ABSTRACT

A COMPARISON OF LEAN AND OBESE GAIT CHARACTERISTICS OF CHILDREN AND ADULTS DURING LEVEL WALKING

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Increased body mass affects gait kinematics and kinetics in adults. It is however unknown if increased body mass produces similar adaptations in children and adults. The duration of obesity in children is shorter than in adults, thus the magnitude of adaptation to increased mass is expected to be less in obese children's gait. Alternatively, obese children and adults may have similar gait adaptations, indicating that obese gait evolves relatively rapidly after or while becoming obese and has no cumulative effect on the magnitude of gait adaptations. The purpose of this study was to compare gait kinematics and kinetics between lean and obese children and adults.

Lean (age 13 ±1.6 y, BMI =18 ±1.5 kg/m^2) and obese (age 13 ±1.7, BMI = 31 ±3.9) children and lean (age 36 ±4.7, BMI = 24 ±1.9) and obese (age 34 ±7.7, BMI = 48 ±8.8) adults walked at 1.5 m/s on a level surface while gait kinematics and kinetics were measured in one session. Kinematic and kinetic variables were analyzed with a 2x2 factorial analysis of variance followed by Tukey's post-hoc test.

Children and adults walked with many stride characteristics, with obese individuals spending 4% more time in stance phase than swing phase compared to lean individuals. In the knee, there was an age ($p = 0.046$), mass ($p = 0.001$), and a borderline age by mass interaction effect ($p = 0.053$) with obese vs lean individuals producing more impulse and obese adults

producing the highest impulse. In the ankle, there was an age, mass, and interaction effect (all $p = 0.001$) with obese producing higher impulses compared to lean and obese adults producing the highest impulse.

In conclusion, the magnitude of adaptation in kinetics was similar in children and adults at the hip and ankle joint but adults' adaptation was significantly greater at the knee. It is possible that the unique neuromuscular adaptations in obese gait in children and adults are due to adults being obese for a longer time than children.

A Comparison of Lean and Obese Gait Characteristics of

Children and Adults During Level Walking

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By

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Chapter 1: Introduction

Obesity levels continue to rise in the United States and around the world. In 2003-2004, 17.1% of the United States children and adolescents were overweight and 32.2% of adults were obese. In 2005, there were approximately 1.6 billion adults who were overweight and at least another 400 million that were obese. By 2015, it is estimated that more than 700 million adults will be obese (Ogden, Carroll, Curtin, McDowell, Tabak, & Flegal, 2006).

Although the walking pattern of healthy humans in its gross appearance seems immutable, many conditions bring about modifications in human gait. For example, natural aging causes a distal to proximal shift in joint torques (DeVita & Hortobagyi, 2000; Winter, Patla, Frank, & Walt, 1990), knee osteoarthritis related pain tends to unload the painful limb during stance (Sturmer, Gunther, & Brenner, 2000; Hortobagyi, Westerkamp, Beam, Moody, & Holbert, 2005; Kaufman, Hughes, Morrey, Morrey, & An, 2001), and individuals whose knee function is fully restored after anterior cruciate ligament surgery, still walk many months after surgery with a visually non-detectable reduction in knee extensor torque (Knoll, Kiss, & Kocsis, 2004; Berchuck, Andriacchi, & Bach, 1990). It is then reasonable to expect that large body mass also produces adaptations in human gait.

Indeed, several studies have documented that obese adults change the basic structure of their gait compared with lean adults. Kinematic changes show obese adults walking with a shorter step length, increased step width, and a slower self-selected speed. Obese adults tend to spend more time in stance phase to increase stability. To increase this stability, Lai et al (2008) reported obese individuals increase hip adduction in terminal stance and pre-swing. The increase use hip adductors, along with hip extensors and ankle plantarflexors, are an adaptation to try to keep a similar velocity to that of lean adults. There are also decreases in knee torque and flexion (Foti, Davids, & Bagley, 2000).

Some of these gait adaptations have been also described to occur in children. In obese compared with lean children, there is evidence for a decrease in cadence and an increase in stride width (Hills, 1992; Nantel, Brochu, & Prince, 2006; Gushue, Houck, & Lerner, 2005). The increase in stride width is most likely due to the large inner thigh adipose tissue. As in adults, there is an increase in time spent in stance phase and a decrease in stride length. The only available research on children also displayed differences in gait kinetics between lean and obese children. There was an observed decrease in energy produced by hip extensors and increased energy absorption by hip flexors (Nantel, Brochu, & Prince, 2006). There was decrease in peak knee flexion, but obese children knee extension was similar to lean children.

None of these studies have directly compared gait characteristics between lean and obese children and adults. Such a comparison, although only cross-sectional, could shed light on how obese adult gait evolves and whether there is an interaction between age and obesity. Because children, due to their age, are assumed to be obese for a shorter time than adults, the differences in obese children's versus adults' gait may exhibit an interaction between age and obesity, which would indicate that exposure to increased body mass only for a few years can bring about functionally meaningful adaptations in gait.

Purpose

The purpose of this study is to compare lower extremity kinematic and kinetic gait characteristics of obese and lean children to the lower extremity kinematic and kinetic gait characteristics of obese and lean adults during level walking a fixed speed of 1.5 m/s.

Expectation

Because there are limited studies in the literature on the effects of obesity on gait kinematics and kinetics, and there also are no preliminary data, generation of a formal hypothesis is not possible. The expectation in this study is the obese child gait will be similar to the obese adult gait. However, we expect to observe some differences in gait between the child and adult groups based on the time each group has been obese. We expect to see signs of greater adaptations in the gait obese adults than in obese children since the adults have been obese for a longer period of time.

Limitations

The following delimitations and limitations were incorporated and identified for this experimental design:

1) The study was delimited to subjects having no history of lower extremity injury or disease.

2) Obese patients, besides being obese, were otherwise healthy with no other symptoms of disease or osteoarthritis.
3) Children were between 10 to 16 years of age and adults were between 21 to 60 years of age.
4) Children with a BMI less than 21 were considered lean and adults with a BMI less than 30 were considered lean.
5) Children and adults with a BMI greater than 30 were considered obese.
6) Only a speed of 1.5 m/s on a level surface was examined.
7) Data limited to accuracy of instruments which has been determined to be acceptable for the purposes of this research.

Assumptions

The following assumptions were made for this experimental design:

1) Laboratory equipment did not interfere with any part of the subject's performance.
2) Any information given by the subject was considered to be true.
3) Appropriate approximation of anthropometric measures and equations were made for each subject.
4) Muscle function was considered to be symmetrical between the right and left legs.

Operational Definitions

The following operational definitions were used for this experimental design:

1) WOMAC: Western Ontario and McMaster Osteoarthritis Index
2) Age Effect: differences between children and adults, regardless of mass
3) Mass Effect: differences between lean and obese, regardless of age
4) Age by Mass Interaction: occurs when the differences that occur within child group, between lean and obese, were not the same differences that occurred within the adult group between lean and obese.

Chapter 2: Review of Literature

Obesity levels continue to rise here in the United States and around the world. In 2005, there were approximately 1.6 billion adults who were overweight and at least another 400 million that were obese. By 2015, it is estimated that more than 700 million adults will be obese (Organization, 2006). In 2003-2004, 17.1% of the United States children and adolescents were overweight and 32.2% of adults were obese (Ogden, Carroll, Curtin, McDowell, Tabak, & Flegal, 2006).

Despite an overwhelming amount of research on obesity, the nature verses nurture debate in the cause of obesity is still undecided. Recent efforts to identify and link specific genes to obesity have been mostly unsuccessful. Frayling et al (2007) have identified a single-nucleotide on chromosome 16 in fat cells that is associated with type 2 diabetes and is also thought to be associated with childhood obesity. Christakis et al (2007) may have found more of a nurturing effect, observing that obesity spreads through social networks depending on social interactions. Findings suggest that friends of the same sex have more influence on weight gain than spouses who shared the same living environment. There is also strong evidence for a parental influence on childhood obesity: children with 2 obese parents are twice as likely to develop obesity compared to those with 2 lean parents (Treuth, Butte, & Sorking, 2003).

Obesity, whether its cause is genetic, environmental, or both, affects all aspects of a person's life. Obesity has many comorbidities, such as an increased risk of cardiovascular disease, hypertension, dyslipidemia, diabetes mellitus, and gallbladder disease. There is also an increased prevalence and mortality ratios for selected types of cancer, and socioeconomic and psychosocial impairment (Fallon, et al., 2005; Panel, 1991). Obesity also affects mobility and gait.

Characteristics of Lean and Adult Obese Gait

It is reasonable to expect that large body mass modifies the pattern of gait. There are numerous conditions that produce gait adaptations. There is evidence to suggest that gait adaptations occur during natural aging (DeVita & Hortobagyi, 2000; Winter, Patla, Frank, & Walt, 1990), in the course of developing knee osteoarthritis (Sturmer, Gunther, & Brenner, 2000; Hortobagyi, Westerkamp, Beam, Moody, & Holbert, 2005; Kaufman, Hughes, Morrey, Morrey, & An, 2001), and even after full rehabilitation, and resumption of sport activities after anterior cruciate ligament injuries (Knoll, Kiss, & Kocsis, 2004; Berchuck, Andriacchi, & Bach, 1990). Several studies also demonstrated gait differences between obese and lean adults.

Obese gait resembles the gait of pregnant women during their last trimester, around 35-40 weeks of gestation (Foti, Davids, & Bagley, 2000). Foti et al. (2000) found that there was an increase in time spent in double stance and less time spent in swing phase. The increased pelvis width causes increased hip adduction to allow one foot to remain under the center of mass during the single support phase. There was an increased use of hip adductors, hip extensors, and ankle plantar flexion due to increased body weight, but also to keep gait velocity, stride length, cadence, and joint angle the same (Foti, Davids, & Bagley, 2000).

Lai et al. (2008) compared the gait of lean and obese adults at a self-selected speed. The results suggest that obese adults walked slower, used shorter strides, and spent more time in stance phase. Many other studies have confirmed these findings (DeVita & Hortobagyi, 2003; Browning, Baker, Herron, & Kram, 2006). Browning et al. (2006) found that the perferred walking speed is adopted by obese individuals to help minimize energy cost per distance traveled.

Another study by Browning and Kram (2007) compared obese individuals and normal weight individuals by observing ground reaction forces (GRFs) and lower sagittal plane joint moments at different walking speeds. There were greater absolute GRFs in obese gait, however, this was proportionate to body weight. As walking speed decreased, so did GRFs in obese adults. There was greater movement at the hip, knee, and ankle relative to greater GRFs experienced by the obese subjects (Browning & Kram, 2007). This, however, is contradictory to the findings by DeVita and Hortobagyi (2003). DeVita and Hortobagyi (2003) performed a study examining how lower kinetics effects adult obese gait. Their study found less hip and knee flexion, and more ankle plantar flexion in obese individuals, producing a more erect walking pattern. There was also a decrease in knee torque and power in proportion to body weight, which probably serves to decrease the knee joint load. DeVita and Hortobagyi (2003) speculate that knee torque starts to become coupled with body weight around a BMI of ~30 kg/m^2, a threshold where there is a neuromuscular adaptation to increased body weight.

In obese gait, it is speculated a threshold exists between BMI and when gait pattern changes due to obesity begins. DeVita and Hortobagyi (2003) saw this change in gait in their subjects with a mean BMI of 42.3 kg/m^2, whereas Browning & Kram (2007) did not see a significant change in gait in their subjects with a BMI of 35.5 kg/m^2. DeVita and Hortobagyi (2003) suggest differences in results could be affected by how long the individual has been obese, the strength of lower extremity limbs, presence of early stage osteoarthritis, or in data collection methods. The differences in gait between obese and normal weight individuals do not only appear in adults, but also in children.

Characteristics of Gait in Lean and Obese Child Gait

Obesity is a serious health concern in children. Similar to obese adults, obese verses lean children typically walk more slowly, and spend longer time in stance phase (McGraw, McClenaghan, Williams, Dickerson, & Ward, 2000; Nantel, Brochu, & Prince, 2006; Hills & Parker, 1993). The longer stance phase is a possible adaptation to increase stability (McGraw, McClenaghan, Williams, Dickerson, & Ward, 2000; Nantel, Brochu, & Prince, 2006). Remaining longer time in stance allows the center of mass to be supported between the feet for greater stability (Nantel, Brochu, & Prince, 2006). To increase stability during swing phase, there is a decreased stride length and wider step width. The excess adipose tissue between the thighs contributes to wider step width (Gushue, Houck, & Lerner, 2005; Nantel, Brochu, & Prince, 2006).

Hills' (1992) study looked at the affect of obesity in children walking at various speeds above and below their self-selected pace. He found that obese children walk with a slower cadence and spent more time in double support than lean children. When walking slower than their preferred speed, obese children had greater difficulty with stability. This may be contributing to weight status and low physical activity levels (Hills, 1992).

Nantel et al (2006) found a difference in hip kinetics of obese children when compared to lean children. There was a decrease in energy generated by the hip extensors and an increase in energy absorption by the hip flexors. Nantel et al (2006) suggests that increased energy absorption by the hip flexors is used to generate more power, but even with this increased absorption, obese children still are not as energy efficient as lean children.

Gushue et al (2005) performed a study examining knee kinematics and kinetics of obese children. He found a decrease in peak knee flexion angle during early stance compared to lean children, but similar knee extension in both groups. The decrease in knee flexion in the obese children was hypothesized to keep the knee extension similar to a lean child's gait.

Comparing Adult Gait and Child Gait

Studies have been performed to determine when children establish a mature gait. Sutherland et al. (1980) compared gaits between one-year-olds, two-year-olds, and seven-year-olds to that of adults. Sutherland found that the gait of a seven-year-old was nearly that of an adult. By the age of seven, heel-strike, knee-flexion wave, reciprocal arm-swing, and an adult pattern of joint angles throughout the walking cycle are established. Other gait characteristics, such as step length and walking velocity, will increase with growth and maturation. Whether the gait of a child is mature or immature, it differs only slightly from the adult gait.

Many studies have compared the effects of obesity in adults and children in separate studies, but no single study exist comparing both obese adults to obese children. Because lean children and adults have similar gaits, the benefit of directly comparing the gait between lean and obese children and adults is to test the idea that age and obesity interact. Because children, due to their age, are assumed to be obese for a shorter time than adults, obese children's versus adults' gait may exhibit similar relative adaptations in kinematics and kinetics. Alternatively, an absence of interaction between age and obesity would indicate that exposure to increased body mass only for a few years can bring about functionally meaningful adaptations in gait. Therefore, the purpose of this study is to compare gait characteristics of obese and lean children to the gait characteristics of obese and lean adults during level walking at their preferred speed and at a fixed speed of 1.5 m/s.

Chapter 3: Methodology

This study tested the expectation that obese children would adopt a similar gait pattern to obese adults, with greater adaptation occurring in obese adults than in obese children since the adults have been obese for a longer period of time. This chapter will describe the procedures that were used in this study.

Subject Selection and Recruitment

This study involved four groups of participants that were divided both by age and by mass. Group 1 consisted of children between the ages of 10 and 16 with a BMI above 30. Group 2 consisted of children between the ages of 10 and 16 with a BMI below 20. Group 3 consisted of adults above age 21 with a BMI greater than 30. Group 4 consisted of lean adults above age 21 with a BMI less than 25.

Recruitment flyers for all participants were placed in local newspapers, electronic bulletin boards, and local group facilities (e.g. health and fitness clubs, swimming pools, churches, etc.). For the children, flyers were also sent home to the parents from the school by obtaining special permission from the Pitt County School Board. Interested participants were then able to call the facility where a phone interview was conducted.

Phone interviews were conducted to determine general demographics, functionality, and medical characteristics of potential subjects. The children's parent was given a simple phone interview to help determine the child's BMI, from age, height and weight. We used the Centers for Disease Control and Prevention BMI Percentile Calculator for Child and Teen website to determine the BMI-for-age percentile. We accepted kids who fell above the 95^{th} percentile for their age. We also screened for musculoskeletal problems, neurological disorders, diabetes, high blood pressure, and respiratory issues. If any of these questions are answered yes, further information is requested to determine if it would interfere with the study results.

The adult phone interview was more in depth to screen for disease or disorders that may occur with age, such as arthritis. The responses to the phone interview questions would then be matched against inclusion and exclusion factors in Tables 1 and 2 respectively. Potentially healthy lean and obese adults will be included in the study if they meet the study requirements, inclusion and exclusion criteria, and answered at an appropriate level to all interview questions. Adult subjects were included in the study if they met the criteria without any other medical issues (See Table 1). Subjects were excluded due to other medical complications to remove the analysis of confounding factors due to disease or dysfunction (See Table 2). Subjects were excluded from the study if s/he had one or more of the exclusion criteria, currently smoked cigarettes, or had a relevant medical condition by answering "Yes" to any medical question. Lean subjects were also excluded if they answer "Mild", "Moderate", "Severe", or "Extreme" to one or more of the questions of pain or difficulty in functional test. Obese subjects were accepted if they answer "Mild" for pain or "Mild" and "Moderate" for mobility difficulty in functional tasks because mobility restriction is an intrinsic characteristic of obesity (Wearing et al. 2006). Potentially healthy lean and obese patients were included in the study if they met the study requirements, inclusion and exclusion criteria, answered at an appropriate level to all interview question questions about difficulty and pain in functional tasks.

Table 1

Obese Adult Inclusion Criteria
• Ages between 21-60 • Male or Female • BMI between 30 to 50 kg/m^2 • WOMAC score < 36

Table 2

Adult Exclusion Criteria	
• Active coronary artery disease (CAD) • Cancer (with past or present history of chemotherapy or radiation treatment) • Congestive Heart Failure (CHF) • Chronic Obstructed Pulmonary Disease (COPD) • Diabetes (Blood Glucose > 126 mg/dL) • Dementia • Heart rhythm other than sinus rhythm • High Blood Pressure (>140/90 mm Hg) • History of current anemia with Hgb below 11.0 • History of multiple falls within the last year • History of renal failure or renal insufficiency with creatinine above 2.0 • History of spinal surgery • Joint injury (ACL, meniscus) but no surgery • Joint replacement in the lower extremity	• Hypertension treated with beta blockers or calcium channel blockers with a resting heart rate < 66 bpm • Joint surgery on the lower extremity • Osteoporosis with vertebral or hip fracture • Pain in the lower extremities from unknown cause • Parkinson's disease or history of stroke • Peripheral neuropathy • Peripheral vascular disease (PVD) • Presence of pacemaker • Rheumatoid arthritis • Use of ambulatory walking aid (cane, walker, etc.) • Visual impairment that restricts independent ambulation and if the person currently smokes or has stopped smoking but has smoking related health problems

Procedure

When subjects arrived to the lab, all were provided written informed consent in accordance to university policy. This written consent discussed the procedures, conditions, and risks to the research study. All subject data remained anonymous and confidential.

Obese adult subjects were then completed the Likert-version of the WOMAC. The Likert-version of the WOMAC was used to access pain (5 items, maximum score 20), stiffness (2 items, maximum score of 8), and physical function (17 items, maximum score 68). There were 5 possible responses listed for each item representing an increasing level of intensity (none, mild, moderate, severe, and extreme) scored 0 to 4. The final score of the WOMAC was tallied by adding the collection of scores for pain, stiffness, and physical function. The higher the score the more likely the patient is to have pain and difficulty due to weight and/or osteoarthritis. This questionnaire has been tested for reliability, validity, and responsive evaluation of knee osteoarthritis (Bellamy et al. 1988). A score less than 36 (24 questions * 1.5: "Mild" and "Moderate") as a cutoff for inclusion for lean and obese adult subjects into the study.

All children and adult subjects were then asked to change into fitted shorts and shirt. The subject would then be fitted with a Helen Hayes marker set for gait trials. Anatomical landmarks were found to identify the subject's pelvis and right leg, including: right and left iliac crest, left and right posterior superior iliac spine, right and left anterior superior iliac spine, right and left greater trochanter, medial and lateral joint line of the knee, medial and lateral malleoli, calcaneous, and the 1st and 5th metatarsal heads. Rigid rectangular plates with 4 markers attached to each corner was placed on the lateral thigh and shank. A rigid plate with 3 markers attached was placed over the midfoot. A five second static trial of the subject in standing anatomical position with arms crossed over the chest was then collected. The calibration markers, medially and laterally of each joint, were then be removed and a static trial without calibration markers was recorded.

All subjects completed level gait trials on a 15-m walkway at 1.5 m/s (all ±5%). Before beginning any level gait trials the subject practiced walking through the environment until they felt comfortable walking. Subjects were instructed on how to walk through the collection volume to ensure proper foot strike placement on the force plate. A research associate modified the starting point for each subject in order for the target foot to naturally strike the center of the force plate. Once five successful trials at self-selected speed were recorded, the subject was then advised of the correct pace to achieve 1.5 m/s (±5%). The subject then practiced walking at the selected speed, about 5 passes with the research associate adjusting the starting point to ensure that the right foot strikes the force plate. Five successful trials were then recorded.

We avoided fatigue by 1) determining if there is a systematic reduction in gait speed from trial-to-trial and 2) determining if step length shortened between first acceptable and last acceptable trials by 20%. If fatigue occurred the subject was retested at a later date. Also, testing was stopped and rescheduled if a subject states that s/he is tired or if the research associate is suspicious that the subject is fatigued. Subjects had the opportunity to rest between trials.

All level walking gait trials were collected using Qualisys Tracking Manager software (Innovision Systems Inc., Columbiaville, MI), a camera motion capture system (ProReflex Motion Capture system, Qualysis Medical AB, Gothenbury, Sweden), a force platform (AMTI Model LG6-4-2000, Newton, MA), and an infrared timing system (Brower timing systems, model IRD-T175, Salt Lake City, Utah). The eight cameras surround a volume of recording space measuring 4 m long by 3 m high by 2 m wide. This space is sufficient for measuring the entire stride (swing and stance phases) in all gait tests. Kinematic data of the right lower extremity and pelvis in 3D were obtained in all subjects at 120 Hz for each trial. Ground reactions forces and moments on the force plate during the stance phase of gait were measured in 3D at 960 Hz. The vertical force channel is routinely calibrated with known weights ranging from 0 to 2100 N. The voltage outputs were highly linear throughout the tested range and the coefficient of determination between force and voltage were $R^2 = 0.999$. The timing gates were placed 1.5 m on either side of the force platform and measured the time required for the subjects to walk this interval. Trials were discarded if the subject walked more than 5% faster or slower than the required pace, if the test foot does not fully make contact with the force platform, or if the subject takes a visually unusual step to, "target," the force platform.

Data Analysis

Motion analysis in 3D is performed on the 15 tracking markers system and 1 force plate platform. This analysis focuses on movement of the right leg and during level walking. The data was reduced using the Qualysis Track Manager software (Innovision Systems Inc., Columbiaville, MI) that produced the position data for all trials of every subject in the global coordinate system. Using the static trial, we created a model to locate the virtual joint centers, segment center of masses, define the local coordinate system of each segment, and calculated a transformation matrix to determine the location of all markers in the global coordinate system. We processed the digitized Cartesian coordinates of the 15 reflective markers describing the stance phase on the force platform through a low-pass digital filter that automatically selected the cut-off frequency based on Winter's Method (Winter 1990). The mean cut-off frequency was about 6.0 Hz. We computed linear velocity and acceleration for each point during the stance phase followed the computation of joint angular position and velocity at the hip, knee, and ankle. The temporal and spatial gait characteristics are step width (m), stride length (m), walking velocity (m/s), cadence (steps/min), support time (%), nonsupport time (%), and double-support time (%). Joint angular positions are peak flexion and extension values, range of motion, average position over the stance phase (all in degrees) and joint angular velocity in the sagittal plane (deg/s). In the frontal plane, we computed knee adduction and abduction as measured of dynamic knee alignment during gait. Such instrumentation and processing of raw kinematic data yields resolutions of 1 degree orientation and 1 mm position (Antonsson, 1989).

Joint torques and powers were computed using Visual 3D (C-Motion Inc., Rockville, MD) through inverse dynamics. Joint reaction forces and torques were calculated using linear and Angular Newton-Euler equations of motion throughout the stance phase of the lower extremity. Magnitude of the segmental masses, their moments of inertia, and the locations of the mass centers were estimated from the position data using anthropometric data (Lu & O'Connor, 1999) and the individual subject's anthropometric data (i.e. body mass). Ground reaction forces and moments on the force platform were used to calculate the center of pressure and the point location of the ground reaction forces. Support torque was calculated as the sum of the joint torques and used to compare the total muscle effort between groups. Torque curves were characterized by calculating the peak extensor and flexor torques at each joint and the angular impulses under the extensor and flexor phases. Abduction torque at the knee was computed in the frontal plane. The torques represent the internal torques produced by the skeletal muscles and other tissues crossing the joints. Positive torques represent net extensor or plantarflexor, internal rotation, and abduction directions.

Statistical Analysis

A four group factorial ANOVA was performed on kinematic and kinetic gait characteristics for age effect, mass effect, and an age by mass interaction effect. A Tukey's post hoc test was also done with a significance level set at $p<0.05$.

Chapter 4: Results

It was expected that the obese child gait would be similar to the obese adult gait, but with some differences based on the time each group has been obese. We expected to see greater adaptation in the obese adults than in obese children since the adults have been obese for a longer amount of time. We tested this expectation by comparing the gait kinematics and kinetics of obese and lean children and adults while walking at a set speed of 1.5 meters per second. This chapter describes the kinetic and kinematic analysis of the data that was collected.

In this chapter interaction effects are identified. The mass effect compared the means between lean and obese groups (pooled across age). The age effect compared the means of between children and adults (pooled across lean and obese groups). The interaction effect identifies a significant difference between all four groups.

Subject Characteristics

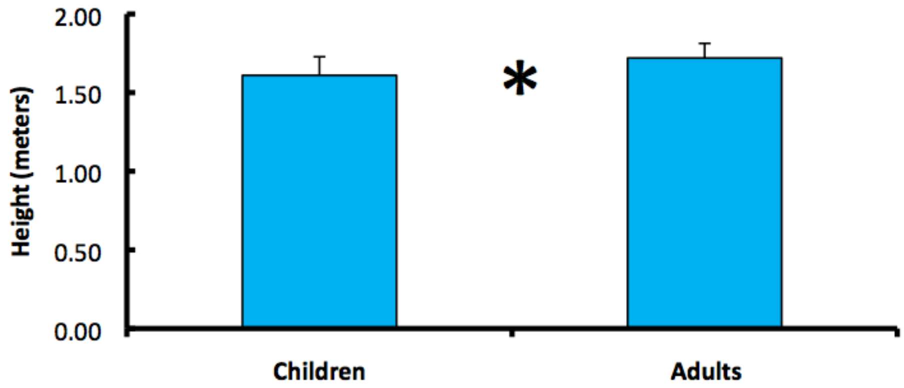
This section is arranged that Appendix A shows the mean and standard deviation of variables in table form that are not included in the text.

The anthropometric characteristics of study participants are listed in Table 1. There was not a significant height difference within children or adult groups, but there was a significant height difference between the children and adult groups (F=13.095, p=0.001), which was expected. Figure 1 shows the significant difference in height between the two groups.

Table 1: Biometric Characteristics of Subjects

	Children		Adult	
Variable	**Obese**	**Lean**	**Obese**	**Lean**
Gender	6M, 6F	7M, 7F	5M, 7F	5M, 7F
Age (yr)	12.8 ± 1.7	12.8 ± 1.6	34.3 ± 7.7	36.8 ± 4.7
Height (m)	1.63 ± 0.1	1.60 ± 0.1	1.72 ± 0.1	1.72 ± 0.1

Figure 1. Age Effect in Height

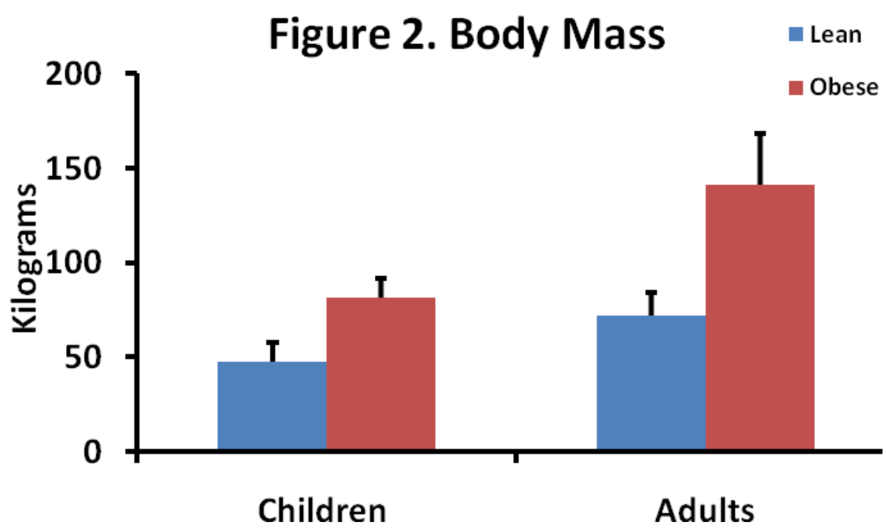


* p<0.05

Table 2 shows the mean and standard deviation for body mass. There was an age by mass interaction in body mass among the four groups (F=15.0, p=0.001): Obese vs lean children were 33.6 kg or 70.4% heavier and obese vs lean adults were 69.3 kg or 96.3% heavier. Figure 2 shows the age by mass interaction in body mass, indicating that obese adults were 74% heavier than obese children compared with their lean counterparts. There were no significant age or mass main effects.

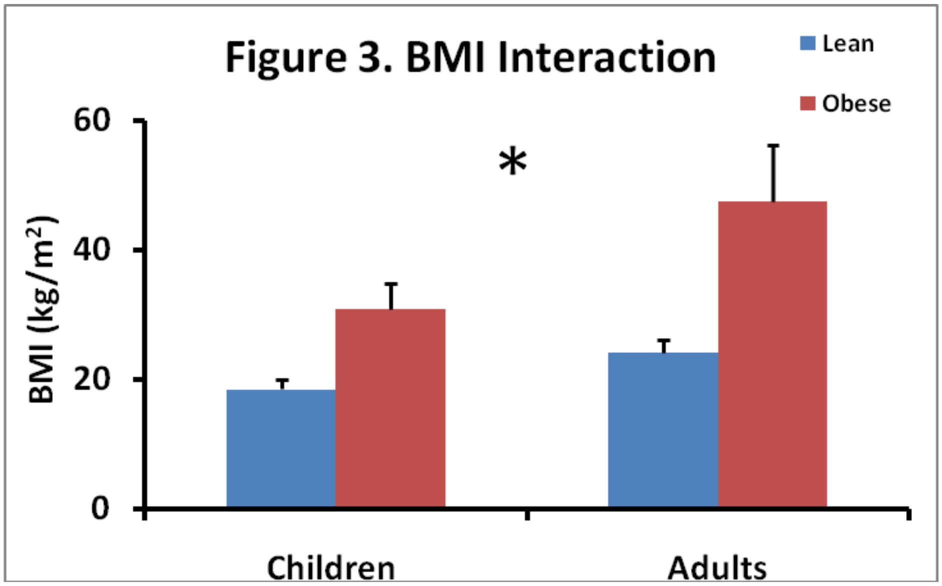
Table 2. Body mass of lean and obese children and adults. *Body Mass in kg.*

Age	Group	Mean	SD	N	F	P
Children	Lean	47.7	10.0	14		
	Obese	81.2	10.8	12		
Adults	Lean	72.0	12.0	12		
	Obese	141.3	27.0	12		
Interaction					15.0	0.001
Mass Effect	Lean	58.9	16.4	26	124.7	0.001
	Obese	111.3	36.7	24		
Age Effect	Children	63.2	19.9	26	84.0	0.001
	Adults	106.7	40.9	24		



* Age by Mass Interaction (p<0.05)

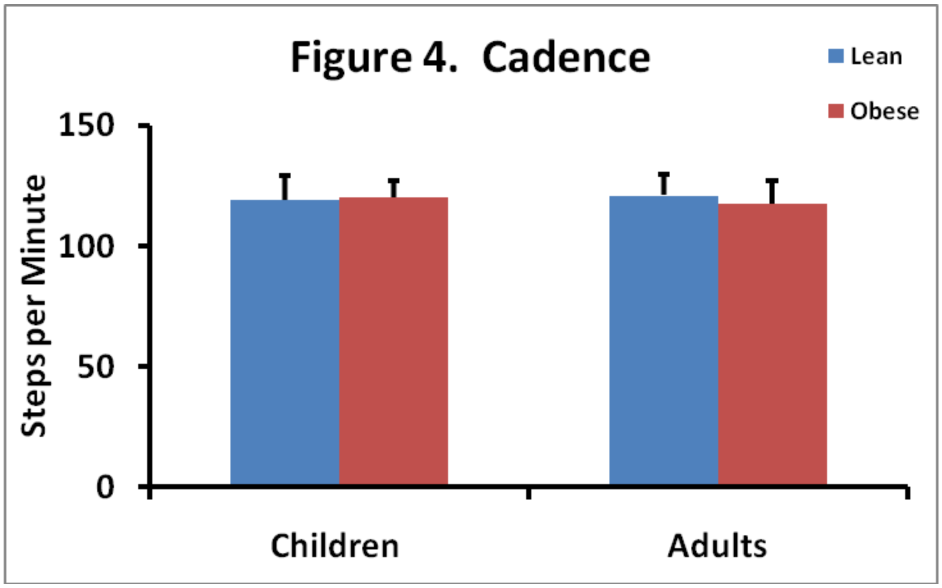
There was an age by mass interaction in BMI among the four groups (F=16.1, p=0.001). There was a 66.8% difference in BMI between obese vs lean children and 96.9% difference in BMI between obese vs lean adults. Figure 3 shows the age by mass interaction of BMI between groups. There were no significant age or mass main effects. There was a significant age main effect between the obese children and adults and the length of time they had been obese (F=14.1, 0.001), which as expected the obese adults have been obese 83% longer than the obese children.

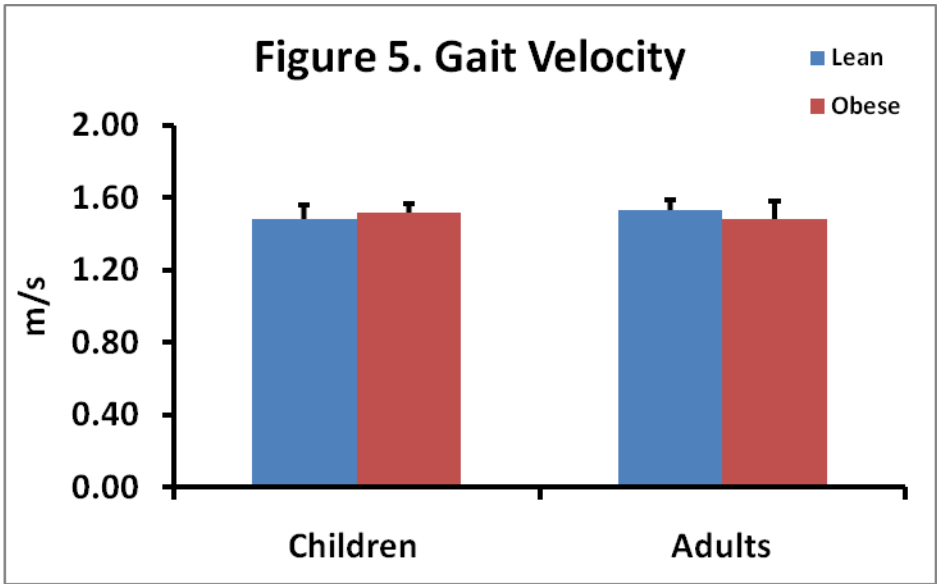


* Age by Mass Interaction ($p<0.05$)

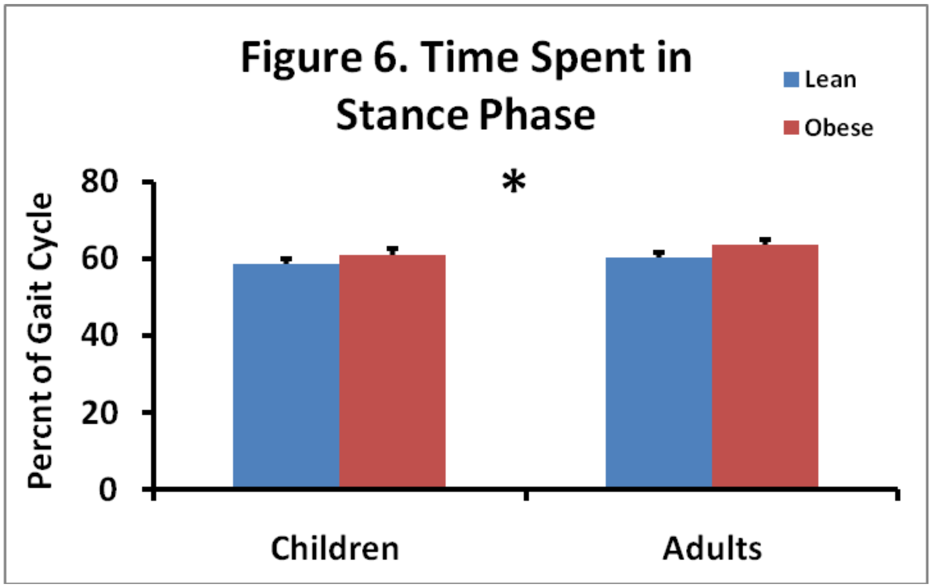
Stride Characterisitcs

This section is organized that Appendix B shows the mean and standard deviation of all variables in table form. There were no significant findings in differences in stride length between lean and obese children and adults. Stride length is one stride characteristic that has been previously recorded to be different in obese vs lean individuals. There were also no significant findings in cadence. Figure 4 shows that obese children walked 1% faster than the lean children, but the obese adults walked 2.8% slower than the lean adults. Figure 5 shows there were no significant differences in gait velocity between the four groups, confirming that we successfully controlled subject's velocity.





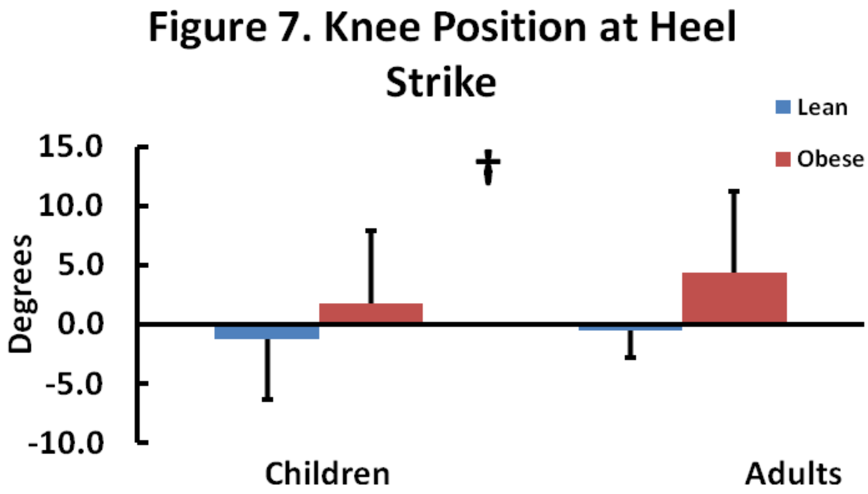
In swing time and stance time there were no age by mass interactions. There was an age and mass main effect in both stance and swing phase time. Figure 6 shows obese individuals spent 4.8% more time in stance phase than lean individuals.



* Age by Mass Interaction (p<0.05)

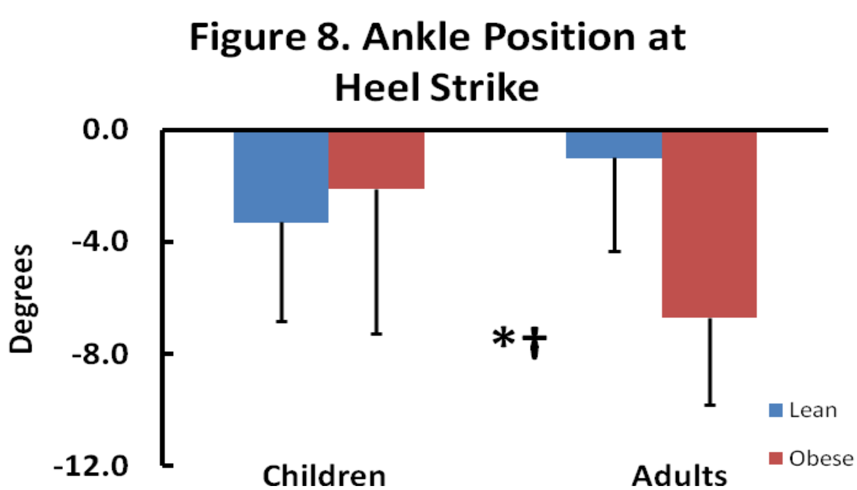
Kinematics

This section is organized that Appendix C shows the mean and standard deviation of all variables in table form. There were no significant main effects in the hip position at heel strike. The knee position at heel strike did show a significant mass main effect (F=7.049, 0.011): Obese groups had a more extended knee at heel strike than their lean counterparts. Figure 7 shows there was no age by mass interaction in knee joint position at heel strike and there was also not an age main effect.



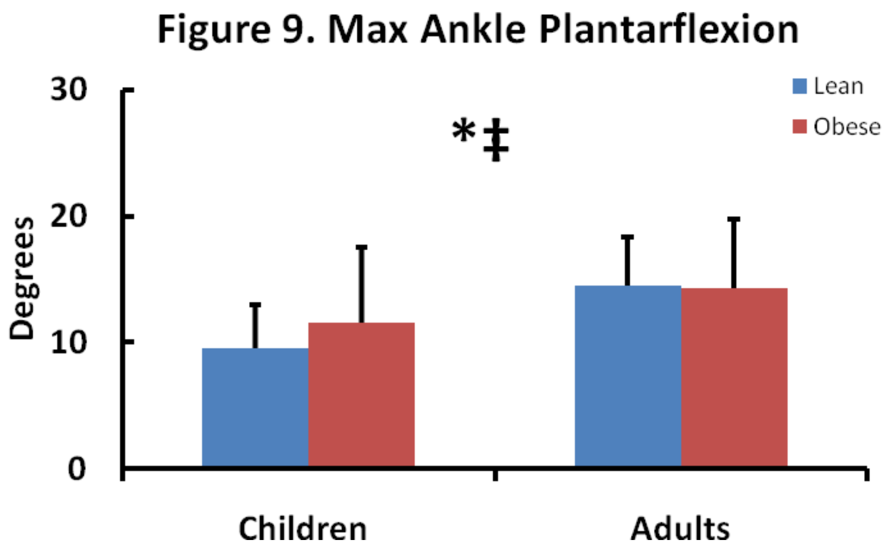
†Mass Main Effect ($p<0.05$)

There was a significant age by mass interaction in ankle position at heel strike ($F=9.400$, $p=0.004$): Obese children were less dorsiflexed at heel strike than lean children vs obese adults being more dorsiflexed at heel strike than lean adults. Figure 8 shows the age by mass interaction of ankle position at heel strike. There was also a significant mass main effect ($F=4.223$, $p<0.046$) in the ankle joint position at heel strike.



*Age by Mass Interaction, †Mass Main Effect ($p<0.05$)

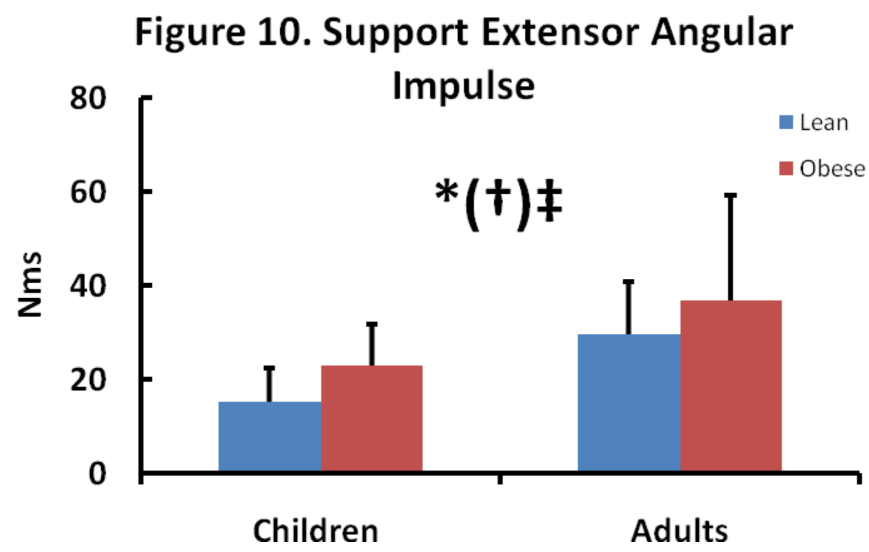
There was no significant differences in maximal hip and knee flexion in any comparisons between groups. The maximal ankle plantarflexion showed there was a significant age main effect between the children and adults (F=7.882, p=0.007). Figure 9 shows the age by mass interaction of maximal ankle plantarflexion: the children walked with 3.9 degrees or -26% less ankle plantarflexion than adults (F=0.729, p=0.398).



*Age by Mass Interaction, ‡ Age Main Effect (p<0.05)

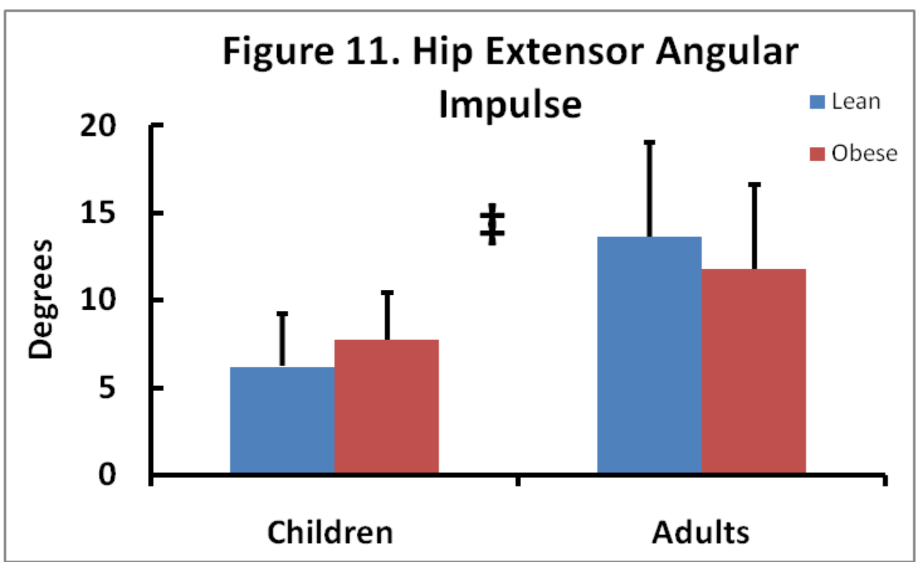
Kinetics

This section is organized that Appendix D shows the mean and standard deviation of all variables in table form. Figure 10 shows that there was an age by mass interaction in support extensor angular impulse among the four groups (F=0.985, p=0.003): Obese vs lean children walked with 50% more support extensor angular impulse and obese vs lean adults walked with 24% more support extensor angular impulse. There was also a significant age main effect (F=13.557, p=0.001) and a borderline mass effect (F=3.772, p=0.058).



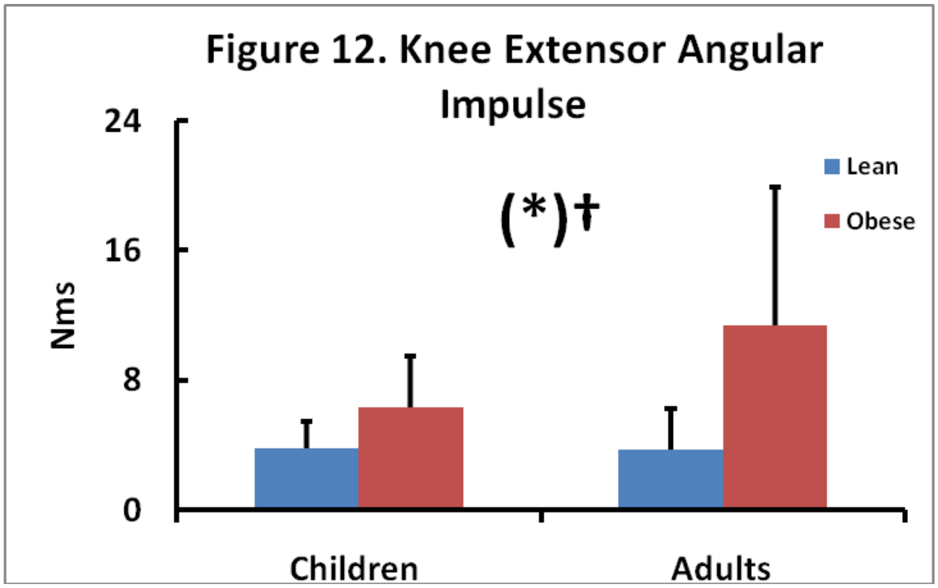
* Age by Mass Interaction (p<0.05), (†) Borderline Mass Main Effect (p=0.058),
‡ Age Main Effect (p<0.05)

There was a significant age main effect (F=24.497, p=0.001) in the hip extensor angular impulse. Children walked with 45.8% less hip extensor angular impulse than adults. There was no significant age by mass interaction or mass main effect. Figure 11 shows the age main effect of hip extensor angular impulse.



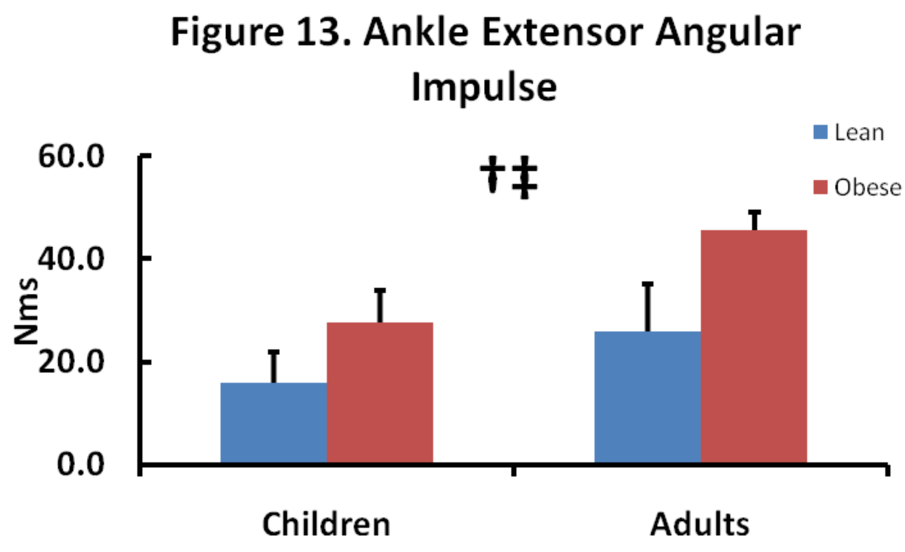
‡ Age Main Effect (p<0.05)

The knee extensor angular impulse showed a borderline age by mass interaction between the four groups (F=3.864, p=0.055). Figure 12 shows obese children had 64.7% more knee extensor angular impulse than lean children and obese adults had 208% more knee extensor angular impulse than lean adults. There was a significant mass main effect (F=14.590, p=0.001).



(*) Borderline Age by Mass Interaction (p=0.055), † Mass Main Effect (p<0.05)

There was no age by mass interaction in ankle plantarflexor impulse, but there was a significant mass main effect (F=36.620, p= 0.001) and age main effect (F=28.592, p=0.001). Figure 13 show obese children walked with 73.4% more ankle plantarflexor angular impulse than lean children and obese adults walked with 76.9% more ankle plantarflexor angular impulse than lean adults.



† Mass Main Effect, ‡ Age Main Effect ($p<0.05$)

Summary

To summarize the significant findings in this section, the obese adults were 96.3% heavier than lean adults and obese children were 70.4% heavier than lean children. Obese adults were obese18 years longer than obese children. Stride characteristics, except for obese subjects spending ~5% more time in stance phase than lean, were similar between obese sub-groups. At heel strike, obese vs lean adults knee was more extended. There was an age by mass interaction in the ankle dorsiflexion at heel strike so that obese children walked with less dorsiflexion than lean but obese vs lean adults walked with more dorsiflexion. A borderline age by mass interaction occurred in the knee extensor angular impulse and there was a mass main effect in knee extensor angular impulse and ankle plantarflexor impulse. Overall, the results confirm the expectation of small differences in kinematics and kinetics between the sub-groups of this study, a finding that underscores rapid gait adaptations to obese children and possibly a small role for time spent being obese.

Chapter 5: Discussion

This study was designed with the purpose of comparing gait characteristics of obese and lean children to the gait characteristics of obese and lean adults during level walking at a fixed speed of 1.5 m/s. This purpose was developed from the expectation that obese children would have similar gait adaptations as obese adults, but with some differences in the magnitude of adaptation found between children and adults based on the time each group has been obese.

Three-dimensional gait analysis comparing lean and obese children and adults walking at a set speed of 1.5 m/s was performed to compare the kinematic and kinetic differences. The results from this comparison will be discussed in the topics: 1) Development of the Expectation, 2) Causes of Differences in Lean and Obese Gait in Children and Adults, 3) Summary and Conclusions. Throughout the Discussion the statistical terms, Age Main Effect, Mass Main Effect, and Age by mass interaction will be used. Respectively, each refers to a difference between children and adults (age effect), lean vs obese (mass effect) and the differences that occur within the child group, between lean and obese, that were not the same differences that occurred within the adult group between lean and obese (age by mass interaction).

Development of the Expectation

Previous literature has shown that there are many kinematic and kinetic gait differences in comparing the gait of lean and obese adults. Obese adults tend to have a slower self-selected speed, decreased stride length, and spend more time in double support phase (DeVita & Hortobagyi, 2003; Browning, Baker, Herron, & Kram, 2006). Obese adults have a more erect posture during stance phase walking with less hip flexion, less knee flexion, and more ankle plantarflexion (DeVita and Hortobagyi, 2003). DeVita and Hortobagyi (2003) found that obese walk with a greater support torque due to larger ankle plantarflexor torque, but walk with similar hip and knee torques despite the greater mass. Previous literature also has shown similar kinematic and kinetic differences when comparing lean and obese gait in children. Obese children spend more time in double support, walk with less knee flexion in stance phase, and have, like adults, increased ankle plantarflexor torques (McGraw, McClenaghan, Williams, Dickerson, & Ward, 2000). By age 7, children have established a heel-strike pattern, knee-flexion wave, reciprocal arm-swing, and adult joint angle patterns (Sutherland, Olshen, Cooper, & Woo, 1980).

From previous literature, it seems that both obese children and adults have some of the same gait adaptations, indicating that obese gait evolves relatively rapidly after or while becoming obese, assuming that duration of children in the previous studies is shorter than that of adults. Thus, the magnitude of adaption in increased mass is expected to be less in obese children's gait. By comparing lean and obese children and adult gait we can test the idea if age and obesity interact. This led us to the expectation that there is an interaction between age and obesity in gait kinematic and kinetics. To test this, a comparison of kinematic and kinetic gait characteristics of obese and lean children and adults was performed during level walking at their preferred speed and at a fixed speed of 1.5 m/s.

Causes of Differences in Lean and Obese Gait in Children and Adults

1. Subject Characteristics

To our knowledge this was the first study to quantify the length of time an individual has been obese. Obese adults reported they had been obese 83% longer than obese children. We used a crude measure of self-reported obesity data by asking obese adults and the parents of obese children, "How long have you or your child been overweight or obese?" Obese adults reported being obese for an average of 18 years, in contrast to parents who replied their children had experienced 3 years of obesity on average. A more reliable measure of length of time is definitely needed, since self-reporting maybe biased due to adults or parents not wanting to admit their struggle with obesity or simply not remembering correctly.

2. Stride Characteristics

There were little differences within or between groups in cadence and velocity showing that our study was well constrained to the 1.5 m/s gait speed. Some studies have found that stride length to be shorter in obese individuals, however in our study there was not a significant age main effect, mass main effect, or age by mass interaction. DeVita and Hortobagyi (2003) support our findings reporting that obese and lean adults walked at a similar step length at a set speed of 1.5 m/s. Browning et al. (2006) found that obese and lean subjects walked with similar step lengths at 6 different speeds. Lai et al (2008) reported at self-selected speeds obese adults walked with shorter stride lengths when stride length was normalized to height. Malatesta et al (2009) reported a 6% shorter stride length in obese adults at a preferred walking speed. Hills et al (1991) and Nantel (2006) both reported that both lean and obese children walked at similar stride lengths. Although stride length is a key descriptor of human gait, including obese gait, there is little consistency in the literature whether obese adults and children use shorter steps than their lean counterparts. Perhaps these inconsistencies are related to the instructions how to walk at either a self-selected speed or set speed. Recent experiments in the Biomechanics Laboratory seem to underscore this statement because when young adults are instructed to walk at a self-selected pace, they often select a speed that is substantially slower than the speed healthy old adults choose, creating the appearance that age does not affect gait speed. Another possibility could be that there is a large variation in the physical (fitness) and psychological (depression) state of the samples in different laboratories, introducing a confounding factor in how such individuals select gait speed (Lemke et al, 2000).

It has been previously noted that both obese children and adults spend more time in stance phase than swing phase compared to their lean counterparts (Lai et al 2008, McGraw et al 2000). In our study, obese children spent 4% more time in stance phase than lean children, and this value is significantly different from the adult group, where obese spent ~6% more time in stance phase than lean adults. This relationship maybe affected by the different mass ratios within the child and adult groups or a result of the length of time obese. Hills et al. (1991) found that obese children spent a greater amount of time in stance phase due to decreased stability. During the stance phase, the center of mass is inside the base of support bounded by both feet increasing the amount of stability, so Nantel et al (2006) thought this to be an adaptation to increase stability. The more time an obese individual spends in double support phase, the less time the large amount of mass has to be supported by a single limb, thereby decreasing muscular effort needed to support the weight (Foti et al, 2000).

3. Kinematics

At heel strike, knee kinematics was similar in all groups with obese subjects being more hyperextended. Quesda et al (2000) found that as backpack load increased, knee extension increased, supporting the data that obese adults walked more hyperextended than obese children versus lean groups, due to the greater mass of the obese adults (96% greater than lean) versus lean children (70% greater than lean).

In contrast to the graded adaptation in knee hyperextension, ankle position at heel strike was opposite relative to lean. Obese adults walked with much more dorsiflexion than lean, but obese children walked with more plantarflexion than lean causing a mass effect. Since obese children do not have the same adaptation as obese adults the greater ankle dorsiflexion may be due to the length of time that the children have been obese.

DeVita and Hortobagyi's (2003) findings in obese adults were similar to the findings here in obese children. The obese adults in this study walked with ~8° less knee flexion in early stance, ~4% less knee flexion throughout stance and ~6% more ankle plantarflexion throughout stance. This increase in knee hyperextension and ankle plantarflexion at heel strike as observed in the obese children maybe an adaptation of walking with a more erect posture (DeVita et al 2003; Hills, 1992). The adaptation maybe an attempt to decrease metabolic cost of walking, as suggest by Browning et al (2007), that the more erect posture reduces muscle force required to support the body. Little age and mass main effect-related differences occurred at hip position at heel strike.

4. Kinetics

Though there were not any significant findings, our data show that obese children in our study walked with greater hip extensor angular impulse than lean, while obese adults walked with less hip extensor angular impulse than lean. The large standard deviation in the hip extensor angular impulse probably prevented our finding of an age by interaction effect. Our findings in the hip are both supported and contradicted by previous literature. The mass difference in our children group was 70% and the increase in hip extensor angular impulse was support by both Browning et al (2007) study, whose difference in lean and obese was 48%, and Foti et al (2000) study, whose difference in pregnancy versus 1 year post partum was 21% (13 kg). The decrease we observed in hip extensor angular impulse in our obese adults is supported by DeVita and Hortobagyi's study (2003) whose difference in mass was 87%, whereas our adult group demonstrated as mass difference of 97%. Further studies may suggest that a mass threshold may exist to cause the decrease in hip impulse or it may be due to the length of time that subjects have been obese.

There was a significant mass main effect in the knee extensor angular impulse due to the obese individuals walking with greater impulse than the lean but within the subgroups there was significantly less adaptation in the obese children than the obese adults. These findings contradict those of DeVita and Hortobagyi's study (2003), whose study concluded that at the same speed obese adults walked with an equal amount knee extensor angular impulse as lean adults though the obese adults were 80% larger.

At the ankle, obese individuals walked with greater extensor angular impulse than lean individuals though the effect was greater in the obese adults than obese children. There was not an age by mass interaction probably due to the large standard deviation.

In contrast to adults, obese versus lean children simply produced more extensor effort to propel the body forward and did not show the reorganization of muscular effort between joints. This was also observed in the obese population used by Browning et al (2007). Browning et el (2007) results showed an increase in hip extensor moment, knee extensor moment, and ankle plantarflexor moment. The percent difference between Browning's lean and obese group was 63.5% which was similar to the percent difference within our children group of 70%. Not knowing the time Browning's subjects were obese, the differences between our adult and child groups may be due to either mass percentage differences or length of time obese differences.

To determine if the neuromuscular adaptation seen in obese adults and children are the result of chronic and not just acute adjustment of gait, the lab conducted a control experiment of 4 healthy young adults who walked at 1.5 m/s with and without 30% mass attached to the trunk with most of the weight located anterior to the abdomen to simulate obesity. The individuals walked a bit more extended with an increase in knee torque in early stance and ankle torque at late stance producing an increase in support torque throughout stance phase. To counteract the increase in knee torque individuals reduced knee flexion and extension velocities. These healthy adults displayed changes in gait to adjust to the increase in mass, confirming that acute changes in gait may take place due to obesity.

Previously, obese versus lean adults walked with similar hip extensor torque (DeVita et al 2003) and presently obese adults walk with eve less hip extensor torque, but have increased knee and ankle torque. DeVita and Hortobagyi (2003) found the shift of muscle effort distally to the ankle was not due to pain in their study, since all subjects reported being pain-free, but due to neuromuscular function with aging. We administered the WOMAC to our subjects as a way to measure the amount of pain they had with daily activities of living. All obese adults tested had a score of less than 36 on the modified WOMAC, suggesting they were free of pain and other complications. The modified WOMAC was concluded by Yang (2007, J Bone Jt Surg Br, 89, 1, 50) to be a valid method of evaluating pain. The distal shift observed in the obese adults is opposite than the proximal shift observed in aging individuals. The proximal shift of greater hip angular impulse (DeVita & Hortobagyi, 2000) in aging is likely to be a compensatory mechanism for decreased strength and function of distal joints. However, obese adults develop greater muscular strength in the lower extremity from having to propel their larger mass, which may change the neuromuscular adaptations they will experience with aging.

Obese children do not exhibit the same distal shift of angular impulse to the ankle. Obese children walked with more hip extensor torque. This difference maybe an adaptation that occurs with increasing length of time obese, both in both data sets obese shifted muscle effort distally, to the ankle, but walked with more knee extensor effort.

Summary and Conclusions

It seems that adaptations in gait due to obesity are different in children than adults even with gait being constrained to 1.5 m/s. In general, obese individuals spend more time in stance phase than lean individuals, confirming previous findings. At heel strike, knee kinematics were similar in all groups, but all obese subjects were hyper-extended, with more hyperextension occurring in adults, confirming previous data of a more erect obese gait. In contrast to the graded adaptation in knee hyper-extension, ankle position at heel strike in obese was the opposite relative to lean: less dorsiflexion in children and more dorsiflexion in adults.

There were no significant adaptations to obesity in hip extensor torques, but obese did shift muscle effort distally to the ankle, as in previous literature (DeVita & Hortobagyi, 2003). Obese in this study did walk with more knee extensor effort than in other studies. The magnitude of adaptation in kinetics was similar in children and adults at the hip and ankle joint but adults' adaptation was significantly greater at the knee. It is possible that the unique neuromuscular adaptations in obese gait in children and adults are due to adults being obese for a longer time than children. Future research will have to include lean and obese individuals along the age and obesity continuum for a more accurate determination of how the interaction between age and obesity evolves.

This interaction is not due to an interaction of body mass between the four groups and signifies different neuromuscular adaptations to obesity in children and adults. Perhaps obese adults had a longer time to develop the hallmarks of obese gait.

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Appendix A: Subject Characteristics

Table 1. Summary of Subject Characteristics

	Children		Adult	
Variable	**Obese**	**Lean**	**Obese**	**Lean**
Gender	6M, 6F	7M, 7F	5M, 7F	5M, 7F
Age (year)*	12.8 ± 1.7	12.8 ± 1.6	34.3 ± 7.7	36.8 ± 4.7
Height* (meters)	1.63 ± 0.1	1.60 ± 0.1	1.72 ± 0.1	1.72 ± 0.1

*Age Effect, p<0.001

Table 2. Body mass of Lean and Obese Children and Adults.

Age	Group	Mean	SD	N	F	P
Children	Lean	47.7	10.0	14		
	Obese	81.2	10.8	12		
Adults	Lean	72.0	12.0	12		
	Obese	141.3	27.0	12		
Interaction					15.0	**0.001**
Mass Effect	Lean	58.9	16.4	26	124.7	**0.001**
	Obese	111.3	36.7	24		
Age Effect	Children	63.2	19.9	26	84.0	**0.001**
	Adults	106.7	40.9	24		

Body Mass in kg.

Table 3. BMI of Lean and Obese Children and Adults.

Age	**Group**	**Mean**	**SD**	**N**	**F**	**P**
Children	Lean	18.5	1.5	14		
	Obese	30.8	3.9	12		
Adults	Lean	24.1	1.9	12		
	Obese	47.5	8.8	12		
Interaction					16.097	**0.001**
Mass Effect	Lean	21.1	3.3	26	167.69	**0.001**
	Obese	39.1	10.8	24		
Age Effect	Children	24.1	6.9	26	66.197	**0.001**
	Adults	35.8	13.5	24		

BMI in kg/m^2.

Table 4. Time Obese for Children and Adults

Age	**Mass**	**Mean**	**SD**	**N**	**F**	**P**
Children	Obese	3	3.11	8		
Adults	Obese	18	10.74	12		
Age Effect	Obese	11	11.2	20	14.068	0.001

Appendix B: Stride Characteristics

Table 1. Stride Length in Lean and Obese Children and Adults

Age	Group	Mean	SD	N	F	P
Children	Lean	1.50	0.14	14		
	Obese	1.51	0.09	12		
Adults	Lean	1.52	0.09	12		
	Obese	1.52	0.14	12		
Interaction					0.089	0.767
Mass Effect	Lean	1.51	0.12	26	0.005	0.944
	Obese	1.51	0.11	24		
Age Effect	Children	1.50	0.11	26	0.276	0.602
	Adults	1.52	0.12	24		

Stride Length in meters.

Table 2. Cadence in Lean and Obese Children and Adults

Age	Group	Mean	SD	N	F	P
Children	Lean	119	10	14		
	Obese	121	7	12		
Adults	Lean	121	9	12		
	Obese	117	9	12		
Interaction					0.957	0.333
Mass Effect	Lean	120	9	26	0.133	0.717
	Obese	119	8	24		
Age Effect	Children	120	9	26	0.158	0.693
	Adults	119	9	24		

Cadence measured in steps per minute.

Table 3. Velocity in Lean and Obese Children and Adults

Age	Group	Mean	SD	N	F	P
Children	Lean	1.48	0.08	14		
	Obese	1.52	0.05	12		
Adults	Lean	1.53	0.06	12		
	Obese	1.48	0.10	12		
Interaction					3.006	0.090
Mass Effect	Lean	1.51	0.07	26	0.594	0.445
	Obese	1.50	0.08	24		
Age Effect	Children	1.50	0.07	26	0.271	0.606
	Adults	1.51	0.08	24		

Velocity measured in meters per second.

Table 4. Swing Phase in Lean and Obese Children and Adults

Age	Group	Mean	SD	N	F	P
Children	Lean	41.3	1.1	14		
	Obese	39.0	1.5	12		
Adults	Lean	39.8	1.2	12		
	Obese	36.4	1.4	12		
Interaction					2.262	0.139
Mass Effect*	Lean	40.6	1.4	26	60.762	0.001
	Obese	37.7	2.0	24		
Age Effect*	Children	40.3	1.8	26	30.662	0.001
	Adults	38.1	2.2	24		

Swing phase measured as a percent of gait cycle. *, $p<0.001$

Table 4. Stance Phase in Lean and Obese Children and Adults

Age	Group	Mean	SD	N	F	P
Children	Lean	58.7	1.1	14		
	Obese	61.0	1.5	12		
Adults	Lean	60.2	1.2	12		
	Obese	63.6	1.4	12		
Interaction					2.232	0.142
Mass Effect*	Lean	59.4	1.4	26	60.719	0.001
	Obese	62.3	2.0	24		
Age Effect*	Children	59.7	1.8	26	30.665	0.001
	Adults	61.9	2.2	24		

Stance phase measured as a percent of gait cycle. *, $p<0.001$

Appendix C: Kinematic Data

Table 1. Hip Joint Position at Heel Strike

Age	Group	Mean	SD	N	F	P
Children	Lean	-25.7	4.8	14		
	Obese	-27.7	5.5	12		
Adults	Lean	-25.1	2.3	12		
	Obese	-25.6	3.9	12		
Interaction					0.384	0.538
Mass Effect	Lean	-25.4	3.8	26	1.022	0.317
	Obese	-26.6	4.8	24		
Age Effect	Children	-26.7	5.1	26	1.339	0.253
	Adults	-25.3	3.1	24		

Joint position measured in degrees. Negative values are flexed positions.

Table 2. Knee Joint Position at Heel Strike

Age	Group	Mean	SD	N	F	P
Children	Lean	-1.3	5.0	14		
	Obese	1.8	6.0	12		
Adults	Lean	-0.5	2.4	12		
	Obese	4.4	6.8	12		
Interaction					0.390	0.535
Mass Effect*	Lean	-0.9	4.0	26	7.049	0.011
	Obese	3.1	6.4	24		
Age Effect	Children	0.1	5.6	26	1.243	0.271
	Adults	1.9	5.6	24		

Joint position measured in degrees. Positive values are extended positions and negative values are flexed positions. *, $p<0.011$.

Table 3. Ankle Joint Position at Heel Strike

Age	Group	Mean	SD	N	F	P
Children	Lean	-3.3	3.5	13		
	Obese	-2.1	5.2	12		
Adults	Lean	-1.0	3.3	12		
	Obese	-6.7	3.1	12		
Interaction*					9.470	0.004
Mass Effect**	Lean	-2.2	3.5	25	4.223	0.046
	Obese	-4.4	4.8	24		
Age Effect	Children	-2.7	4.3	25	1.121	0.295
	Adults	-3.9	4.3	24		

Joint position measured in degrees. Negative values are dorsiflexed positions.
*, $p<0.01$. **, $p<0.05$.

Table 4. Maximal Hip Flexion

Age	Group	Mean	SD	N	F	P
Children	Lean	-26.2	4.8	14		
	Obese	-27.9	5.6	12		
Adults	Lean	-25.5	2.4	12		
	Obese	-26.0	3.7	12		
Interaction					0.259	0.614
Mass Effect	Lean	-25.9	3.8	26	0.897	0.349
	Obese	-27.0	4.7	24		
Age Effect	Children	-27.0	5.1	26	0.125	0.294
	Adults	-25.8	3.1	24		

Joint position measured in degrees. Negative values are flexed positions.

Table 5. Maximal Knee Flexion

Age	Group	Mean	SD	N	F	P
Children	Lean	-17.2	6.2	14		
	Obese	-16.0	7.3	12		
Adults	Lean	-17.3	4.0	12		
	Obese	-12.9	7.2	12		
Interaction					0.806	0.374
Mass Effect	Lean	-17.3	5.2	26	2.476	0.122
	Obese	-14.4	7.3	24		
Age Effect	Children	-16.6	6.6	26	0.700	0.407
	Adults	-15.1	6.1	24		

Joint position measured in degrees. Negative values are flexed positions.

Table 6. Maximal Ankle Plantarflexion

Age	Group	Mean	SD	N	F	P
Children	Lean	9.5	3.5	13		
	Obese	11.6	5.9	12		
Adults	Lean	14.5	3.9	12		
	Obese	14.3	5.4	12		
Interaction					0.729	0.398
Mass Effect	Lean	11.9	4.4	25	0.499	0.484
	Obese	12.9	5.7	24		
Age Effect*	Children	12.9	4.8	25	7.882	0.007
	Adults	14.4	4.6	24		

Joint position measured in degrees. Positive values are plantarflexed positions.

*, $p<0.05$

Appendix D: Kinetic Data

Table 1. Support Extensor Angular Impulse

Age	Group	Mean	SD	N	F	P
Children	Lean	15.3	7.3	14		
	Obese	23.0	8.9	12		
Adults	Lean	29.6	11.2	12		
	Obese	36.9	22.3	12		
Interaction*					0.985	0.003
Mass Effect(*)	Lean	21.9	11.7	26	3.772	0.058
	Obese	29.9	18.1	24		
Age Effect**	Children	18.8	8.8	26	13.557	0.001
	Adults	33.2	17.6	24		

Angular impulse measured in Newton meters per second. *, $p<0.05$. **, $p<0.001$.
(*), $p<0.058$

Table 2. Hip Extensor Angular Impulse

Age	Group	Mean	SD	N	F	P
Children	Lean	6.2	3.0	14		
	Obese	7.7	2.7	12		
Adults	Lean	13.6	5.4	12		
	Obese	11.8	4.8	12		
Interaction					1.974	0.167
Mass Effect	Lean	9.6	5.6	26	0.020	0.888
	Obese	9.8	4.4	24		
Age Effect*	Children	6.9	2.9	26	24.497	0.001
	Adults	12.7	5.1	24		

Angular impulse measured in Newton meters per second. *, $p<0.001$

Table 3. Knee Extensor Angular Impulse

Age	Group	Mean	SD	N	F	P
Children	Lean	3.8	1.6	14		
	Obese	6.3	3.2	12		
Adults	Lean	3.9	2.5	12		
	Obese	11.4	8.5	12		
Interaction (*)					3.864	0.055
Mass Effect*	Lean	3.7	2.1	26	14.59	0.001
	Obese	8.9	6.8	24		
Age Effect (**)	Children	5.0	2.7	26	3.514	0.067
	Adults	7.6	7.3	24		

Angular impulse measured in Newton meters per second. *, p<0.001. (*), p<0.55.
(**), p<0.067.

Table 4. Ankle Plantarflexion Angular Impulse

Age	Group	Mean	SD	N	F	P
Children	Lean	15.9	6.0	14		
	Obese	27.6	6.3	12		
Adults	Lean	25.8	9.4	12		
	Obese	45.6	3.5	12		
Interaction					2.431	0.126
Mass Effect *	Lean	20.5	9.1	26	26.6	0.001
	Obese	36.6	13.8	24		
Age Effect *	Children	21.3	8.5	26	28.592	0.001
	Adults	35.7	15.2	24		

Angular impulse measured in Newton meters per second. *, p<0.001.

Appendix E: IRB Approval and Consent Forms

EAST CAROLINA UNIVERSITY
University & Medical Center Institutional Review Board Office
1L-09 Brody Medical Sciences Building• 600 Moye Boulevard • Greenville, NC 27834
Office **252-744-2914** • Fax **252-744-2284** • **www.ecu.edu/irb**

TO: Tibor Hortobagyi, PhD, Dept. of EXSS, ECU-332 A Ward Sports Medicine Building

FROM: UMCIRB

DATE: April 19, 2010

RE: Expedited Continuing Review of a Research Study

TITLE: "Gait Analysis in Obesity"

UMCIRB #05-0540

The above referenced research study was initially reviewed and approved by expedited review on 11/11/2005. This research study has undergone a subsequent continuing review using expedited review on 04/15/2010. This research study is eligible for expedited review because it is a collection of data through non-invasive procedures (not involving general anesthesia or sedation) routinely employed in clinical practice, excluding procedures involving x-rays or microwaves. Where medical devices are employed, they must be learned/approved for marketing. (Studies intended to evaluate the safety and effectiveness of the medical device are not generally eligible for expedited review, including studies of cleared medical devices for new indication.). Examples: (a) physical sensors that are applied, whether to the surface of the body or at a distance, and do not involve input of significant amounts of energy into the subject or significant amounts of energy into the subject or an invasion of the subject's privacy; (b) weighing or testing sensory acuity; (c) magnetic resonance imaging; (d) electrocardiography, electroencephalography, thermography, detection of naturally occurring radioactivity, electroretinography, ultrasound, diagnostic infrared imaging, Doppler blood flow, and echocardiography; (e) moderate exercise, muscular strength testing, body composition assessment, and flexibility testing where appropriate given the age, weight, and health of the individual.

The Chairperson (or designee) deemed this **unfunded** study **no more than minimal risk** requiring a continuing review in **12 months**. Changes to this approved research may not be initiated without UMCIRB review except when necessary to eliminate an apparent immediate hazard to the participant. All unanticipated problems involving risks to participants and others must be promptly reported to the UMCIRB. The investigator must submit a continuing review/closure application to the UMCIRB prior to the date of study expiration. The investigator must adhere to all reporting requirements for this study.

The above referenced research study has been given approval for the period of **04/15/2010** to **04/14/2011**. The approval includes the following items:

- Continuing Review Form (dated 04/08/2010)
- Informed Consent – Adult
- Informed Consent – Children
- Minor Assent

The Chairperson (or designee) does not have a conflict of interest on this study.

The UMCIRB applies 45 CFR 46, Subparts A-D, to all research reviewed by the UMCIRB regardless of the funding source. 21 CFR 50 and 21 CFR 56 are applied to all research studies under the Food and Drug Administration regulation. The UMCIRB follows applicable International Conference on Harmonisation Good Clinical Practice guidelines.

IRB00000705 East Carolina U IRB #1 (Biomedical) IORG0000418
IRB00003781 East Carolina U IRB #2 (Behavioral/SS) IORG0000418
IRB00004973 East Carolina U IRB #4 (Behavioral/SS Summer) IORG0000418
Version 3-5-07

UMCIRB # 05-0540
Page 1 of 1

Biomechanics Laboratory
Tibor Hortobágyi, PhD
252.737.4564

Paul DeVita, PhD
252.737.4563

332 Ward Sports Medicine Building
East Carolina University
Greenville, NC 27858

Consent To Participate in the Research Project:
Gait Analysis in Obesity - Adults

I am being asked to voluntarily participate in this research project conducted by Tibor Hortobágyi, Ph.D. and Paul DeVita, Ph.D. The **purpose** of this study is to determine how children and adults who are light or heavy walk. Depending on how much I am interested in the study, I have the opportunity to volunteer for one or more 2-hour long sessions. There will be approximately 100 participants in this study over several years.

I understand that I must voluntarily agree to participate in this study. I understand that I may not participate in this study if I have certain medical conditions. I will not be able to take part in the study if one of my legs is longer than the other leg, I was born with cerebral palsy, my feet have grown abnormally (for example, club foot), have had a stroke, have: cancer, glucose levels higher than 126 mg/dL, blood pressure higher than 140/90, abnormal heart rhythms, a joint replaced in my leg, osteoporosis, pain in legs from unknown cause, peripheral neuropathy, peripheral vascular disease, low red blood cell count, a history of multiple falls, a history of spinal surgery, a pacemaker, a cane to walk, visual impairment that hinders my gait, and my body weight does not meet study requirements.

Procedures: I will be involved in the procedures that are indicated with a check (√) mark:

Preparation: The preparation lasts about 30 minutes. In the laboratory, I will be asked to put on shorts that will be provided, T shirt, and wear a comfortable pair of athletic shoes with white socks (tennis, running shoes are acceptable). (I can bring my own clothing as well.) I will be asked to kick a ball 3 times to determine which leg is the dominant leg. About 25 reflective markers will be attached to the clothing or taped on the skin. These markers look like tiny balls and brightly reflect light. Finally, 9, small self-adhesive electrodes will be placed on the muscles of the front and back of thigh and leg. These electrodes detect the activity of muscles.

Walking tests: These tests last about 1 hour and 20 minutes. I will have the opportunity to practice each task until I feel comfortable to perform them. I will practice to walk at a given speed and step with my dominant leg on a metal plate that measures the forces under the foot.

______ One task will be to simply walk at a pace I choose.

______ For the second task, one of the staff persons in the laboratory will tell me how fast to walk. This pace will be probably a little bit faster than the pace in the first task.

______ In the third task I will be asked to jog.

______ The fourth task is to climb a stairwell of 4 steps and then descent the same stairwell.

______ Finally, I may be asked to walk up and down on an incline surface (like a ramp).

I will be asked to perform each task 5 times, totaling about 30-40 trials. The distance I will walk is about 20 feet in each task. I can sit down and rest between tasks or trials.

 Subject's Initials ________

______ <u>Leg strength test.</u> This test lasts about 10 minutes. I will be asked to perform this test either before or after the walking tests. Leg strength will be measured on machine that looks like a leg press in a gym. I will sit on the seat of this special leg press machine. Comfortable straps will be put around the trunk, hips, and dominant leg to help me give a good effort. The ankle of the dominant leg will be strapped to a padded cuff. I will practice a few times using mild, medium, and strong efforts to press with my leg into the footplate of the machine. After a few minutes of rest, I will be asked to exert as hard as I can for 5 seconds. I will rest for 1 minute and repeat the effort 2 more times with 1 minute of rest between efforts. Neither the machine nor my leg will move.

Risks: Any tests that require maximal effort represent risks in terms of high blood pressure, stroke, heart attack, temporary pain, and muscle strain or joint sprain. Such test is the Leg Strength Test. The Walking tests represent low risks although during rapid walking temporary breathlessness or dizziness may develop. Ascending and especially descending stairs can be hazardous for individuals who are heavy and cannot fully see the steps. All these risks will be reduced by: allowing me to participate only if I feel comfortable performing the tasks; by carefully explaining and demonstrating the tasks, and by having me properly warmed up for and thoroughly familiarized with the tests.

Benefits: All results will be explained to me. If I am interested in being counseled on the health benefits of physical activity, the laboratory staff will make every effort to freely refer me to an ongoing physical activity program on the ECU campus or elsewhere. I will be entitled to receive $25 per session. The payment will be available to me upon the completion of the study or will be prorated in proportion to the extent of participation.

Withdrawal, Injury, Confidentiality: The nature and purpose of the procedures, the known risks involved, and the possibility of complications have been explained to me and I understand them. I understand that not all risks and side effects of these procedures are foreseeable.

I understand that participation in this study is voluntary and refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled. I may discontinue participation at any time without penalty. The policy of East Carolina University does not provide for compensation or medical treatment for subjects because of physical or other injury resulting from this research activity. However, every effort will be made to make the facilities of the School of Medicine available for treatment in the event of such physical injury.

I understand that my personal data will be held in strict confidence by the investigators. I understand that if any publications result from this study my name or any identifiable codes will not be used. This experiment does not produce any "video" image of my face or body. The recording equipment is sensitive only to the reflective markers and does not record, digitally or in any other form, my face or body.

Contact person. If I have any questions about the research or possible research-related injury, I may contact Dr. Hortobágyi at home (252.355.7715) or work (252.737.4564). Also, if questions arise about my rights as a research subject, I may contact the Chair of the University and Medical Center Institutional Review Board (252.744.2914).

I have read the above material and Dr. Hortobágyi has it explained to me. I have been encouraged to ask questions about the study and all inquiries have been answered to my satisfaction. I will receive a copy of this consent form.

UMCIRB APPROVED FROM 4/15/2010 TO 4/14/2011

Subject's Name (Print)	Signature of Subject	Date
Witness's Name (Print)	Signature of Witness	Date
Principal Investigator's Name (Print)	Signature of PI	Date

Biomechanics Laboratory
Tibor Hortobágyi, PhD
252.737.4564

Paul DeVita, PhD
252.737.4563

332 Ward Sports Medicine Building
East Carolina University
Greenville, NC 27858

**Consent To Participate in the Research Project:
Gait Analysis in Obesity - Children**

My child is being asked to voluntarily participate in this research project conducted by Tibor Hortobágyi, Ph.D. and Paul DeVita, Ph.D. The **purpose** of this study is to determine how children who are light or heavy walk. Depending on how much my child is interested in the study, my child have the opportunity to volunteer for one, 2-hour long session or for two sessions, 2 hours each conducted about 2 weeks apart. There will be approximately 100 participants in this study over several years.

My child understands that s/he must voluntarily agree to participate in this study. As a parent or guardian I will help my child to decide whether s/he should participate or not. My child understands that s/he may not participate in this study if s/he has certain medical conditions. For example, my child will not be able to take part in the study if one of her/his legs is longer than the other leg, was born with cerebral palsy, has had a stroke, her/his feet have grown abnormally (for example, club foot), or her/his body weight happens to be in a specific range (between 85^{th} and 95^{th} percentile for age and gender).

Procedures: My child will be involved in the procedures that are indicated with a check (√) mark:

Preparation: The preparation lasts about 30 minutes. In the laboratory, my child will be asked to put on black bicycle shorts that will be provided, T shirt, and wear a comfortable pair of athletic shoes with white socks (tennis, running shoes are acceptable). My child will be asked to kick a ball 3 times to determine which leg is the dominant leg. About 25 reflective markers will be attached to the clothing or taped on the skin. These markers look like tiny balls and brightly reflect light. Finally, 9, small self-adhesive electrodes will be placed on the muscles of the front and back of thigh and leg. These electrodes detect the activity of muscles.

Walking tests: These tests last about 1 hour and 20 minutes. My child will have the opportunity to practice each task until s/he feels comfortable to perform them. My child will practice to walk at a given speed and step with her/his dominant leg on a metal plate that measures the forces under the foot.

_____One task will be to simply walk at a pace my child chooses.

_____For the second task one of the staff persons in the laboratory will tell my child how fast to walk. This pace will be probably a little bit faster than the pace in the first task.

_____In the third task my child be asked to jog. The fourth task is to climb a stairwell of 4 steps and then descent the same stairwell.

_____Finally, my child will be asked to walk up and down on an incline surface (like a ramp). S/he will be asked to perform each task 5 times, totaling about 30-40 trials. The distance s/he will walk is about 20 feet in each task. My child can sit down and rest between tasks or trials.

_____ Leg strength test. This test lasts about 10 minutes. My child may be asked to perform this test either before or after the walking tests. Leg strength will be measured on machine that looks like a leg press in a gym. My child will sit on the seat of this special leg press machine. Comfortable straps will be put around the trunk, hips, and dominant leg to help my child give a good effort. The ankle of the dominant leg will be strapped to a padded cuff.

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Subject's Initials ________

My child will practice a few times using mild, medium, and strong efforts to press with her/his leg into the footplate of the machine. After a few minutes of rest, my child will be asked to exert as hard as s/he can for 5 seconds. S/he will rest for 1 minute and repeat the effort 2 more times with 1 minute of rest between efforts. Neither the machine nor my leg will move.

Risks: Any tests that require maximal effort represent risks in terms of high blood pressure, stroke, heart attack, temporary pain, and muscle strain or joint sprain. Such test is the Leg Strength Test. The Walking tests represent low risks although during rapid walking temporary breathlessness or dizziness may develop. Ascending and especially descending stairs can be hazardous for individuals who are heavy and cannot fully see the steps. All these risks will be reduced by: allowing children to participate who have been previously cleared by their parents or guardians; carefully explaining and demonstrating the tasks, and by having subjects properly warmed up for and thoroughly familiarized with the tests.

Benefits: All results will be explained to me and to my child. If I am or my child is interested in being counseled on the health benefits of physical activity, the laboratory staff will make every effort to freely refer my child to an ongoing physical activity program on the ECU campus or elsewhere. My child will be entitled to $25 if s/he participates in one session and $50 if s/he participates in two sessions. The payment will be available to my child upon the completion of the study or will be prorated in proportion to the extent of participation.

Withdrawal, Injury, Confidentiality: The nature and purpose of the procedures, the known risks involved, and the possibility of complications have been explained to me and to my child and my child understands them. My child understands that not all risks and side effects of these procedures are foreseeable.

My child understands that participation in this study is voluntary and refusal to participate will involve no penalty or loss of benefits to which my child is otherwise entitled. My child may discontinue participation at any time without penalty. The policy of East Carolina University does not provide for compensation or medical treatment for subjects because of physical or other injury resulting from this research activity. However, every effort will be made to make the facilities of the School of Medicine available for treatment in the event of such physical injury.

My child understands that her/his personal data will be held in strict confidence by the investigators. My child understands that if any publications result from this study my name or any identifiable codes will not be used. This experiment does not produce any "video" image of my child's face or body. The recording equipment is sensitive only to the reflective markers and does not record, digitally or in any other form, my child's face or body.

Contact person. If my child has any questions about the research or possible research-related injury, my child may contact Dr. Hortobágyi at home (252.355.7715) or work (252.737.4564). Also, if questions arise about my child's rights as a research subject, I may contact the Chair of the University and Medical Center Institutional Review Board (252.744.2914).

As the parent or guardian of my child I have read the above material and Dr. Hortobágyi has it explained to me. My child has been encouraged to ask questions about the study and all inquiries have been answered to my satisfaction. A copy of this consent form shall be given to the person signing as the subject or as the subjects authorized representative.

Subject's Name (Print) ______ Parent or Legal Guardian's Name (Print) ______ Date ______

Signature of Subject, Parent or Legal Guardian ______ Date ______

Witness's Name (Print) ______ Signature of Witness ______ Date ______

Principal Investigator's Name (Print) ______ Signature of PI ______ Date ______

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APPROVED
FROM 4/15/2010
TO 4/14/2011

Minor Assent Document

Title of Research Study: Gait Analysis in Obesity - Children
Principal Investigator: Tibor Hortobágyi
Telephone #: 252.737.4564

You should ask the study doctor or the study coordinator to explain any words or information that you do not understand.

What is the research study about?
The purpose of this study is to compare the walking pattern of children who are light (weigh little) and who are heavy. Walking pattern means how big or wide steps children take as they walk.

Who will be in the research study?
This study examines children age 6-13 including boys and girls from the Greenville area.

What will I be asked to do?
You will be asked to walk on flat surface, run on flat surface at a pace similar to slow jogging, walk up and down a stairwell that has 4 steps, and walk up and down a slanted ramp.

Where will the research study take place?
This study takes place in the Biomechanics Laboratory in the Ward Sports Medicine Building. This building is located next to the football stadium

How can I participate?
You can sign up for the study if your parents give permission, if you meet certain requirements, and if you and your parents together decide that you can sign this form and the informed consent form and if they also sign the informed consent form. "Certain requirements" mean that your age, body weight, and height have to be within certain values. Researchers must limit who can participate in a study because we are not able to include every person since it is very time consuming and expensive to conduct these studies.

What happens if I change my mind about participating?
Participating in this study is your choice. You may stop at any time during the study. No one will be upset with you if you decide not to participate.

Who can answer any questions that I might have later on?
You can talk to Dr. Tibor Hortobágyi at 252.737.4564 if you have more questions at any time during the study. You can also call the university office at 252.744.2914 if you are concerned about how you have been treated in the study.

If I put my name at the end of this form it means I agree to be in this study. I will be given a copy of this form to keep after I sign it and so will my parents.

Print your name ____________________________

Sign your name____________________________

Date ____

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