arise as early as childhood.

Cawley & Speiess (2008) and Mond et al. (2007) found that obese male children between the ages of 2-9 years were less able to perform gross motor skills efficiently compared to normal weight children. Obese boys were also reported to be less able to perform balancing tasks that required the even distribution of the body's center of mass due to lack of muscular functioning and stability (Wearing et al., 2006; Goulding et al., 2003; Deforche et al., 2009). Additionally, muscular strength and power was significantly poorer in obese children, particularly in the lower limbs (Riddiford-Harland et al., 2006). However, obese children displayed greater performance in tasks that required upper limb strength, suggesting that obese children possess greater upper limb power compared to normal weight children (Riddiford-Harland et al., 2006).

McMillian et al. (2009) reported that within the frontal plane, overweight boys between the ages of 10-12 years displayed a collapsed hip adduction and knee valgus during stance phase. In a more recent study, McMillian et al (2010) found that within the sagittal plane, obese adolescents (12-17 years) displayed less knee flexion and lower knee flexion moments from initial contact to late stance phase. Within the frontal plane, obese children displayed knee abduction throughout the entire stance phase and had greater peak knee angles and moments

(McMillian et al., 2010). In addition, Gushue et al. (2005) reported that obese children, ages 11-12 years, had an increased joint moment in all lower-extremity joints within the frontal, sagittal, and transverse planes during preferred and fast walking cadences.

Hills & Parker (1991) reported that obese pre-pubertal children (8.5- 10.9 years) showed greater asymmetry in their gait patterns and displayed greater step width while walking. Obese children also displayed a significantly longer gait cycle duration, lower cadence, slower walking velocity, and a longer time spent in stance phase compared to non-obese children (Hills, Parker, 1991). In a more recent study, McGraw et al. (2002) found that obese boys ages 8-10 years, showed a decreased gait cadence and walking speed compared to non-obese boys.

In this study, we investigated the relation between gait patterns and body size in children ages 3-5 years while walking on flat and sloped surfaces. More specifically, this study examined the association between cadence, walking velocity, and the variability in step width and step length between each walking trial with age and sex specific BMI percentiles. We hypothesized that as BMI-for-age-and sex percentiles increased, cadence and walking velocity would decrease while walking on flat, inclined, and declined surfaces. We also hypothesized that as BMI-for-age-and sex percentiles increased, step width and step length variability would increase between each trial while walking on each of the three surface conditions.

Methods

Participants

We recruited a convenience sample of 30 healthy children, 17 male and 13 female, ages 3-5 years, to participate in our study. Participants were recruited from two university-based preschools located on the Pennsylvania State University, University Park campus; the Child Development Lab and Bennett Family Center. Children with a history of or exhibiting any known neurological or developmental disorders that may affect growth or the ability to walk efficiently were excluded from the study. A parent or guardian completed a demographic information questionnaire form as well as an approved consent form prior to data collection. All methods and procedures were reviewed and approved by the Institutional Review Board at the Pennsylvania State University.

Anthropometric data

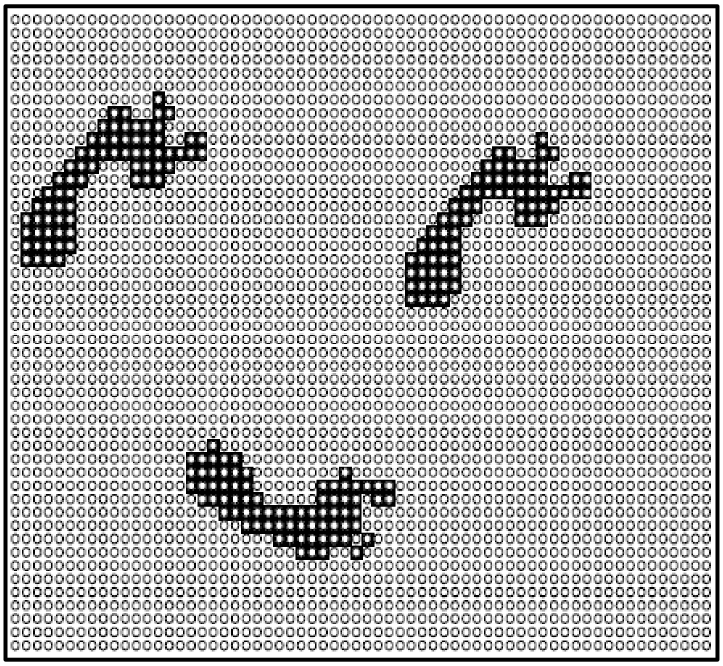
Anthropometric data were collected for each child according to the measurement techniques described by Lohman (Lohman, 1991). All measurements of body size were made during the data collection session. The child's body weight was measured using a high-precision digital scale (Seca 416 Infantometer, Seca Corp., Hamburg, Germany) and the child's height was measured using a portable stadiometer (Seca 240 Stadiometer, Seca Corp., Hamburg, Germany). 3 measurements of the child's weight and height were obtained and recorded. The average body weight and height measurements were then used to calculate BMI-for-age-and sex percentiles for each child using SAS computer software (Verison 9.1.3, Cary, NC). All anthropometric data was collected by trained staff members and while the child was in light clothing and without shoes.

Measurement of gait patterns

Walking parameters were analyzed using a 425cm GAITRite Electronic Walkway (Gait Mat). The GaitMat was placed upon a custom made ramp that had a width of 2 feet, a length of 4 feet, and a fixed slope of 15-degrees. The height of the ramp was 1 foot off the ground and the floor surface was covered with a rubber mat to prevent the ramp from slipping. Each child was instructed to walk at their preferred speed across the Gait Mat. Participants completed 5-7 walking trials while walking on the three surface conditions: level, 15-degree uphill, and 15-

degree downhill. As the participants ambulated across the Gait Mat, sensors encapsulated in the electronic walkway were activated due to the pressure exerted by the feet of the participants (Fig. 2.1). These pressure points were then grouped together and identified as a footprint using special algorithm equations utilized by the Gait Mat computer software (GAITRite, 2006). Study personnel stood near the ramp surfaces at all times to ensure the safety of the child.

Figure 2.1: Gait Mat Sensor Grouped Together to Identify a Footprint



Source: GAITRite Electronic Walkway. Measurements & Definitions. CIR Systems Inc. Revision A.2;2006.

Cadence and walking velocity were measured in all three surface conditions using Gait Mat analysis software. Cadence was measured as the frequency or number of steps taken within each condition and walking velocity was measured as the distance traveled over the time elapsed. Gait variability also was analyzed by the Gait Mat using Gait Mat software, examining the variability in step width and step length for each child between walking trials. Step width was measured as the distance from the midline of one foot to the midline of the opposite foot, and step length was measured as the line between the heel points of two consecutive footprints of the same foot

(GAITRite System, 2006). Variability was defined as the dispersion of step width and step length measurements for each child between trials. Step width and step length standard deviations were formulated for each surface condition in order to assess the variability in step width and step length while walking on each surface condition.

Statistical analysis

Data were analyzed using SPSS software. Bivariate correlations were calculated between BMI-for-age-and sex- percentiles and each of the tested gait variables: cadence, walking velocity, step length, and step width. The significance level was set at $p<0.05$.

Results

The maximum BMI percentile in our sample of children was 94.30 and the minimum BMI percentile was 3.50. The average weight and height measurements for male and female subjects were 17.7 kg and 106.5 cm. The average BMI for male and female subjects was 15.6 and the average BMI percentile was 52.3. For female subjects, the average BMI was 15.6 and the average BMI percentile was 52.3. For male subjects, the average BMI was 15.7 and the average BMI percentile was 51.5. Table 2.1 and table 2.2 display the characteristics and anthropometric data of our sample of children in the study.

Table 2.3 presents the relation between BMI-for-age and sex percentiles with cadence and walking velocity on level, uphill, and downhill surfaces. Table 2.4 shows the relation between BMI-for-age and sex percentiles with step length and step width variability between each walking condition. With the significance level set at $p<0.05$, results indicate that BMI-for-age and sex percentile were not associated with differences in cadence and walking velocity (p>0.05). In addition, no relation was found between BMI-for-age and sex percentiles and variability in step length or step width for each child between trials (p>0.05).

Subject Characteristics

TABLE 2.1

MALE N= 17	Age (Months)	Weight (kg)	Weight z score	Weight Percentile	Height (cm)	Height z score	Height Percentile	BMI (kg/m^2)	BMI z score	BMI Percentile
Mean	52.6	17.5	0.2	55.3	105.5	0.2	55.9	15.7	0.0	51.5
St. Dev.	6.4	1.6	0.7	24.7	3.6	0.8	25.4	1.2	1.0	29.7

TABLE 2.2

FEMALE N= 13	Age (Months)	Weight (kg)	Weight z score	Weight Percentile	Height (cm)	Height z score	Height Percentile	BMI (kg/m^2)	BMI z score	BMI Percentile
Mean	56.2	17.9	0.2	57.2	107.8	0.5	65.0	15.4	0.1	53.3
St. Dev.	7.2	1.5	0.7	22.0	4.3	0.7	17.7	1.0	0.7	24.1

Relation between BMI-for-Age-and-Sex Percentiles and Measured Gait Variables

Table 2.3 Cadence and Walking Velocity

Variables	**Pearson Correlation (r)**	**P value (<0.05)**
Cadence: Level	-0.4	0.40
Cadence: Uphill	0.10	0.28
Cadence: Downhill	0.01	0.47
Velocity: Level	-0.03	0.43
Velocity: Uphill	0.04	0.41
Velocity: Downhill	-0.03	0.42

Table 2.4 Variability in Step Length and Step Width

Variables	**Pearson Correlation (r)**	**P value (<0.05)**
Step Length SD: Level	0.09	0.31
Step Length SD: Uphill	0.19	0.15
Step Length SD: Downhill	-0.10	0.28
Step Width SD: Level	0.18	0.16
Step Width SD: Uphill	-0.09	0.30
Step Width SD: Downhill	-0.08	0.32

Discussion

The purpose of this study was to investigate the association between gait patterns and BMI in children ages 3-5 years while walking on flat, inclined, and declined surfaces. We hypothesized that as BMI-for-age-and sex percentiles increased, cadence and walking velocity would decrease while walking on flat, inclined, and declined surfaces. We also hypothesized that as BMI-for-age-and sex percentiles increased, step width and step length variability would increase between each trial while walking on each of the three surface conditions. Our hypotheses were not supported by our results. Specifically, we found no relation between BMI-for-age-and sex percentiles and cadence, walking velocity, and gait variability (step length, step width).

Our results are in contrast to those of Hills & Parker (1991) and McGraw et al. (2002) despite our similarity in terms of the gait variables tested (cadence, walking velocity, step width, step length). Hills & Parker and McGraw et al. found significant differences between gait characteristics and body size. These authors observed that when walking on a level, steady state surface, cadence, walking velocity, gait cycle duration, and time spent in stance phase were significantly different between obese and non-obese pre-pubertal males (Hills, Parker, 1991; McGraw et al., 2002). These authors also reported that gait asymmetry and step width were significantly different between obese and non-obese children (Hills, Parker, 1991; McGraw et al., 2002).

In addition, previous research has found that obese children are more likely to exhibit a collapsed hip adduction and knee valgus compared to non-obese children (McMillian et al., 2009).Previous research has also reported that obese children display less knee flexion and lower knee flexion moments in the sagittal plane of stance phase compared to children of normal weight (McMillian et al., 2010). Lastly, obese children have been found to exhibit increased joint moments in all lower-extremity joints within the frontal, sagittal, and transverse planes compared to non-obese children (Gushue et al., 2005).

One possible reason for our lack of conformity with previous studies may be due to the walking surfaces we used to test our subjects. To our knowledge, this was the first study that examined the relation between gait characteristics and BMI while walking on both flat and sloped surfaces. Previous research has simply examined children while locomoting on steady state, level walking surfaces. They have not examined the differences in gait characteristics while walking on level and sloped surfaces as implemented in our study design. The significance of evaluating gait on level and sloped surfaces is that ramps induce further demands to the locomotor control system (Prentice et al., 2003). Using this technique of walking on level and sloped surfaces challenges and stresses the system, requiring the body to make specific modifications in gait patterns, posture, muscle activation, and joint stability in order to accommodate for the change in surface conditions (Prentice et al., 2003). Thus, adding ramps was intended to increase the expected differences in gait patterns between overweight and non-overweight children. We were surprised by our results given that the expected differences in gait patterns while walking on the sloped surfaces were not found.

Another possible reason our results differed from previous studies could be related to the age range of the children studied. Previous studies examined older children from the ages of 8-10 years. However, our study tested a younger sample of children between the ages of 3-5 years. Studies have shown that within this specific age range, significant development occurs in locomotion skills and gait stabilization (Sutherland, 1997). Sutherland (1997) reported that in addition to normal body growth, the gait parameters of step length, cadence, and walking velocity all show significant evidence of a maturation process that is influenced by central nervous system development until the age of 4 years. In our sample of children, the average age for male subjects was 4.4 years and the average age for female subjects was 4.6 years. Since rapid growth and development occurs throughout much of childhood, BMI differences in gait patterns may not be evident or may be difficult to evaluate within young children.

A third possible reason our results differed from previous studies may be due to our sample of children used in the study. Previous studies recruited obese children that were ≥ 95th BMI-for-age-and sex percentile and compared them to children who were in the normal percentile range for their weight status (5th to ≤85th BMI-for-age-and sex percentile). Our study recruited a convenience sample of 30 children from two university-based preschools. Within this sample, the average BMI-for-age-and sex percentile was 52.3. Only 13% of children in our sample was ≥ 85th BMI-for-age-and sex percentile whereas 87% of our sample was <85th BMI-for-age-and sex percentile. These percentile values suggest that the majority of our sample was at a healthy weight, proposing that our children may have been more physically fit and active compared to those children in previous studies. Our study may have not had enough overweight children to have the statistical power to observe BMI-percentile related differences in gait patterns. The normal weight children, who typically display normal gait patterns, may have "washed out" the effects of BMI in our sample.

The last possible reason our results differed from previous studies may be due to us using BMI as an indicator for body fatness. BMI is commonly used to estimate adiposity levels within children and also used for the identification of overweight and obesity (CDC, 2010). However, BMI is not a direct indicator of adiposity but rather a proxy for body fatness. BMI does not have the ability to distinguish between body fatness, muscle mass, and skeletal mass (Freedman, Sherry, 2011). During childhood, BMI percentiles are not necessarily related to adiposity (Freedman, Sherry, 2011; Wells 2000).For example, within relatively fat children between the ages of 5 to 8 years (≥95th BMI for-age-and sex percentile), BMI can be a good indicator for body fatness. However, within normal weight children between the ages of 5 to 8 years (≤85th BMI for-age-and sex percentile), BMI differences can be a result of an increase in fat-free mass (Freedman, Sherry, 2011). In addition, Wells (2000) demonstrated that a poor relation exists between BMI and body fatness for children ages 8-12 years due to the differences in fat-free mass and fat mass during body growth and development (Wells, 2000). This key assumption of our research design, that as BMI percentile increases fat mass increases, remains a significant limitation of the work. We cannot rule out that our lack of an association between BMI percentiles and walking patterns is simply because BMI percentiles are not closely related to fat mass at this age.

Future studies of assessing the association between body size and gait patterns within children should employ the same design as implemented in our study, using both level and sloped surfaces to increase the expected differences in gait patterns due to body size. However, to measure body size and body fatness, a more direct and accurate approach should be used instead of BMI for-age-and sex percentiles. In particular, multiple studies have shown dual-energy x-ray absorptiometry (DXA) to be a reliable and easy to use method that can accurately assess body fat levels within children ages 6 to 18 years (Lazzer et al., 2008; Elberg et al., 2004; Sopher et al., 2011). The sample of children used for analysis should also be taken into consideration, focusing on the comparison of children in the ≥95th BMI for-age-and sex percentile to children of normal weight (5th to ≤85th BMI for-age-and sex percentile).

In summary, our findings demonstrate no relation between body size and gait patterns in children ages 3-5 years while walking on flat, inclined, and declined surfaces. Our findings suggest that BMI-for-age-and sex percentiles were not associated with cadence, walking velocity, and gait variability (step length, step width) during all three conditions of walking. This pilot study does not suggest that children’s body mass index percentile is related to certain gait patterns while walking on flat and sloped surfaces in children ages 3-5 years. Future studies with larger samples and more direct measures of body composition would provide a more comprehensive view of the nature of early growth and body composition and the effects on locomotion.

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RELATED EXPERIENCE

- ***Undergraduate Teacher’s Assistant***
    - Kinesiology 202: Functional Anatomy; *2010*
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RESEARCH

- ***Honors Thesis:*** “The Effect of Body Mass Index on Children’s Gait Patterns While Walking on Flat and Sloped Surfaces”
- ***Research Assistant***
    - Longitudinal study on the influence of body size on motor skill performances within adolescents; *2010*
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OTHER EXPERIENCE

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ASSOCIATIONS

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