

5-2010

## Effects of obesity on the biomechanics of children's gait at different speeds

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<http://dx.doi.org/10.34917/1606584>

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EFFECTS OF OBESITY ON THE BIOMECHANICS OF  
CHILDREN'S GAIT AT DIFFERENT SPEEDS

by

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Bachelor of Science  
University of Pretoria, South Africa  
2006

Honors in Sport Science  
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2007

A thesis submitted in partial fulfillment  
of the requirements for the

**Masters of Science in Kinesiology**  
**Department of Kinesiology and Nutrition Sciences**  
**School of Allied Health Sciences**  
**Division of Health Sciences**

**Graduate College**  
**University of Nevada, Las Vegas**  
**May 2010**

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## THE GRADUATE COLLEGE

We recommend the thesis prepared under our supervision by

**Philana-Lee Gouws**

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**Effects of Obesity on the Biomechanics of Children's Gait at  
Different Speeds**

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**May 2010**

## ABSTRACT

### **Effects of Obesity on the Biomechanics of Children's Gait at Different Speeds**

by

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Associate Professor of Biomechanics, School of Allied Health Sciences  
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The purpose of the study was to investigate the relationship between body mass index (BMI) and spatio-temporal gait characteristics of overweight/obese and non-obese school-aged children (12-14 years) at two different walking speeds. Eighty-four overweight/obese (n=28; age:  $13.96 \pm 0.79$  yrs; mass:  $74.8 \pm 18.21$  kg; height:  $159.2 \pm 7.1$  cm and BMI:  $29.28 \pm 5.64$  kg/m<sup>2</sup>) and non-obese students (n=56; age:  $13.72 \pm 0.79$  yrs; mass:  $51.7 \pm 10.2$  kg; height:  $157.8 \pm 8.3$  cm and BMI:  $20.69 \pm 2.74$  kg/m<sup>2</sup>) with no present injuries were recruited. Participants were instructed to walk across an electronic walkway in each of two experimental conditions: a self-selected comfortable walking speed and a “walk more quickly” speed. Dependent variables of interest were cadence, gait velocity, step length (left and right), base of support (left and right) and percent double support (left and right). Independent t-tests reported a significant difference for BMI between groups ( $p < 0.000$ ). Results for 2 (group) x 2 (speed) mixed model ANOVAs identified no significant interactions, while walking speed produced significantly different velocity, cadence, step length, and percent double support characteristics. Bilateral double support percent and bilateral base of support were significantly different between groups. It was observed that the noncontributory mass (additional excess fat) possessed by overweight/obese children may contribute to

biomechanical inefficiency of movement and impaired stability. Many growing children, more commonly obese children, display considerable disruption to normal spatio-temporal gait characteristics when walking at a slower or more quickly and normal walking pace. The obese group showed pronounced alteration in gait for both base of support as well as double support (% gait cycle). These changes have been interpreted as representing underlying instability in obese children, with a normal, comfortable walking speed and longer periods of double support and base of support thought to assist with the maintenance of dynamic balance when performing everyday movement tasks. An exploratory multiple regression analysis was performed to predict BMI as the dependent variable from gait-related variables identified (n=17) for each walking speed. Results identified double support time was a primary predictor of BMI in 12-14 year old children. The unreliability of gait patterning observed in obese children is related to body composition and is affected by speed of walking. The evaluation of gait may also provide an indication of potential problems with the persistence of obesity.

## TABLE OF CONTENTS

ABSTRACT .....	iii
LIST OF TABLES .....	vii
LIST OF FIGURES .....	viii
ACKNOWLEDGEMENTS .....	ix
CHAPTER 1            INTRODUCTION .....	1
Purpose of the Study.....	3
Research Hypothesis .....	3
Assumptions .....	4
Limitations .....	4
Definition of Terms .....	4
CHAPTER 2            REVIEW OF RELATED LITERATURE .....	9
Defining adult overweight and obesity .....	9
Defining childhood overweight and obesity.....	10
Factors leading to/ influencing obesity .....	12
Biomechanics of normal gait .... ..	13
Biomechanics of obese gait (Adults vs. children) .....	15
Speed Variability .....	17
Obesity as a medical problem .....	19
Childhood obesity prevention and physical activity .....	20
GAITRite validity and reliability .....	21
Summary .....	22
CHAPTER 3            METHODOLOGY .....	23
Participants .....	23
Instruments .....	23
Protocol .....	26
Data Reduction and analysis .....	27
Statistical Analysis .....	28
CHAPTER 4            RESULTS .....	29
CHAPTER 5            DISCUSSION .....	34
Conclusion .....	44
APPENDIX I            IRB FORMS .....	45
APPENDIX II            GAITRITE CALCULATIONS OF SELECTED VARIABLES..	49
APPENDIX III            HISTOGRAMS OF VARIABLES .....	51
APPENDIX IV            LIST OF VARIABLES AND REGRESSION EQUATIONS.....	58

REFERENCES .....	60
VITA .....	68



## LIST OF TABLES

Table 1.	Spatio-temporal parameters of gait .....	27
Table 2.	Physical characteristics of non-obese and overweight/obese children .....	29
Table 3.	Independent T-test Summary for Age, Height and BMI .....	30
Table 4.	Gait parameter mean and standard deviation values .....	31
Table 5a.	ANOVA Summary Table for Dependent Variables .....	33
Table 5b.	ANOVA Summary Table for Dependent Variables .....	33
Table 6.	Prediction of BMI for preferred speed .....	41
Table 7.	Prediction of BMI for fast speeds .....	41

## LIST OF FIGURES

Figure 1.	GAITRite electronic walkway .....	24
Figure 2.	Measuring height and weight .....	26
Figure 3.	Measuring bilateral leg length .....	26
Figure 4.	Represent a child walking on the GAITRite electronic walkway at both preferred and “as quick as you can” speed .....	27
Figure 5.	Represent a child walking on the GAITRite electronic walkway at both preferred and “as quick as you can” speed .....	27
Figure 6.	Graphic representation of base of support (L) for both preferred and fast speed .....	37
Figure 7.	Graphic representation of base of support (R) for both preferred and fast speed .....	38
Figure 8.	Graphic representation of double support % (L) for both preferred and fast speed .....	39
Figure 9.	Graphic representation of double support % (R) for both preferred and fast speed .....	40
Figure 10.	Illustrates three footprints recorded by the GAITRite electronic walkway ... ..	50
Figure 11.	Histogram illustrating the velocity as variable of significance between speed . .....	52
Figure 12.	Histogram illustrating cadence as a variable of significance between speed .....	52
Figure 13.	Histogram illustrating step length (left) as a significant variable between speed . .....	53
Figure 14.	Histogram illustrating step length (right) as a significant variable between speed .....	53
Figure 15.	Histogram illustrating stride length (left).....	54
Figure 16.	Histogram illustrating stride length (right).....	54
Figure 17.	Histogram illustrating gait cycle time (left) .....	55
Figure 18.	Histogram illustrating gait cycle time (right).....	55
Figure 19.	Histogram illustrating double support (left) as a significant variable between both speeds and groups .....	56
Figure 20.	Histogram illustrating double support (right) as a significant variable between both speeds and groups .....	56
Figure 21.	Histogram illustrating base of support (left) as a significant variable between group . .....	57
Figure 22.	Histogram illustrating base of support (right) as a significant variable between groups .....	57

## ACKNOWLEDGEMENTS

***"I can do everything through him who gives me strength." Philippians 4: 13***

Two years ago, my flight landed in Las Vegas, I remember the pounding of my heart against my chest walls, as I took a deep breath and realized that Las Vegas and the University of Nevada was going to be my home for the next two years. It was an unforgettable feeling, and while I think back, the accomplishment of my Masters Degree /thesis is another exciting moment in time that I will forever remember. I want to thank God for all the faith and grace, for all the strength and wisdom He has given me, and for being with me on this journey. To my committee chair Dr. Janet Dufek, I have learned so many things from you. Your enthusiasm, inspiration and great efforts throughout my time at UNLV and during my thesis-writing period, encouraged me to grow and expand my thinking. Thank you for your motivation and support. My thanks and appreciation goes to my committee members, Dr. John Mercer, Dr. Richard Tandy and Dr. James McWhorter for their knowledge and expertise. Dr. John Young who always made me smile and for all the kind words of encouragement when I knocked on his door. I want to thank my friends, the Smith-family, Caroline Santoro, Dean Baker, Shama and Shamier Perveen, Shelly and Seth Stanford as well as Central Church for all their love, support and prayers. To my best friend Jaco Liebenberg, thank you for always being my friend and for teaching me to never give up, no matter what the situation or circumstances. We made it, and I am proud of both us.

To my grandmother and uncle, Pieter Gouws, thank you for your motivation and prayers on this journey.

I would like to thank my parents, Phillip and Sharon Gouws for their love, support and prayers. Thank you, mom and dad for encouraging me to follow my heart and reach for my dreams. To my brother, Je-Handrey Gouws thank you for your sense of humor and always making laugh, I am very proud to have you as a brother.

*This thesis is dedicated to my parents, whom I love and miss a lot...*

## CHAPTER 1

### INTRODUCTION

Obesity is recognized as a global epidemic disease, a major health problem in many parts of the world and the incidence of the condition is escalating at an alarming rate (James, 1995). In the United States between 1980 and 2002, obesity prevalence doubled in adults aged 20 years or older and overweight prevalence tripled in children and adolescents aged 6 to 19 years (Ogden et al., 2006). The estimates from the National Health and Nutrition Examination Survey (NHANES) conducted in 2003-2004 provide the most recent prevalence estimates of over-weight and obesity in the United States which suggests that among children and adolescents aged 2-19 years, 17.1% were overweight and 32.2% of adults aged 20 years or older were obese. With these recently documented increases in prevalence, pediatric obesity now represents one of the most pressing nutritional health issues facing children in the United States today (Troiano, Flegal, Kuczmarski, Campbell, & Johnson, 1995). This global trend of increasing obesity and especially childhood obesity is likely to challenge worldwide public health because it suggests that current measures in preventing, treating, and managing the condition are ineffective (Drewnowski, & Popkin, 1997).

Obesity is defined as a condition of abnormal or excessive fat accumulation in adipose tissue and can be associated with serious medical complications that impair quality of life (Kopelman, 2000). Must and Strauss, (1999) suggested that adult obesity can be characterized by significant increases in the risk of developing numerous medical conditions including hypertension, stroke, respiratory disease, type 2 diabetes, gout, osteoarthritis, certain cancers and various musculoskeletal disorders, particularly of the

lower limbs and feet (Messier, Gutekunst, Davis, & DeVita, 2005). As stated previously, children are not immune to this epidemic, and it is important to improve the health of children.

Obesity modifies body geometry, increases the mass of the different segments, and imposes functional limitations, primarily affecting the lower limbs (Kortt, & Baldry, 2002), which can significantly influence the biomechanics of activities during daily living predisposing obese individuals to injury (Wearing, Henning, Byrne, Steele, & Hills, 2006). One such common activity which may be affected is the activity of walking. Human locomotion is described as a complex biomechanical process involving an intricate interplay between muscular and inertial forces that results in the smooth progression of the body moving through space (Winter, 1980). Subjective references are often made to the physical limitations, including movement difficulties, of the obese. Problems commonly cited include general discomfort in simple activities of daily living such as walking and stair-climbing, pain in the joints of the lower extremity, poor circulation including oedema, and soreness or numbness of the feet, particularly following periods of standing (Frankel, & Nordin, 1987). During normal walking the major joints of the lower extremity are exposed to considerable loads with joint reaction forces of approximately three to five times body weight (Frankel, & Nordin, 1987). Messier et al. (1996) suggest that persistent loading of the musculoskeletal system of the obese has been implicated in predisposition to pathological gait patterns, loss of mobility and subsequent progression of disability.

For an obese individual, the difficulties associated with increasing age, along with the lack of regular physical activity, are capable of making the gait dysfunctions even

more severe (De Souza et al., 2005). Excess weight reduces the mechanical effectiveness of gait because of the shorter amplitude of movements, discomfort, early fatigue and the ability to absorb shock leading to joint degeneration. A gait analysis of obese middle-aged adults conducted by Spyropoulos, Pisciotto, & Pavlou, (1991) reported similar temporal and kinematic differences between obese and normal weight individuals to those found for children. Quantitative temporal and spatial aspects of gait have been reported for normal-weight children and for a variety of pathological conditions including Parkinson's disease and cerebral palsy. However, despite the relative simplicity of these measures, there is still little detailed information regarding the basic characteristics of obese gait, particularly in children (Bohannon, 1997).

#### Purpose of the Study

The purpose of the research study was to investigate the relationship between body mass index (BMI) and spatio-temporal gait characteristics of overweight/obese and non-obese school-aged children (12-14 years) at two different walking speeds.

#### Research Hypothesis

It is hypothesized that overweight/obesity in children will lead to deviations from normal gait patterns with longer cycle durations, lower cadence, lower gait velocity, greater base of support, and longer stance periods.

### Assumptions

1. The validity and reliability of the results relied on the subject's compliance. It was assumed that all instructions were given to the subjects, and that they followed the instructions during the experiment.
2. The subjects were healthy school children (aged 12-14 years). They had no history of surgical intervention, chronic pain, orthotic use or current injury in their lower extremities, and had experience in walking.

### Limitations

1. Obesity is a condition that can be described in many different ways.
2. Children were wearing different shoes, which was a limitation that could have influenced the gait parameters while walking.
3. The testing location had limited space at the terminal end of the electronic walkway for a complete walk through.

### Definition of Terms

**Asymmetry:** Bilateral differences consistent between non-dominant and dominant lower limbs. It is any absence of balance or equivalence between two limbs that are otherwise comparable.



**Base of support:** It is the vertical distance from heel center of one footprint to the line of progression formed by two footprints of the opposite foot. In Figure 10 (Appendix II) , the height of the triangle (ADG) is (DL) which is the base width of the right foot. The unit of measure is centimeters.

**Cadence:** The number of steps per unit time, expressed at steps/min.

**Double-support phase:** Periods when both feet are in contact with the ground.

**Gait cycle time:** The elapsed time between the first contacts of two consecutive footfalls of the same foot. It is measure in seconds (sec).

**Gait velocity:** The average horizontal speed of the body along the plane of progression measured over one or more stride periods. It is obtained after dividing the distance traveled by the ambulation time, and expressed in centimeters per second (cm/sec).

**Heel centers:** Points (A), (D) and (G) are the heel centers of each footprint (Figure 10, Appendix II).

**Hypertension:** High blood pressure: a common disorder in which blood pressure remains abnormally high (a reading of 140/90 mm Hg or greater).

**Initial double support:** From heel contact of one footfall to toe-off of the opposite footfall. It is measured in seconds (sec) and is expressed as a percent of the gait cycle time for the same foot.

**Joint moments of force:** This is the net result of all internal forces acting on a joint and includes the moments due to muscles, ligaments, joint friction, and structural constraints.

**Leg length:** It is measured in centimeters from the greater trochanter to the floor, bisecting the lateral malleolus.

**Line of progression:** It is defined as the line of connecting the heel centers of two consecutive footfalls of the same foot. Illustrated in Figure 10, (Appendix II), the line of progression is formed by connecting point (A) to point (G).

**Moment of force:** The product of a force acting at a distance about an axis of rotation, which causes an angular acceleration about the axis. It is measured in Newton-meters (N.m).

**Sagittal-plane:** It is a vertical plane that divides the body into right and left parts.

**Single-support phase:** The time elapsed between the last contact of the current footfall to the first contact of the next footfall of the same foot. Single support time is equal to the swing time of the opposite foot. It is measured in seconds (sec) and expressed as a percent of the gait cycle time of the same foot.

**Stance phase:** The weight-bearing portion of each gait cycle. It is initiated by heel contact and ends with toe-off of the same foot. It is the time elapsed between the first contact and the last contact of two consecutive footfalls on the same foot. It is also presented as a percentage of the gait cycle time.

**Step length:** It is measured along the line of progression, from the heel center of the current footprint to the heel center of the previous footprint on the opposite foot. In Figure 10 (Appendix II), line (DL) is perpendicular to the line of progression (AG). The length of line (AL) is the step length of the right foot, while the length of line (LG) is the step length of the second left foot. The step length can be a negative value if the subjects fails to bring the landing foot heel point forward of the stationary foot heel point. The unit of measure is centimeters.

**Stride length:** It is measured on the line of progression between the heel points of two consecutive footprints of the same foot (left to left, right to right). In Figure 10 (Appendix II), (AG) is the stride length of the left foot. The unit of measure is centimeters.

**Swing time:** It is initiated with toe off and ends with heel strike. It is the time elapsed between the last contact of the current footfall to the first contact of the next footfall on the same foot. It is expressed in seconds (sec) and it is also presented as a percent of the gait cycle of the same foot. The swing time is equal to the single support time of the opposite foot.

**Vertical ground reaction force:** According to Newton's third law, "...to every action there is always opposed an equal reaction; or, the mutual actions of two bodies upon each other are always equal and directed to contrary parts". For example, when an individual's foot strikes the ground, the surface pushes back against the individual with equal force in the opposite direction, which is referred to as ground reaction forces.

## CHAPTER 2

### REVIEW OF THE LITERATURE

The global epidemic of obesity results from a combination of genetic susceptibility, increased availability of high-energy foods and decreased requirement for physical activity in modern society (Kopelman, 2000). Obesity should no longer be regarded as a cosmetic problem affecting certain individuals, but an epidemic that threatens global well being.

#### Defining Adult Overweight and Obesity

The World Health Organization (WHO; 2003), reported the underlying assumption that most variation in weight for persons of the same height is due to fat mass and the formula most frequently used and internationally recognized as a definition for adult obesity in epidemiological studies is body-mass index (BMI). The BMI is defined as the weight in kilograms divided by the square of the height in meters ( $\text{kg/m}^2$ ). A BMI of 25 to 29.9  $\text{kg/m}^2$  is defined as overweight, and a BMI of over 30  $\text{kg/m}^2$  as obese. The National Institutes of Health reported that a BMI of 30  $\text{kg/m}^2$  is about 30lbs (13.6kg) overweight. The correlation between the BMI number and body fatness according to the CDC (Centers for Disease Control and Prevention) is fairly strong; however BMI varies by gender, race and age. It is important to understand that at the same BMI, (1) women tend to have more body fat than men, (2) older adults tend to have more body fat than younger people, and lastly (3) high trained athletes may have a higher BMI because of more muscularity.

Most studies that have examined the relationship of BMI to body fatness across racial or ethnic groups have been relatively small and have not considered the possibility that the racial or ethnic differences in body fatness may vary according to the BMI level. However, it is important to understand that there are racial or ethnic differences in body fatness among children, but these differences vary by BMI-for-age (Freedman, et al., 2008).

### Defining Childhood Overweight and Obesity

The criteria used to assess obesity in children and adolescents vary widely (Guillaume, 1999). Therefore, it appeared essential to determine the most appropriate measurement with which to define obesity in children and adolescents for global use before the worldwide prevalence of childhood and adolescent obesity can be explored. According to Rolland- Cachera et al. (1982) BMI in childhood changes substantially with age. At birth the average BMI values are as low as  $13 \text{ kg/m}^2$ , which increases to  $17 \text{ kg/m}^2$  at age 1, decreases to  $15.5 \text{ kg/m}^2$  at age 6, and then increases to  $21 \text{ kg/m}^2$  at age 20. Specific cutoff points related to age are needed to define child obesity, based on the same principle at different ages (Power, Lake, & Cole, 1997). Although other measures, such as triceps skinfold thickness, offer direct measurements of subcutaneous fat and are reasonably well correlated with percentage body fat, measurements by different observers and measurements of fatter subjects are difficult to reproduce. In contrast, Dietz and Bellizzi, (1999) reported that the high reliability of measurements of height and weight suggests that a variant of weight-for-height provides a more reliable measure of adiposity that can be used to compare adiposity within and between populations.

Furthermore, as stated before individuals of different heights or body builds may have similar fat masses yet substantially different proportions of total body fat, and because obesity connotes a condition of excess body fat, body fat expressed as a percentage of body weight (percentage body fat) is the most relevant measure against which anthropometric measurements should be correlated.

In the United States, the 85<sup>th</sup> and 95<sup>th</sup> percentiles of body mass index for age and gender based on nationally representative survey data have been recommended as cut off points to identify overweight and obesity in children (Barlow, & Dietz, 1998).

Internationally the use of this definition raised two questions: Why base it on data from the United States, and why use the 85<sup>th</sup> or 95<sup>th</sup> percentile? Other countries are unlikely to base a cutoff point solely on American data, and the 85<sup>th</sup> or 95<sup>th</sup> percentile is intrinsically no more valid than other cutoff point such as the 91<sup>st</sup> or 97<sup>th</sup> percentile (Cole, Bellizzi, Flegal, & Dietz, 2000). In conclusion, Dietz and Robinson, (1998) illustrated that BMI offers a reasonable measure of fatness in children and adolescents. To provide a consistent assessment of obesity across the life span, the cutoff point selected to identify obesity in children should agree with that used to identify obesity in adults which includes a body mass index of 25 kg/m<sup>2</sup> for overweight and 30 kg/m<sup>2</sup> for obesity (WHO, 1998).

### Factors Leading to/Influencing Obesity

Obesity is the result of an imbalance of energy intake and expenditure and the main causes are linked to environment factors, mainly the factors related to sedentary lifestyles, used by children nowadays. Children's modern lifestyles mean that activities in their spare time are mostly sedentary and unhealthy like screen watching, including television, handheld computer games, and personal computers. Time spent watching television or computer screens and video games appear to be an important index of sedentariness, and a cause of obesity (Dietz, & Gortmaker, 1985). Obesity is a syndrome with a multifactorial aetiology that includes metabolic, genetic, environmental, social, and cultural interactions (Dietz, 1998). Maffels, Schuts, Schena, Zaffanello, & Pinelli (1993) indicated that walking and running are energetically more expensive for obese children than for children of normal body weight.

French, Story, & Jeffrey, (2001) reported that individuals in the United States no longer have sufficient time for traditional food preparation, which created the increased demand for prepackaged and fast food. Time pressures have fueled the need to get to places faster, which causes people to drive rather than walk, to take elevators instead of the stairs, and to look to technology for ways to engineer inefficient physical activity out of our lives. Experts have come to believe that the environment, rather than biology is driving this epidemic. Biology clearly contributes to individual differences in weight and height, but the rapid weight gain that has occurred over the last 3 decades may be a result of the changing environment. The current environment in the United States encourages consumption of energy and discourages expenditure of energy (French et al., 2001).



McCracken et al. (2007) reported that possible factors in the environment include: promoting overconsumption of energy through the easy availability of a wide variety of good-tasting, inexpensive, energy-dense foods and the serving of these foods in large proportions. Another factor within the United States contributing to obesity is the widespread physical inactivity in both adults and children (McCracken, Jiles, & Blanck, 2007). Troiano et al. (2008) showed that only 42% of children (6-11 years of age) and 8% of adolescents (12-19 years of age) meet the United States Surgeon General's recommendation for 60 minutes of physical activity each day. Contributing factors to lower levels of physical activity include increased motorized transport, increased sedentary activities (such as watching television, surfing the Web, playing video games) and decreased opportunity for recreational physical activity. This may be due to a reduction in jobs requiring physical labor and for children, a reduction in energy expenditures at schools (Lobstein, Baur, & Uauy, 2004). Internationally, studies have consistently found associations between physical activity levels, gender and age. It is important to make physical activity part of children's lives. Troiano et al. (2008) also pointed out that boys participate in more physical activity than girls, with a decrease in physical activity occurring as children get older.

### Biomechanics of Normal Gait

Winter (1991) defined walking as moving from one plane to another – to climb stairs to bed, to meet a friend, to walk the aisles at the grocery store. Walking is an important skill and it makes a big difference in how one's life turns out. Walking doesn't come automatically, from a young age we struggle to crawl – and then we crawl

everywhere we can. Next, we try pulling ourselves to stand at a table leg, at father's leg, at the stair steps. We grunt and push and pull and fall and roll and bump, then try again and keep it up over and over again, and never quit in spite of face-falls and nose bruises – all because we want to be what we feel, persons come to be by walking (Winter, 1991).

Locomotion (walking and running) is the most common of human movements. It is one of the more difficult movement tasks that we learn, but once learned it becomes almost subconscious. The sole purpose of walking and running is to transport the body safely and efficiently across the ground (Winter, 1984). Gait is very different between individuals and also varies from step to step within an individual. Gait consists of a harmonious set of complex and cyclical movements of the body parts through a dynamic interaction of the internal and external forces (Sacco and Amadio, 2000). A complete cycle of gait comprises two consecutive contacts of the same heel with the support surface, and the time interval between these two contacts is called the length of the gait cycle. A stride is the distance covered during that period of time. The time elapsed between first contact of the heel on the floor and the loss of contact of the same foot determines the length of the support phase. The phases of gait can be divided into different sub-phases of support that comprise approximately 58 to 61% of the gait cycle. The swing phase varies from 39 to 42% of the cycle. As cadence and velocity of walking increase, both stance and swing phase times decrease (Grieve and Gear, 1966). Other terminology used to describe gait include speed/velocity (distance/time), cadence (number of steps/time), length of a step/stride, and asymmetry.

Natural cadence has been reported in several studies. Drillis (1958) calculated a mean cadence of 112 steps/min, Du Chatinier, Molen, & Rozendal, (1970) revealed that females walked slightly more rapidly than males (females=116 vs males = 122 steps/min) for a population of 72 males and 57 females. Rozendal (1972) also reported for about 500 young adults that the male cadence averaged 113 steps/min compared to 124 steps/min for females. Thus, it is suggested that females have a natural cadence of 6 to 11 steps/min higher than that of males.

#### Biomechanics of Obese Gait (Adults vs. Children)

LeVeau and Bernhardt (1984) reported that during normal walking the major joints of the lower extremity are exposed to considerable loads with joint reaction forces of approximately three to five times body weight. When participating in movement tasks such as stair climbing, jogging and running, it involves joint reaction forces at the higher end of this range and beyond. Based on Newton's Laws of Motion it would appear reasonable to hypothesize that obese individuals will experience greater loads on their joints than normal-weight individuals, and that these loads increase with walking speeds. Browning and Kram, (2007) studied the effects of obesity on the biomechanics of walking at different speeds. Twenty adults (10 obese and 10 normal-weight), were tested as they walked on a level, force measuring treadmill at six speeds (0.5 – 1.75 m/s). Vertical ground reaction forces (GRF) as well as sagittal-plane kinematics were measured, and net muscle moments at the hip, knee and ankle were calculated. Results showed that absolute GRF were significantly greater for the obese versus normal-weight subjects and decreased significantly at slower walking speeds in both groups.

At each walking speed, peak vertical GRF values were approximately 60% greater for obese versus normal-weight subjects. Greater sagittal-plane knee joint moments in the obese subjects also suggest that they walked with greater knee-joint loads than normal-weight subjects. Walking slower reduced GRF and net muscle moments and may be a risk-lowering strategy for treating obesity (Browning & Kram, 2007). For all individuals, irrespective of size and shape, a comfortable self-selected speed of walking is commonly less variable than any imposed walking speed. Therefore, the gait of a mature, normal weight individual is characterized by the ability to display consistency across various speeds of walking. According to Hills, Henning, Byrne, & Steele, (2002) many growing children, especially obese children, display considerable disruption to normal temporal characteristics when walking more slowly or faster than normal.

Hills and Parker (1991) suggests that prepubertal children show greater asymmetry in gait than non-obese children, consistently favoring the right limb. In addition to a compromised ability to adjust to changes in walking speed, several temporal characteristics have been reported to be different between obese and normal-weight prepubertal children (Hills & Parker, 1991). For example, obese children have been classified to have a longer stance phase and slower speed of walking, as reflected by a longer cycle duration, lower cadence and lower relative velocity. Unstable individuals, including the obese, display a longer double-support and a shorter single-limb support time, which reinforces a safer and more tentative ambulation pattern which reduces the non-support time and the potential for instability or loss of balance.

The literature suggests that one of the possible consequences leading to the disruption of gait patterns in obese might be related to an increased need for stabilization and settling of the body structures caused by obesity.

The increased need for stabilization is the result of a wider contact angle of the heel with floor, secondary to genuvalgum, which corresponds to lateral angulation of the leg in relationship to the thigh (knock-knee) due to a larger thigh and an overloading of the internal area in the knees (Spyropoulos et al., 1991). This pattern is consistent with slow body movements, poor fitness and easy fatiguability of obese individuals, along with a large and unstable body mass, requiring a wider base of support. Hills and Parker, (1991) also found additional support for the previous observations of obese adult gait; they reported greater stride lengths, longer gait cycles, slower velocity, greater stride width and longer right step length (asymmetry) in obese compared to non-obese prepubertal children.

### Speed Variability

Changes in speed are a common feature of everyday locomotion (Grieve, & Gear, 1966). Much has been done to characterize the effect of gait speed on temporal and kinematic gait parameters in normal-weight children and adults. Lelas, Merriman, Riley, & Kerrigan, (2003) suggest that walking speed influences the fundamentals of gait - joint rotations (kinematics), GRF, net internal joint moments and joint power (joint kinetics). The importance of walking speed was exemplified in a study done by Stansfield, Hillman, Hazlewood & Robb, (2006) which reported that speed was the primary determinant of kinematic and kinetic changes observed in growing children.

If gait speed influences temporal and kinematic parameters in normal-weight children and adults, what will the effect of gait speed be on overweight/obese children and adults? It is known that obesity in itself causes an unreliability of gait patterning that is related to body composition as well as that walking is a recommended and very popular form of exercise (Hill, Wyatt, Reed & Peters, 2003). Weight-bearing exercise (i.e., walking) may be a critical activity that influences the biomechanical loads experienced at the joints during these activities. Intuitively, it would seem likely that obesity will increase the biomechanical loads involved in walking and that these loads increase with walking speed. There is a general agreement that the duration of the phases of the walking cycle decreases with an increase in cadence, also literature indicates that an increases in walking speeds, up to a point, are accomplished by decreasing the step duration and by increasing step length (Winter, 1991).

Hills and Parker (1991) studied the gait cycles of 10 obese and 10 non-obese pre-pubertal children at 3 different walking speeds: slow (10% less than the preferred), normal (preferred) and fast (30% faster than preferred). The outcome suggested that average cadence during normal speed was 133 steps/min in normal-weight children vs. 125 steps/min in obese children. Obese children also had longer double support times at both the slow and the fast walking speeds. A follow-up study by Hills and Parker (1992) described additional observations including greater stride lengths, longer double-support and stance phases, shorter swing phase and lastly a longer right step length in obese children. They concluded that a decreased activity level, combined with weight status, can be a significant factor contributing to instability at slower speeds of walking, which resulted in the obese children's gait being characterized by longer double-support phases.

Therefore, it is important to understand that gait is an integrated pattern of movements, and changes in one parameter such as walking speed produce changes in the overall pattern of movement (Andriacchi, Ogle, & Galante, 1977).

Studies have shown that many gait parameters, angular limb motion, muscular activity and joint reactions are velocity-dependent (Grieve, & Gear, 1966).

### Obesity of a Medical Problem

Obesity is clinically implicated with musculoskeletal disorders involving the back, hip, knee, ankle and foot (Peltonen, Lindroos, & Torgerson, 2003). In a large study of children aged 2 to 17 years (Krul, van der Wouden, Schellevis and Suijlekom-Smit, 2009) it was found that overweight and obese children reported musculoskeletal problems and lower extremity problems more frequently in daily life than their normal-weight peers.

Childhood obesity increases the risk of multiple acute and chronic medical problems as well as psychological issues, all of which can persist into adulthood and adversely affect quality of life. Obese children can suffer from orthopedic complications, including abnormal bone growth, degenerative disease, and pain (Wills, 2004). The presence of unfused growth plates and softer, cartilaginous bones of children, contributes to the occurrence of orthopedic abnormalities in obese children (Kelsey, 1971). They are also more likely to have low self-esteem, leading to depression and suicidal ideation, and to engage in substance abuse (Strauss, 2000). The estimated 9 million overweight children – including 4.5 million obese children – are at higher risk for type 2 diabetes mellitus, heart disease, cancer, asthma and other pulmonary diseases, high cholesterol,

elevated blood pressure, stroke and other chronic illnesses (Serdula et al., 1993). Compared with children at a normal weight, overweight children are 70% to 80% more likely to be overweight in adulthood (Pi-Sunyer, 1991).

Authors concluded that the maintenance of mobility should be a very high priority in the management of obesity and that the high levels of body fat as well as increased loads on major joints has the potential to lead to pain and discomfort, inefficient body mechanics and further reductions in mobility (Hills et al., 2002).

### Childhood Obesity Prevention and Physical Activity

In the past 3 decades, the annual cost of managing obesity- related diseases among children and adolescents increased more than threefold, from \$35 million in 1979-1981 to \$127 million in 1997-1999 (Wang, & Dietz, 2002). Prevention and treatment of obesity requires a decrease in sedentary activity and an increase in physical activity (Barlow, 2007). Physical activity can increase the quality of life of children, including physical and psychological perceptions (Shoup, Gattshall, Dandamudi, & Estabrooks, 2008). In addition, physical activity increases physical fitness (Ortega et al., 2007) that is negatively correlated to metabolic risk factors and inflammatory markers (Ruiz, Ortega, Warnberg, & Sjorstrom, 2007). Physical activity also decreases adiposity and enhances skeletal muscle health (Ortega et al., 2007). However, overweight children have more difficulty sustaining bouts of high-intensity physical activity, which may be the result of the negative association between adipose tissue and physical fitness (Mamalakis, Kafatos, Manios, Anagnostopoulou, & Apostolaki, 2000). The difficulty in participating in physical activity can also be influenced by musculoskeletal pain.



The majority of participants in a study focused on overweight children and adolescents (5-18 years of age) reported musculoskeletal pain in at least one joint. The most commonly reported musculoskeletal pain occurs in the back, feet and knees (Stovitz, Pardee, Vazquez, & Schwimmer, 2008). Finally, because overweight children have more-self-reported musculoskeletal discomfort and impairment of mobility than normal-weight children, adequate levels of physical activity become more difficult for this population to achieve. We must inspire people to make behavior changes within the current environment that are sufficient to resist the push of environmental factors toward weight gain.

As a society, we should be more willing, for example, to carefully manage the food and physical activity environments of our children at home, in school, and in other places frequented by children (Hill et al. 2003).

#### GAITRite Validity and Reliability

It is imperative that the validity of any gait analysis system be firmly established before it is used in clinical situations. According to Cutlip et al., (2005) the electronic walkway system has been designed to measure spatial and temporal gait parameters with accuracy comparable to sophisticated motion analysis systems, but in an automated fashion. The electronic walkway system is a portable walkway embedded with pressure-activated sensors. The walkway detects the timing of sensor activation as well as relative distances between the activated sensors. The information acquired is then processed by the application software that calculates spatial and temporal gait parameters for individual footfalls as well as an overall average for each parameter.

Thorpe et al., (2005) suggested that the electronic walkway is a reliable and emerging clinical tool for the assessment of gait in children with and without disabilities. Webster et al., (2005) suggested a high degree of similarity between the spatial and temporal gait parameters measured using the electronic walkway and Vicon® systems. The data collected in this study supports previous findings which have shown good concurrent validity of the GAITRite for measures of speed, cadence, and step length (McDonough et al, 2001). More importantly, the present data from Webster et al., (2005) extend literature by demonstrating that the electronic walkway has excellent concurrent validity for measuring individual footstep data. The importance of gait analysis is emphasized because of its use in clinical decision-making.

### Summary

Obesity is an important public health problem that, in recent years, has reached epidemic proportions. Relative to extensive literature available on many aspects of the obese condition, there is a dearth of information pertaining to the functional limitations imposed by overweight and obesity. A limited number of studies have focused on the locomotor characteristics of obese children. The current study was designed to contribute to our knowledge and understanding of the locomotion characteristics of overweight and obese children.

## CHAPTER 3

### METHODOLOGY

The purpose of the research study was to investigate the relationship between body mass index (BMI) and spatio-temporal gait characteristics of overweight/obese and non-obese school-aged children (12-14 years) at two different walking speeds.

#### Participants

Eighty-four overweight/obese and non-obese students ( $n=84$ ; weight:  $60.8 \pm 17.6$  kg; height:  $158.6 \pm 7.8$  cm; age:  $13.80 \pm 0.798$  yrs) with no present injuries were recruited from a local Charter School to volunteer to participate in the study. Testing took place under the supervision of a teacher in the school gymnasium. Subjects as well as their parents were educated on the purpose and requirements of the study and signed informed consent (parent/guardian) or child assent (participant) forms which were approved by the Institutional Review Board (IRB) at the University of Nevada, Las Vegas.

#### Instruments

##### *Height and weight scale*

A physician scale Health-o-meter 500kl was used to measure each individual's height and weight. This information was used to calculate body mass index (BMI).

### *GAITRite System*

A GAITRite system (model 3.9; CIR Systems, Inc.) electronic walkway 14 ft (4.3 m) was used to measure spatial (distance) and temporal (timing) parameters of gait (Figure 1). The standard electronic walkway contains six sensor pads encapsulated in a roll up carpet which resulted in an active area of 24 inches (61cm) wide and 12 ft (3.6 m) long. In this arrangement, the active area is a grid, 48 sensors by 288 sensors placed on a 0.5 inch (1.27cm) centers, totaling 13824 sensors. The portable walkway was placed in a hallway, on a concrete surface that was covered with very thin carpet. There were no external devices placed on the child participants. As the subject walked across the walkway, the system captured spatial and temporal data (80 Hz) for each footfall. The GAITRite data acquisition software version 3.9 was used to store each walking trial by subject.

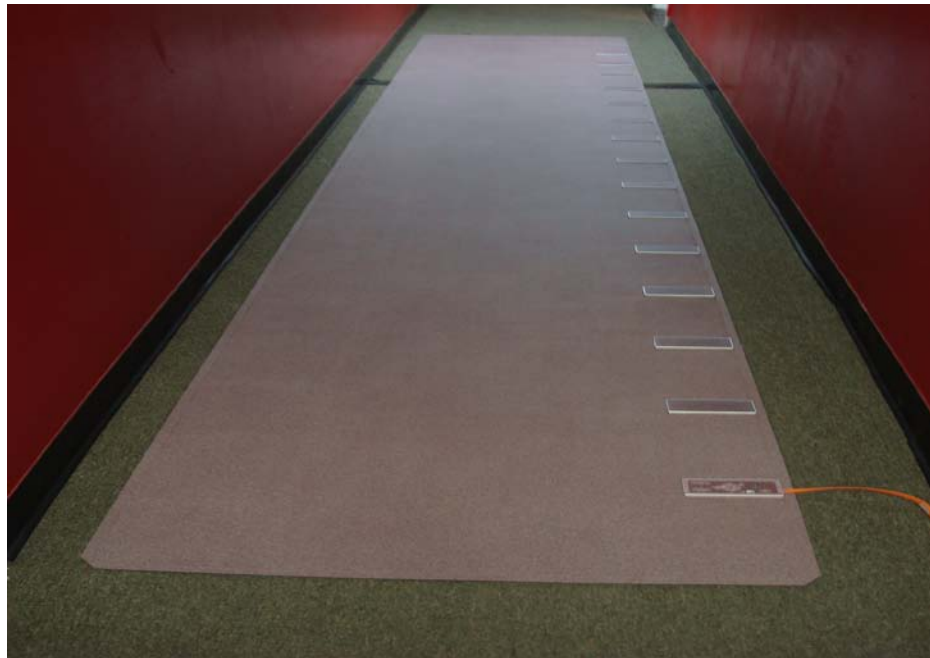


Figure 1. GAITRite electronic walkway

The electronic walkway does not only sense the geometry of the activating footprints but also the relative arrangement between them in a two dimensional space. (Figure 10, Appendix II). The walkway identifies the heel centers of every footfall, a line of progression defined as the line connecting the heel centers of two consecutive footfalls is then formed (Figure 10, Appendix II). The following variables, step length, stride length and base of support can be illustrated and explained via Figure 10 (Appendix II). Step length is measured along the line of progression, from the heel center of the current footprint to the heel center of the previous footprint on the opposite foot. In Figure 10, line (DL) is perpendicular to the line of progression (AG). The length of line (AL) is the step length of the right foot, while the length of line (LG) is the step length of the second left foot. The step length can be a negative value if the subjects fails to bring the landing foot heel point forward of the stationary foot heel point. Stride length is measured on the line of progression between the heel points of two consecutive footprints of the same foot (left to left, right to right). In Figure 10, (AG) is the stride length of the left foot. Base of support is the vertical distance from heel center of one footprint to the line of progression formed by two footprints of the opposite foot. In Figure 10, (Appendix II) the height of the triangle (ADG) is (DL) which is the base width of the right foot.

### Protocol

Subjects were tested during a regular gym class period. Height and weight were obtained in a private screening area (Figure 2). Subjects then stepped out into the hallway, and bilateral leg length was measured with a flexible tape measure. Bilateral leg length was measured in centimeters from the greater trochanter to the floor, bisecting the lateral malleolus (Figure 3). Leg length was a necessary input for the acquisition software, however, was not used for any variables used in this analysis. Participants were then instructed to walk across the electronic walkway in each of two experimental conditions: a self-selected comfortable walking speed and a “walk more quickly” speed. For each speed, two walks consisting of multiple steps were completed across the walkway (Figure 4 and 5).



Figure 2. Measuring height and weight



Figure 3. Measuring bilateral leg length



Figure 4 and Figure 5. Represent a child walking on the GAITRite electronic walkway at both preferred and “as quick as you can” speed

### Data Reduction and Analysis

Spatio-temporal parameters of gait were extracted from each individual’s walking trial data set. For both “comfortable” and “quick walking” speeds, average gait parameter data across 10 strides were calculated. The gait parameters extracted are given in Table 1.

Table 1 - Spatio-temporal parameters of gait

Cadence	Velocity
Double Support % (L & R)	Base of Support (L & R)
Step Length (L & R)	

Children were grouped based upon BMI. A BMI of 15.1 to 24.9 kg/m<sup>2</sup> was defined as normal-weight, 25 to 29.9 kg/m<sup>2</sup> was overweight, and a BMI of over 30 kg/m<sup>2</sup> as obese.

### Statistical Analysis

Mixed model 2 x 2 analysis of variance (ANOVAs) were used for analysis. Factors were groups (overweight/obese and non-obese) and speed (“comfortable” and “quick” walking speed). The spatio-temporal gait dependant variables (Table 1) for each walking speed were determined. SPSS for Windows (Release 16.0) was used for statistical analyses. The alpha level was set at 0.05 as the level of overall significance.



## CHAPTER 4

### RESULTS

The purpose of the research study was to investigate the relationship between body mass index (BMI) and spatio-temporal gait characteristics of overweight/obese and non-obese school-aged children (12-14 years) at two different walking speeds. The physical characteristics of eighty-four children both non-obese (n=56) and obese/overweight (n = 28) studied were grouped according to BMI (overweight/obese  $\geq 25 \text{ kg/m}^2$ ; non-obese  $\leq 24.9 \text{ kg/m}^2$ ) are shown in Table 2. Independent t-tests ( $\alpha = 0.05$ ) were used to evaluate these data. Male and female children were included together in the analysis of these data. The subjects had a body mass index ranging from 15.1 to 40.6  $\text{kg/m}^2$ . The independent variables were overweight/obese and non-obese groups as well as the preferred and fast speed conditions. Dependent variables of interest were cadence, gait velocity, step length (left and right), base of support (left and right) and percent double support (left and right).

Table 2: Physical characteristics of non-obese and overweight/obese children

Group	Age (yrs)	Mass (kg)	Height (cm)	BMI ( $\text{kg/m}^2$ )
Non-obese	$13.72 \pm 0.79$	$51.7 \pm 10.2$	$157.8 \pm 8.3$	$20.69 \pm 2.74$
Obese/ Overweight	$13.96 \pm 0.79$	$74.8 \pm 18.2$	$159.2 \pm 7.1$	$29.28 \pm 5.64$

Note: Values are means  $\pm$  standard deviation.

The presentation of results begins with an overall summary of the descriptive findings at both the preferred and fast walking speeds. Spatio-temporal gait parameters were determined using an electronic walkway, recorded at 80Hz.

Table 3 presents a summary of these results. Average age and height between the overweight/obese and non-obese groups were non-significant, but the average BMI values between groups were significantly different. This suggests that the overweight/obese and non-obese groups indeed were different in this current study.

Table 3 – Independent T-test Summary for Age, Height and BMI

Source	t	p
Age	-1.260	0.324
Height	-1.474	0.093
BMI	-12.920	<0.001*

Note:  $p < 0.05$ .

Table 4 – Gait parameter mean and standard deviation values

	Preferred	Fast
Cadence (steps/min)		
Non-obese	110.11 ± 9.81	126.74 ± 12.19
Obese	107.83 ± 8.04	122.90 ± 7.51
Velocity (cm/s)		
Non-obese	122.47 ± 17.68	160.96 ± 22.85
Obese	117.39 ± 16.06	152.17 ± 18.03
Step Length Left (cm)		
Non-obese	66.13 ± 5.69	75.76 ± 6.35
Obese	65.08 ± 5.98	74.09 ± 6.21
Step Length Right (cm)		
Non-obese	66.99 ± 6.12	76.63 ± 5.89
Obese	65.08 ± 5.99	74.43 ± 6.67
Stride Length Left (cm)		
Non-obese	133.80 ± 11.71	153.10 ± 12.16
Obese	130.94 ± 12.37	149.16 ± 12.64
Stride Length Right (cm)		
Non-obese	133.53 ± 11.52	152.86 ± 12.13
Obese	130.78 ± 12.45	149.14 ± 12.44
Gait Cycle Time Left (sec)		
Non-obese	1.10 ± 0.10	0.96 ± 0.09
Obese	1.12 ± 0.98	0.98 ± 0.06
Gait Cycle Time Right (sec)		
Non-obese	1.10 ± 0.16	0.98 ± 0.23
Obese	1.12 ± 0.08	0.98 ± 0.07

Table 4 continued – Gait parameter mean and standard deviation values

	Preferred	Fast
Base of Support Left (cm)		
Non-obese	$8.55 \pm 3.32$	$8.71 \pm 3.06$
Obese	$11.23 \pm 2.45$	$11.37 \pm 2.64$
Base of Support Right (cm)		
Non-obese	$8.30 \pm 3.35$	$8.77 \pm 2.87$
Obese	$11.27 \pm 2.43$	$11.17 \pm 2.84$
Double Support Left (%GC)		
Non-obese	$23.89 \pm 3.08$	$20.50 \pm 3.11$
Obese	$27.53 \pm 3.02$	$24.06 \pm 2.96$
Double Support Right (%GC)		
Non-obese	$23.83 \pm 3.08$	$20.51 \pm 3.04$
Obese	$27.67 \pm 3.04$	$24.38 \pm 3.06$

Note: %GC = percentage of the gait cycle

While not significantly different, some trends were observed. The mean preferred cadence for non-obese children ( $110.11 \pm 9.81$  steps/min) was higher than for obese children ( $107.83 \pm 8.04$  steps/min). A similar result was observed for the mean fast cadence; non-obese children ( $126.74 \pm 12.19$  steps/min) had higher values than overweight/obese children ( $122.90 \pm 7.51$  steps/min). Subjects took a mean of  $10.93 \pm 1.25$  steps during the data collection period. Mean and standard deviation values for each dependent variable are presented in Table 4.

Results for the 2 (group) x 2 (speed) mixed model ANOVAs identified no significant interactions. Walking speed produced significantly different velocity, cadence, step length, and percent double support characteristics. Bilateral double support percent and bilateral base of support were significantly different between groups. The ANOVA results are summarized in Tables 5a and 5b.

Table 5a - ANOVA Summary Table for Dependent Variables

Source	Velocity (cm/s)		Cadence (s/min)		StepLL (cm)		StepLR (cm)	
	F	p	F	p	F	p	F	p
G	2.86	0.09	2.04	0.40	1.09	0.30	2.40	0.13
S	399.32	<0.001*	294.03	<0.001*	326.97	<0.001*	364.15	<0.001*
G x S	1.02	0.32	0.71	0.40	0.36	0.54	0.088	0.76

Note:  $p < 0.05$ .

G = Groups; S = Speed; G x S (Group by speed interaction); StepLL, StepLR = Step length (left or right).

Table 5b - ANOVA Summary Table for Dependent Variables

Source	DSL (%GC)		DSR (%GC)		BSL (cm)		BSR (cm)	
	F	p	F	p	F	p	F	p
G	29.17	<0.001*	33.02	<0.001*	17.09	<0.001*	17.67	<0.001*
S	199.54	<0.001*	210.67	<0.001*	0.34	0.560	0.498	0.482
G x S	0.033	0.856	0.10	0.922	0.001	0.98	1.26	0.265

Note:  $p < 0.05$ .

G = Groups; S = Speeds; G x S (Group by speed interaction); DSL, DSR = Double Support (left or right), (%GC) = percentage of the gait cycle and BSL, BSR = base of support (left or right).

## CHAPTER 5

### DISCUSSION

The purpose of the research study was to investigate the relationship between body mass index (BMI) and spatio-temporal gait characteristics of overweight/obese and non-obese school-aged children (12-14 years) at two different walking speeds. To accomplish this purpose, overweight/obese and non-obese children walked at a “comfortable” and “as quick as you can” speed across an electronic walkway, measuring gait parameters. Prior to testing gait, the children’s height and weight was measured to determine BMI values.

The goal of this study was to increase our understanding of gait characteristics of overweight/obese children. Such information may provide a clearer understanding of the movement-related difficulties of such individuals and provide insight as to the differences displayed by overweight/obese vs. non-obese children. The evaluation of gait may also provide an indication of potential problems with the persistence of obesity. This study has hypothesized that overweight/obesity in children will lead to deviations from normal gait patterns with longer cycle durations, lower cadence, lower gait velocity, greater base of support, and longer stance periods.

In the current study, 28 overweight/obese children and 56 non-obese children (12-14 yrs), with body mass index ranging from 15.1 to 40.6 kg/m<sup>2</sup> participated. The BMI values for both overweight/obese and non-obese children were significantly different between groups (Table 4). Previous researches investigating the effects of walking speed have related gait parameters to cadence (Andriacchi et al., 1977). Since velocity is the product of cadence and step length, all three parameters are closely related.

Inman et al. (1981) stated that ‘every feature of walking changes when speed changes’. In the current study, cadence was significantly different between speeds but not between groups. While non-significant the mean preferred cadence for non-obese children ( $110.1 \pm 9.8$  steps/min) was higher than for obese children ( $107.8 \pm 8.0$  steps/min). The same (non-significant) observation for the mean fast cadence; non-obese children ( $126.7 \pm 12.2$  steps/min) had higher values than the overweight/obese children ( $122.9 \pm 7.5$  steps/min). These non-significant results are reported simply to illustrate that the observed magnitudes are similar to previous research by Hills and Parker, (1991) suggesting an average cadence of 133 steps/min in normal-weight children and 125 steps/min in obese children. The average velocity in the current study was found to be significant between the preferred speed conditions, but no significance was found between groups. It can be suggested that the occurrence of the non-significant difference in velocity between groups, could lead to a conclusion that all the spatio-temporal gait characteristics changed or the changes still occurred even though the obese children were walking at a constant pace, and that these changes not only occur during slower and faster speeds of walking. The mean averages for walking speed in the current study for both overweight/obese and non-obese children was achieved by uniform changes in both cadence and step length (step length at preferred speed; overweight/obese group = (L):  $65.08 \pm 5.98$  cm; (R):  $65.08 \pm 5.99$  cm and fast speed; (L):  $74.09 \pm 6.21$  cm; (R):  $74.43 \pm 6.67$  cm vs. step length at preferred speed; non-obese = (L):  $66.13 \pm 5.69$  cm; (R):  $66.99 \pm 6.12$  cm vs. fast speeds (L):  $75.76 \pm 6.35$  cm; (R):  $76.63 \pm 5$  cm).

Cavagna and Margaria., (1966) reported an increase in walking speed requires a corresponding increase in energy expenditure, and Katch et al., (1988) attributed some of

the increased energy cost to biomechanical inefficiencies such as upper body forward lean and increased displacement of the center of gravity. It can be hypothesized that this increased energy cost can be particularly evident at faster speeds. Another explanation for the differences between overweight/obese and non-obese children can simply be the overweight state of the obese child.

It would be safe to suggest that the increased energy cost of movement for obese children observed by Katch et al., (1988) might contribute to the decreased physical activity in overweight populations. The noncontributory mass (additional excess fat) may contribute to biomechanical inefficiency of movement and impaired stability. Step length at the preferred speed for the overweight/obese group (Step length (L):  $65.08 \pm 5.98\text{cm}$ ; (R):  $65.08 \pm 5.99\text{cm}$ ), as well as fast speed (Step length (L):  $74.09 \pm 6.21\text{cm}$ ; (R):  $74.43 \pm 6.67\text{cm}$ ) was significantly shorter than the non-obese group preferred (Step length (L):  $66.13 \pm 5.69\text{cm}$ ; (R):  $66.99 \pm 6.12\text{cm}$ ) and fast speeds (Step length (L):  $75.76 \pm 6.35\text{cm}$ ; (R):  $76.63 \pm 5\text{cm}$ ). However, as expected, the step length in both groups increased with faster walking speeds. Terrier and Schutz (2003) observed that gait variability was relatively high in low speed walking compared with natural and fast conditions. It has been suggested that for all individuals, irrespective of size and shape, a comfortable preferred speed of walking is commonly less variable than an imposed walking speed (Hills et al., 2002).

The gait of mature, non-obese individuals is characterized by the ability to display consistency across various speeds of walking (Hills et al., 2002). However many growing children, but more commonly obese children, display considerable disruption to normal temporal characteristics when walking slowly or more quickly than their normal



walking patterns. Another important finding was the significant difference observed between both overweight/obese and non-obese for base of support (Figures 6-7). Base of support was defined as the vertical distance from heel center of one footprint to the line of progression formed by two footprints of the opposite foot. A broad base of support during walking also referred to as “stride width” is believed to be a characteristic for people with unsteady gait and balance problems. Static standing stability has been shown to improve with a wider base of support even in patients with cerebellar and vestibular lesions (Baloh, et al., 1998).

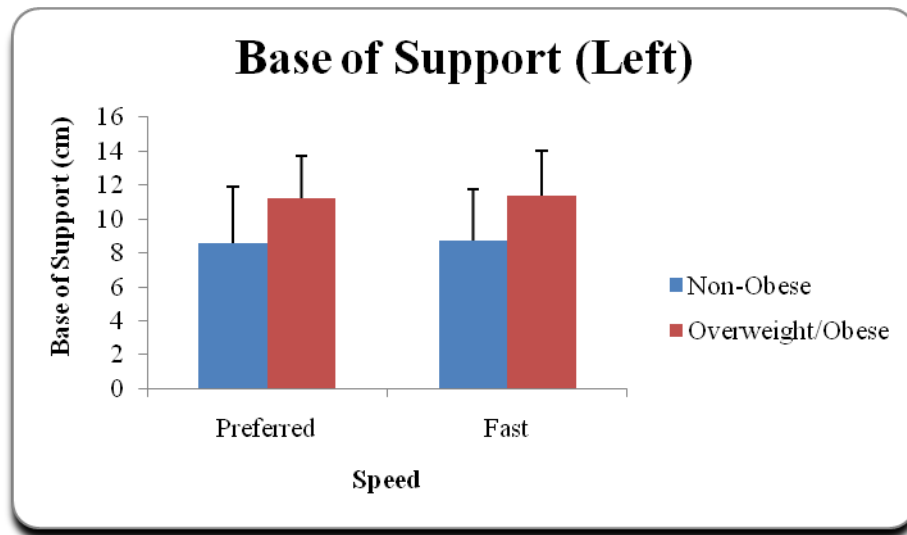


Figure 6. Preferred – Non-obese:  $8.55 \pm 3.32$  cm; Obese:  $11.23 \pm 2.45$  cm  
Fast - Non-obese:  $8.71 \pm 3.06$  cm; Obese:  $11.37 \pm 2.64$  cm

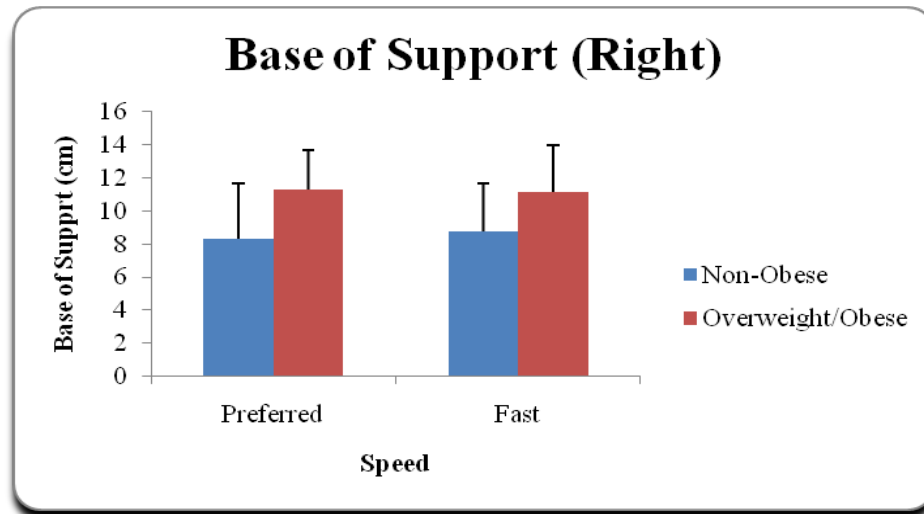


Figure 7. Preferred - Non-obese:  $8.30 \pm 3.35$  cm; Obese:  $11.27 \pm 2.43$  cm  
Fast - Non-obese:  $8.77 \pm 2.87$  cm; Obese:  $11.17 \pm 2.84$  cm

The observed statistical significance between overweight/obese and non-obese children for base of support can be a factor contributing to increased stability during walking especially for the overweight/obese population at different speeds. Another factor to consider relative to obesity and gait is that with an increase in BMI, there is an accumulation of adipose tissue, which leads to an increase in thigh circumference. The increased thigh circumference necessitates circumduction of the leg with each stride. This might also be a reason for increased base of support for the overweight/obese group. The gait pattern adapted by overweight/obese children might be related to an increased need for stabilization and settling of the body structures caused by obesity. A wider base of support as suggested by De Souza et al., (2005) can be seen as the consequence of obesity overloading the lower limbs, as the body fights to keep upright by separating the knees and ankles, in order to achieve a lower center of gravity and more anterior-posterior and lateral stability.

The body deals with a sequence of adaptive processes, and an enlarged support base also triggers longitudinal external deviation of the tibia and the femur, which causes genu valgum knees, pedis planus, and external rotation of the feet (Ribeiro et al., 2003). In both groups the duration of the double support decreased when gait velocity increased, and when compared in the two groups this duration was greater in the obese group whatever the velocity (Figures 8-9). In this study, obese children consistently showed higher double support periods (% of the gait cycle) at each walking speed than the non-obese children. Winter (1987) reported that individuals with less stability will display a lengthened double support period (% of gait cycle), which might contribute to the greater base of support observed in the obese children.

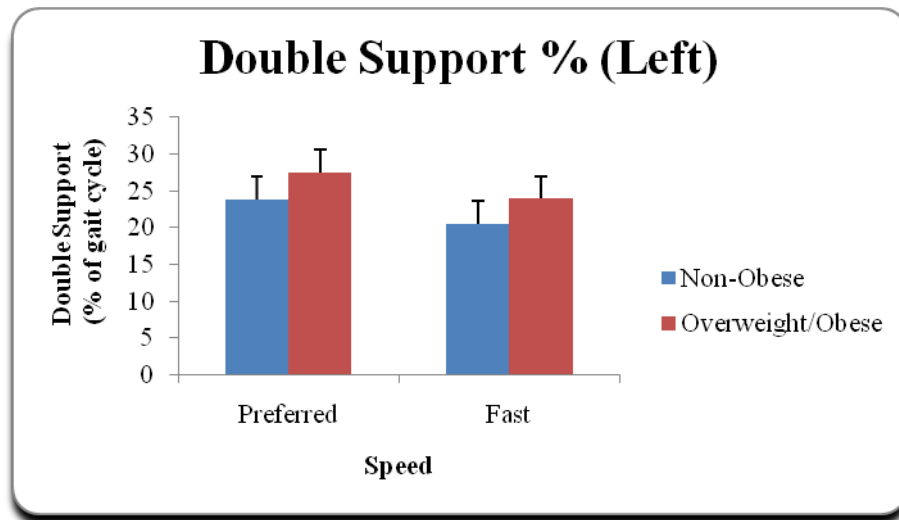


Figure 8. Preferred - Non-obese:  $23.89 \pm 3.08$  sec; Obese:  $27.53 \pm 3.02$  sec  
Fast – Non-obese:  $20.50 \pm 3.11$  sec; Obese:  $24.06 \pm 2.96$  sec

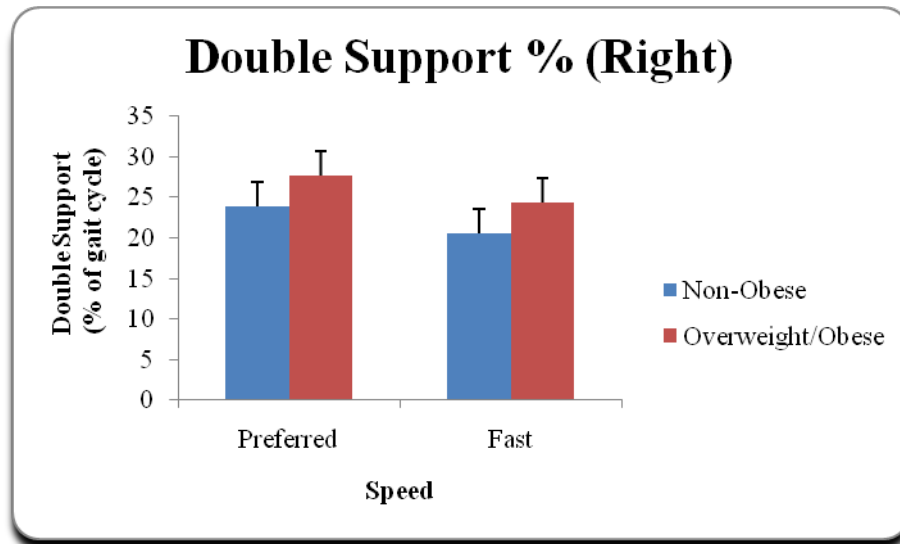


Figure 9. Preferred - Non-obese:  $23.83 \pm 3.08$  sec; Obese:  $27.67 \pm 3.04$  sec  
Fast – Non-obese:  $20.51 \pm 3.04$  sec; Obese:  $24.38 \pm 3.06$  sec

The obese group showed pronounced alteration in gait for both base of support as well as double support (% gait cycle). These findings confirm the common qualitative view of a slower, safer and more tentative walking gait in obese children relative to non-obese children. The measurement tool used in the current study collected multiple gait-related variables ( $n=17$ ), and based on literature (Spyropoulos et al, 1991) the gait-related dependent variables entered into the ANOVA statistical analysis were selected. As for questions raised on whether the gait-related variables chosen were good predictors, an exploratory analysis was performed which involved a multiple regression technique to predict BMI as the dependent variable from all the gait-related variables (Appendix IV) identified ( $n=17$ ) for each walking speed. The model for preferred speed identified two predictor variables with and  $R^2$  change of 51.8% (Table 6). The fast speed model was

slightly stronger with four predictor variables accounting for and  $R^2$  change of 57.7% (Table 7). The resulting regression equations are presented in appendix IV.

The multiple regression analyses indicated that, among all parameters, double support percentage (R) and velocity were significant predictors for BMI during the preferred speed (Table 6).

Table 6 – Prediction of BMI for preferred speed

Variable	R-squared	F	p
DSR (%GC)	0.432	62.261	<0.001*
DSR (%GC), Velocity (cm/s)	0.518	43.468	<0.001*

Note:  $p < 0.05$ .

DSR = Double support (right), (%GC) = percentage of the gait cycle

Table 7 – Prediction of BMI for fast speed

Variable	R-squared	F	p
DSR (%GC)	0.459	69.522	<0.001*
DSR (%GC), BSR (cm)	0.513	42.671	<0.001*
DSR (%GC), BSR (cm), Cycle Time (sec)	0.553	32.985	<0.001*
DSR (%GC), BSR (cm), Cycle Time (sec), StrideLL (cm)	0.577	26.989	<0.001*

Note:  $p < 0.05$ .

DSR = Double support (right), (%GC) = percentage of the gait cycle, BSR = Base of support (right), and StrideLL = stride length (left)

Double support percentage (R), base of support, cycle time and stride length (R) were significant predictors of BMI during the fast speed (Table 7). It is interesting to note that double support percentage (R) had an  $R^2$  change of 43.2% during the preferred speed and 45.9%.

A possible explanation for the significance observed in double support percentage for the right limb in both preferred and fast speeds, as well as the time spent in base of support for the right limb during fast walking indicated greater asymmetry for the right limbs. This phenomenon was suggested by Hills and Parker (1991), which noted that overweight/obese children showed greater asymmetry in gait than non-obese children, consistently favoring the right limb. Velocity is without a doubt also an important factor when predicting BMI, in this study the preferred speed for overweight/obese children was lower ( $117.39 \pm 16.06$  cm/s) vs. non-obese children ( $122.47 \pm 17.68$  cm/s). Although velocity did not enter the fast speed model, a similar measure (cycle time) did.

Other researchers have indicated that at speeds other than normal pace, especially slower speeds, there is a greater difficulty in performing movement tasks. Overweight/obese children have greater difficulty in performing movement tasks vs. non-obese children. Human behavior, functions, and performances are unpredictable; therefore, a prediction of 51.8% and 57.7% for BMI may be considered relatively high.

Literature has suggested that spatio-temporal gait parameters in overweight/obese children vs. non-obese children have to be tested in a large group of overweight/obese vs. non-obese children. In this study 84 children were grouped according to their BMI, and 28 overweight/obese and 56 non-obese children were tested for gait parameters at two different speeds. This study produced similar results as to those found in a study by

Hills and Parker (1991), where 10 overweight/obese and 4 non-obese children were tested. Hills and Parker (1991) suggested that overweight/obese children have a longer stance phase and slower speed of walking, as reflected by a longer cycle duration, and lower cadence. Spyropoulos et al. (1991) tested the biomechanics of men compared to normal-weight individuals, at preferred walking speeds and the obese have been consistently slower, with reductions in step length and step frequency. In addition to the reduced walking speeds, a longer stance phase duration, shorter swing phase and a greater period of double support have been reported when compared to the normal-weight individuals.

These changes have been interpreted as representing underlying instability in obese, with a slower walking speed and longer period of double support thought to assist with the maintenance of dynamic balance when performing everyday movement tasks. Future research should focus on examining whether excess body weight or excess adiposity is a major limiting factor in movement tasks. This study reports that walking is one of the most common forms of human movement, and that differences between overweight/obese and non-obese children were observed. Consequences of being overweight in the pediatric population can result in several orthopedic conditions.

Due to adaptations made by overweight/obese children during different walking speeds, it is important that any future research also examine or identify causes of discomfort experienced by overweight/obese children who might lead to pain and decrease the quality of life in overweight/obese children.

### Conclusion

The present study revealed a number of differences in temporal parameters of walking between obese and non-obese children that could disadvantage the obese in movement tasks. The unreliability of gait patterning observed in obese children (slower walking velocities, shorter stride lengths, and increase in base of support and longer double support percentages) is related to body composition and is affected by speed of walking. In addition, time that individuals spent in double support was a primary predictor of BMI in 12-14 year old children. Walking is a fundamental movement pattern, the most common form of physical activity. The results of this study may provide useful information to the clinician evaluating walking characteristics of child gait.



## APPENDIX I

### IRB FORMS



UNIVERSITY OF NEVADA LAS VEGAS

Office for the Protection of  
Research Subjects

IRB Received Date Stamp—Office Use Only

IRB Protocol Number—Office Use Only

## Graduate Student Research Protocol Addendum for Research Involving Human Subjects

### Instructions:

1. CITI certification ([www.citiprogram.org](http://www.citiprogram.org)) must be current at the time of protocol submission. Certification expires 2 years after completion.
2. Complete all sections. Do not reference other sections as a response (e.g., "see section..." or "see attached...")
3. Obtain all necessary signatures. Original signatures required.
4. Submit one copy of this form. You will be notified if additional copies are necessary.

### Note:

1. Research may not begin until you have received notification of IRB approval and handwritten and incomplete forms cannot be accepted.

### 1. Duration of your portion of the Study

Anticipated Start Date: 1 / 2010

Anticipated Termination Date: 12 / 2010

### 2. General Information

Protocol Title: Translating the Diabetes Prevention Program to a School Setting

Protocol Number: 0909-3227

### 3. Investigator(s) Contact Information

(The PI must be UNLV faculty in all cases involving studies carried out by students or fellows.)

#### A. Principal Investigator (Name and Credentials): Dr. Lori Candela, Psychosocial Nursing

Department: School of Nursing

Mail Stop: 3018

Phone Number: 702- 895- 2443

E-Mail Address: lori.candela@unlv.edu

#### B. Student Investigator (Name and Credentials): Philana - Lee Gouws

☒ Master

☐ Doctorate

☐ Ed Specialist Certificate

☐ Other:

Department: Kinesiology and Nutrition Science

Mail Stop: 3034

Phone Number: 702-806-7288

E-Mail Address: gouwsp@unlv.nevada.edu

This research is for my: ☒ Thesis ☐ Dissertation ☐ Professional Paper ☐ Other (explain):

☒ I am currently a research team member on this protocol

☐ I am not currently a research team member on this protocol

### 4. Complete Description of the Study Procedures

#### Purpose and Methods (describe your unique contribution to your PI's larger research project)

A Describe the purpose of the study for your portion of the research (as opposed to the main protocol):

Obesity is recognized as a global epidemic disease, a major health problem in many parts of the world and the incidence of the condition is escalating at an alarming rate. The purpose of my research study is to investigate spatio-temporal gait measures/ characteristics of overweight/obese and non-obese school-aged children (12-13 years) walking at a normal/ comfortable speed vs. a "walk as fast as you can" speed. The secondary purpose is to investigate symmetry and asymmetry during obese and non-obese school children's walking patterns.

B Provide a **COMPLETE** description of this portion of the research: The gait patterns of obese and non-obese school children, age 12-13 years with no present injuries will be evaluated to provide objective kinematic data. BMI (Body Mass Index) will be used to classify the participants. Testing will take place at the Innovations International Charter School of Nevada under the supervision of a teacher. Subjects will complete at least one practice trial across the GAITRite walkway before administering the test. After practice trials the subjects will be instructed to walk across the walkway in two conditions; a self-selected comfortable speed and a "walk more quickly" speed.

C Please describe what subset of the data collected from the original protocol will be used: Gait data from Grade 7 students only

D Will you be using data that has been previously collected? ☐ Yes (If so, date: \_\_\_\_\_) ☒ No

E Please check all of the following boxes that apply (ensure that any box checked is thoroughly explained in 4B):

- ☐ My research will be conducted at a project site that differs from that of the original protocol
- ☐ My inclusion/exclusion criteria differ from that of the original protocol
- ☐ My consent form or process differs from that of the original protocol
- ☐ My methods for maintaining privacy/confidentiality of subject's data differs from that of the original protocol
- ☐ My recruitment procedures differ from that of the original protocol
- ☐ The risks and benefits of my project differ from that of the original protocol
- ☐ My subjects' payments differ from that of the original protocol
- ☐ I have included additional research instruments/advertisements
- ☐ Other (please specify): \_\_\_\_\_
- ☒ My project does not differ from that of the original protocol

## 5. Signatures of Assurance

**A. FACULTY ADVISOR:** By my signature as Principal Investigator on this research application, I certify that the student/fellow investigator is knowledgeable about the regulations and policies governing research with human subjects and has sufficient training and experience to conduct this particular study in accordance with the approved protocol. In addition:

- I agree to act as the liaison between the IRB and the student/fellow investigator with all written and verbal communications.
- I agree to meet with the student/fellow investigator on a regular basis to monitor the progress of the study.
- I agree to be available and to personally supervise the student/fellow investigator in solving problems, as they arise.
- I assure that the student/fellow investigator will promptly report adverse events to OPRS according to IRB guidelines.
- I will arrange for an alternate faculty advisor to assume responsibility if I become unavailable, as when on sabbatical leave or vacation.
- I assure that the student/fellow investigator will follow through with the storage and destruction of data as outlined in the protocol.
- I authorize the specified data obtained from the referenced protocol to be used for the student's research project.

LORI CANDELA

Principal Investigator's Name (Print)

JANET DUFEK (advisor)

**B. Student Investigator Assurance:**

By my signature as Student/Fellow Investigator on this research application, I certify that I am knowledgeable about the regulations and policies governing research with human subjects and agree to conduct this particular study in accordance with the approved protocol. In addition:


- I agree to meet with my faculty advisor on a regular basis to discuss the progress of the study.
- I agree to meet with my faculty advisor to solve protocol issues, as they arise.
- I will promptly report adverse events to OPRS and my faculty advisor according to IRB guidelines.
- I assure that I will follow through with the storage and destruction of data as outlined in the protocol.

*Lori Candela*  
Principal Investigator's Signature

12/16/09  
Date

12/16/09

PHILANA-LEE GOWNS  
Student/Fellow Investigator Name (Print)

  
Student/Fellow Investigator Signature

12-18-2009  
Date

## APPENDIX II

### GAITRITE CALCULATION OF SELECTED VARIABLES

The following figure represents three footprints by the GAITRite electronic walkway and define line of progression (line segment - AG), step length (line segment - AL (right), LG (left) and base of support (line of segment - DL) is defined.

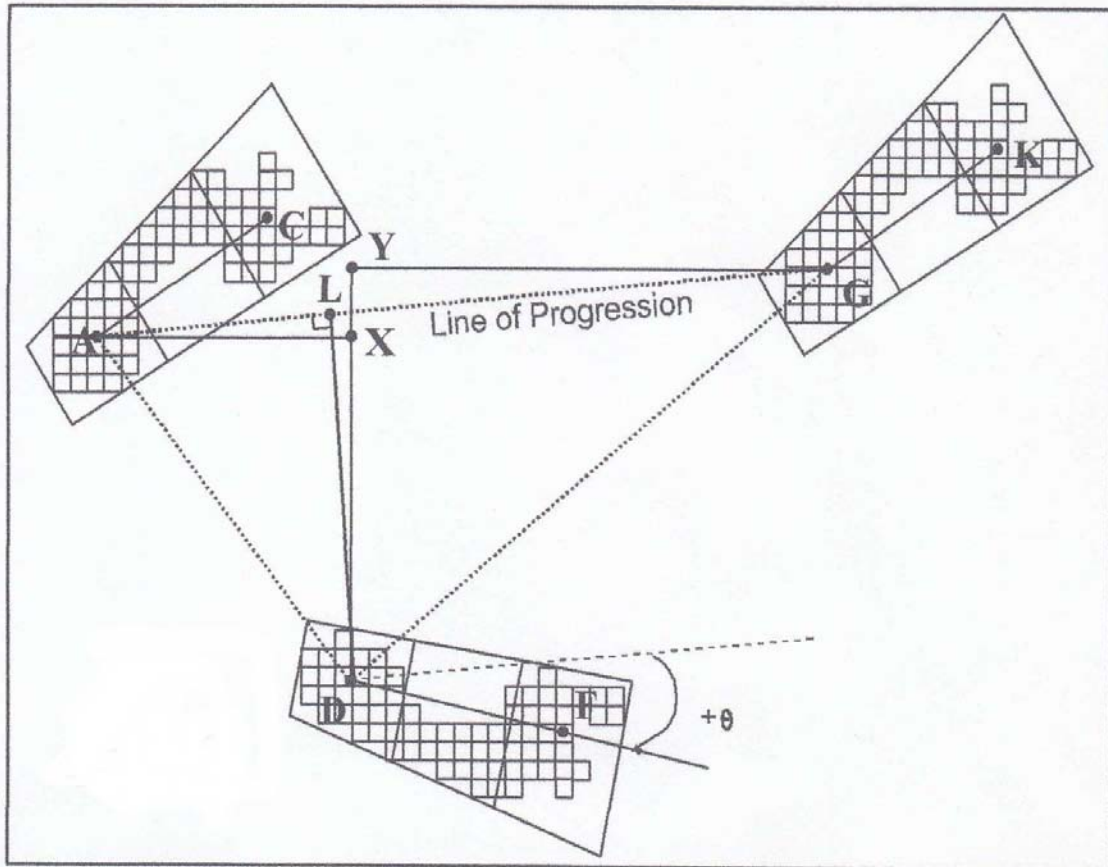


Figure 10. Illustrates three footprints recorded by the GAITRite electronic walkway.



APPENDIX III  
HISTOGRAMS OF VARIABLES

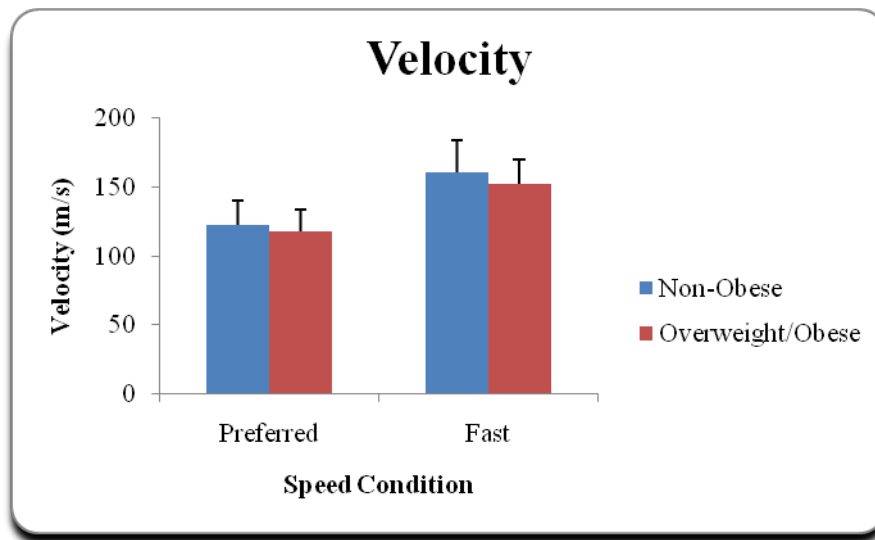


Figure 11. Histogram illustrating the velocity as variable of significance between speeds.

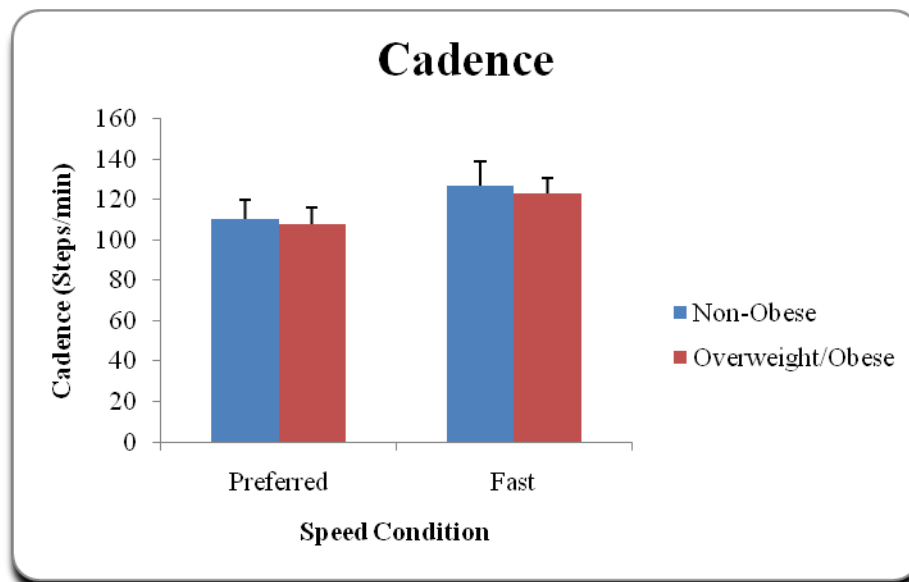


Figure 12. Histogram illustrating cadence as a variable of significance between speeds.



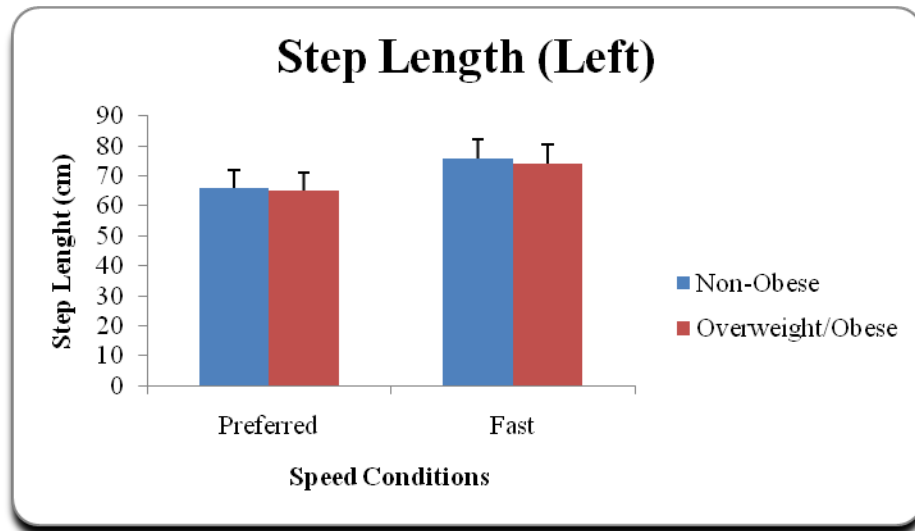


Figure 13. Histogram illustrating step length (left) as a significant variable between speeds.

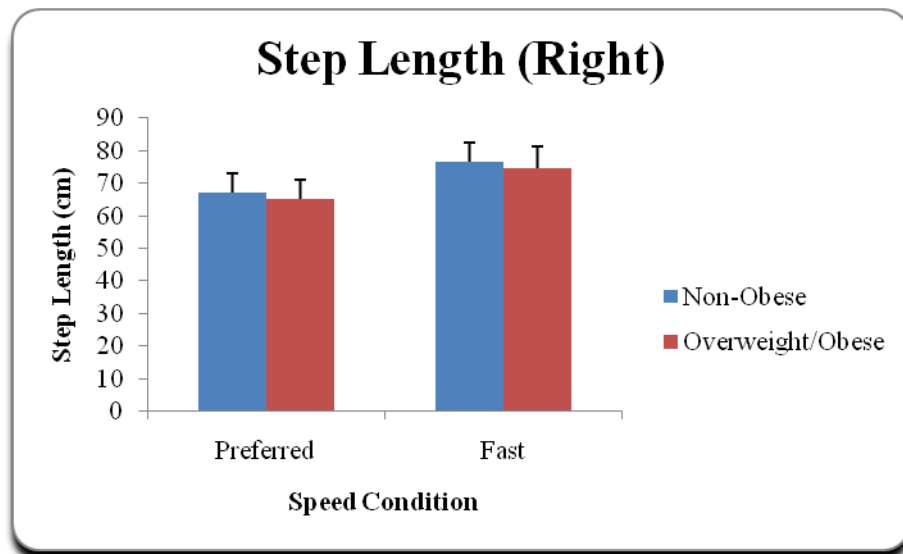


Figure 14. Histogram illustrating step length (right) as a significant variable between speeds.

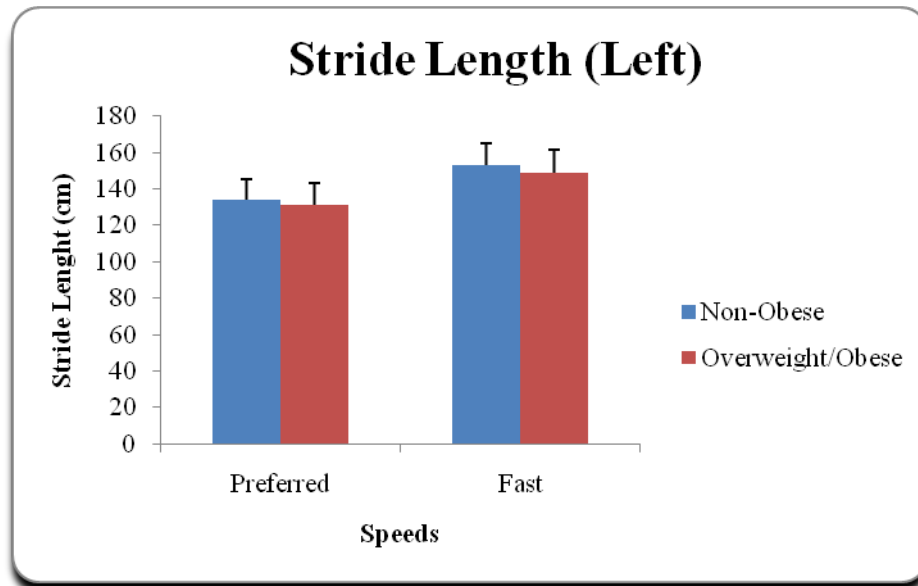


Figure 15. Histogram illustrating stride length (left).

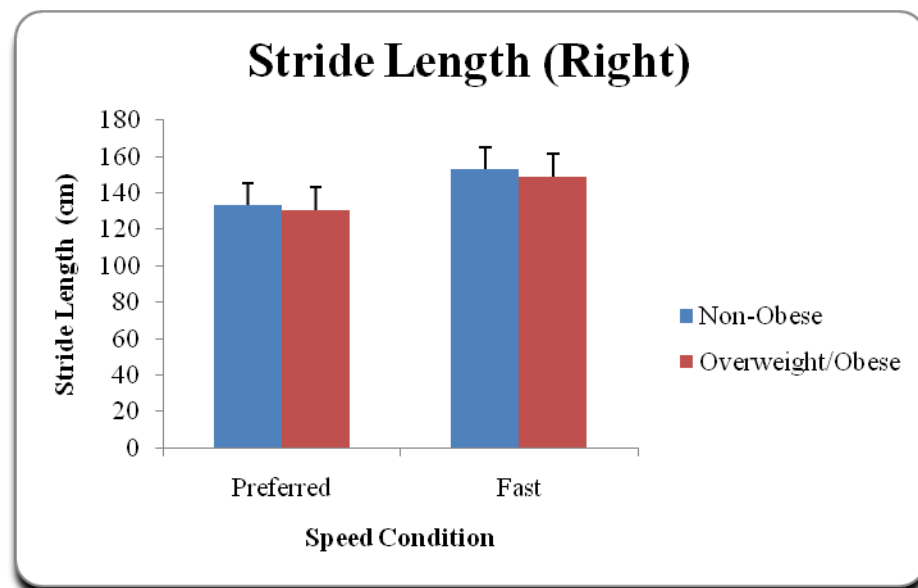


Figure 16. Histogram illustrating stride length (right).

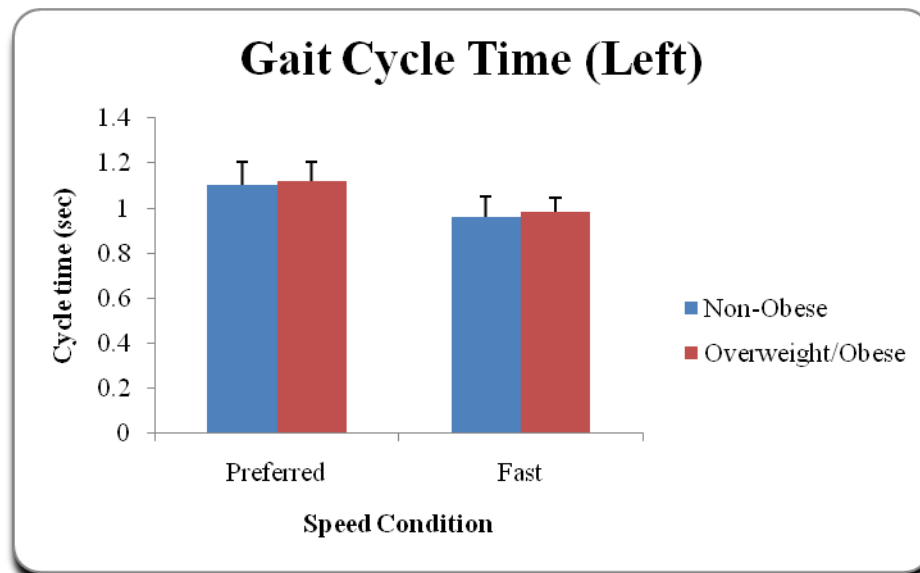


Figure 17. Histogram illustrating gait cycle time (left).

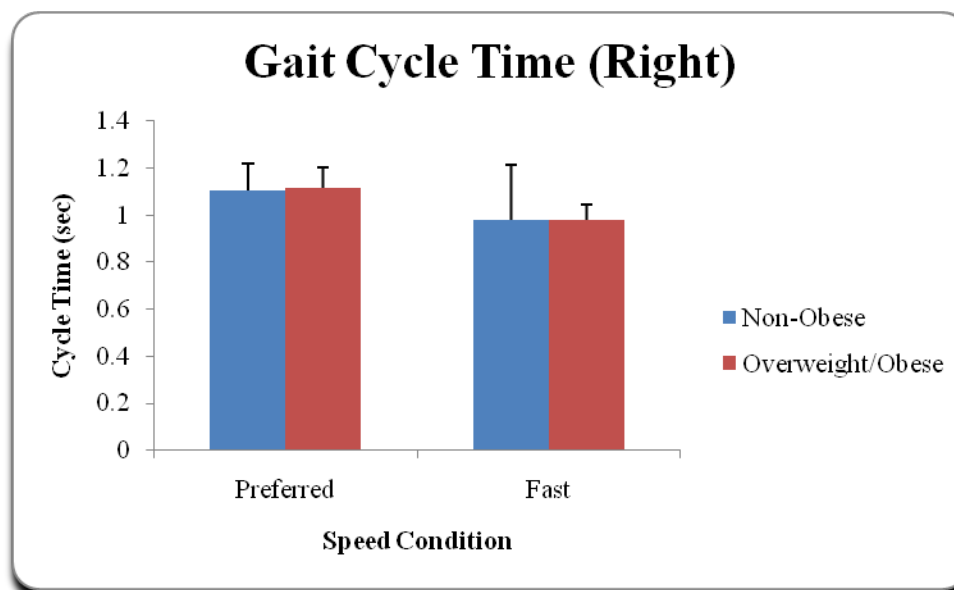


Figure 18. Histogram illustrating gait cycle time (right).

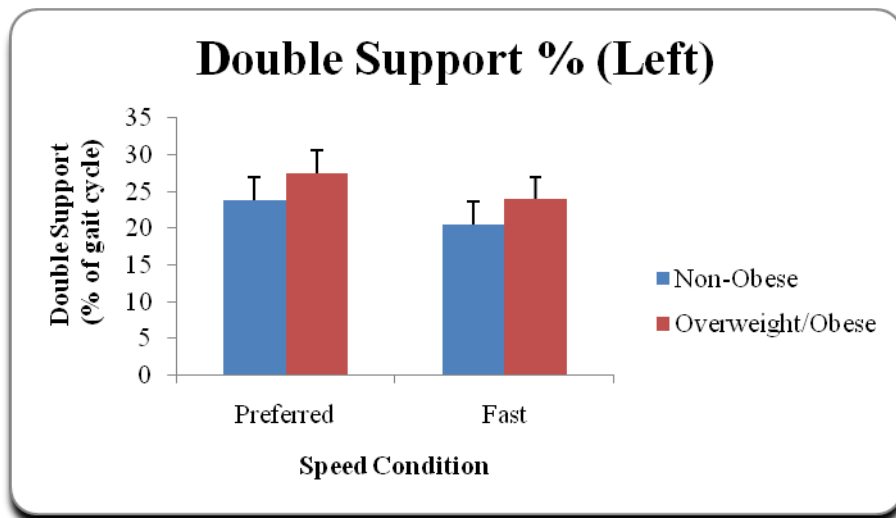


Figure 19. Histogram illustrating double support (left) as a significant variable between both speeds and groups.

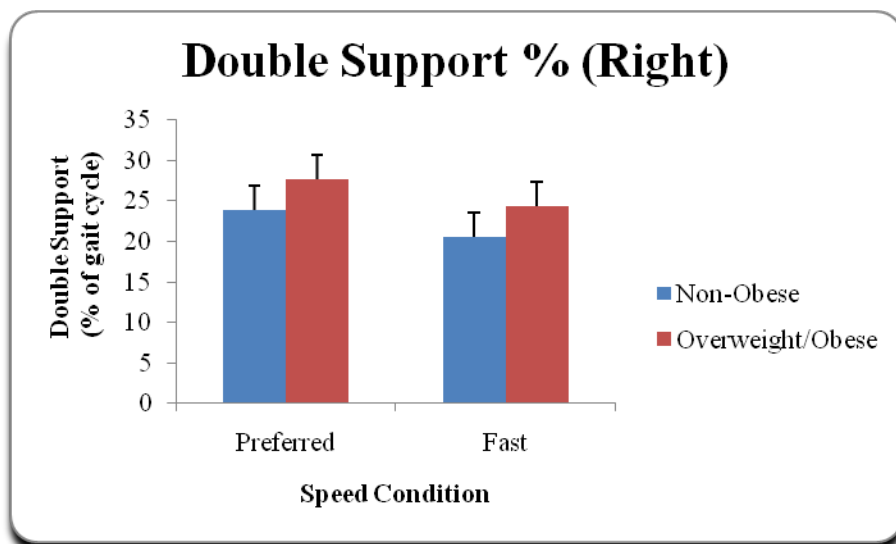


Figure 20. Histogram illustrating double support (right) as a significant variable between both speeds and groups.

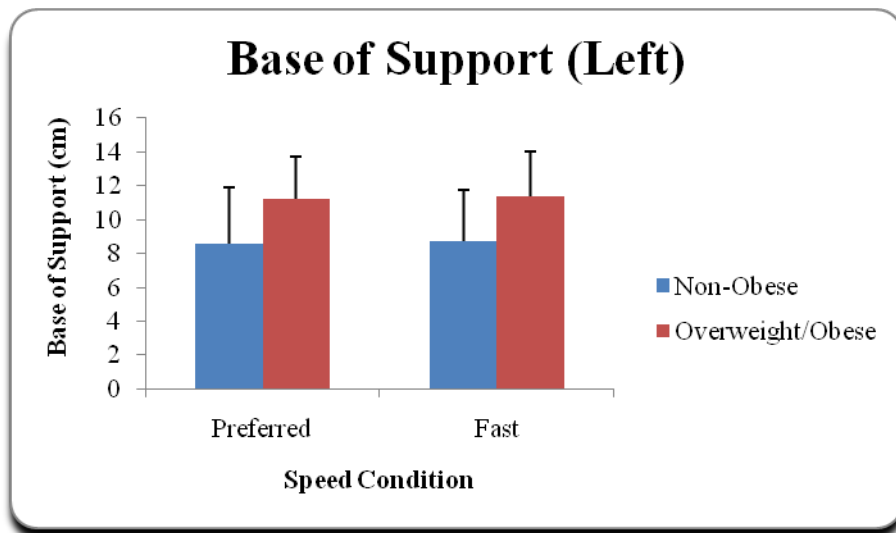


Figure 21. Histogram illustrating base of support (left) as a significant variable between groups.

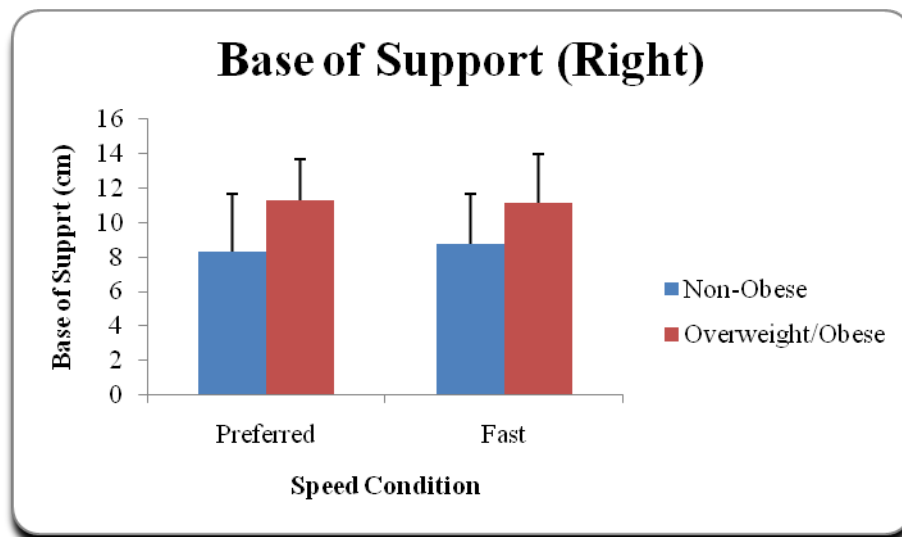


Figure 22. Histogram illustrating base of support (right) as a significant variable between groups.

APPENDIX IV

LIST OF VARAIBLES AND REGRESSION EQUATIONS

### List of Variables:

The list of variables (n=17) that entered both the preferred and fast speed regression models included:

<u>Variables:</u>	<u>Units of Measure:</u>
Velocity	cm/s
Step Count	amount of steps
Cadence	steps/min
Step Length (left/ and right)	cm
Stride Length (left/ and right)	cm
Gait cycle time (left/ and right)	seconds
Stance Time (left/ and right)	seconds
Base of Support (left/ and right)	cm
Single Support Time (left/ and right)	seconds
Double Support Time (left/ and right)	seconds

### Regression Equations

Preferred Speed:

$$\hat{Y} = -26.998 + 1.435 (\text{DSR}) + 0.123 (\text{Velocity})$$

Fast Speed:

$$\hat{Y} = -6.443 + 1.360 (\text{DSR}) + 0.374 (\text{BSR}) + -16.138 (\text{Cycle TL}) + 0.084 (\text{Stride LL})$$

Note:  $\hat{Y}$  = BMI (dependent variable)

DSR = Double support (%GC), BSR = Base of support, Cycle TL = Cycle time (left) and

Stride LL = Stride length (left)

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