

**KINEMATICS & KINETICS ANALYSIS OF THE LOWER EXTREMITY OF
NORMAL WEIGHT, OVERWEIGHT, AND OBESE INDIVIDUALS DURING STAIR
ASCENT & DESCENT**

By

Nok-Hin Law, B.Sc.

Submitted to the Faculty of Graduate and Postdoctoral Studies

in partial fulfillment of the requirement

for the degree of Master of Science in Human Kinetics

University of Ottawa

© Nok-Hin Law, Ottawa, Canada, 2013

Abstract

Objective: To examine the effects of body mass and sex on the joint biomechanics of the lower extremity in three groups, normal weight, overweight, and obese individuals, during stair ascent and descent.

Subjects: The subjects in the study were grouped according to their body mass index (BMI). Nineteen normal weight (8M and 11F; BMI: $22.1 \pm 1.8 \text{ kg/m}^2$), 18 overweight (14M and 4F; BMI: $27.4 \pm 1.3 \text{ kg/m}^2$) and 8 obese subjects (3M and 5F; BMI: $33.3 \pm 2.5 \text{ kg/m}^2$) were recruited.

Measurement: Joint mechanical loading presented by joint moment of force and peak joint angles at the hip, knee, and ankle during stair climbing were recorded and analyzed using a motion analysis system with 10 cameras and 4 force plates.

Results: The MANOVA analysis and linear regression analysis showed significant impacts of body mass on the peak joint moment of force at the knee and ankle in the sagittal plane, while sex differences were found in the peak joint angles in frontal and sagittal plane. A significantly larger knee extensor moment ($p=0.026$) was noted among the overweight participants compared to the normal weight participants during descent. The obese group had a significantly larger ankle abductor moment than the normal weight ($p=0.031$) and overweight ($p=0.002$) during descent. The female had a significantly smaller knee extension angle and larger knee valgus angles compared to the males when descending the stairs. The females also showed significantly larger peak ankle plantar flexion angles during ascent ($p<0.05$; $r(51)=0.61$) and descent ($p=0.004$; $r(51)=0.52$), and larger ankle adduction angles during ascent ($p=0.001$; $r(51)=-0.53$).

Conclusion: There were sex differences in the joint angles in frontal plane during stair climbing regardless of body mass; women tended to abduct their knees more during descent. Body mass did have a significant influence on the knee and ankle joint loading during stair climbing, as the overweight participants experienced higher joint loading particularly at the knee than the normal weight and obese groups during descent.

Keywords: kinematics, kinetics, obesity, stair climbing.

Acknowledgements

First and foremost, I would express my most sincere gratitude to my supervisor, Dr. Jing Xian Li, for her wisdom and guidance throughout my journey as a Masters student. This thesis would not have been possible without her endless support and meaningful teachings. I'm truly grateful for having her as my supervisor and also for the opportunity to experience life as a Masters student, which has been one of the best and most rewarding experiences in my life. It has been a privilege to have to have Dr. Li as my supervisor and mentor.

I would also like to thank the members of my committee, Dr. Mario Lamontagne and Dr. Gordon Robertson, for their thoughtful comments and also for their time spent discussing the methodological issues that were encountered during my thesis. Their experience and knowledge that they shared with me were invaluable in helping me improve my thesis. I would also like to extend my thanks to Dr. Ollie Jay and Dr. Stephanie Amos for their advice and help in the statistical proportion of my thesis. I owe much gratitude to my fellow colleagues and collaborators who helped throughout, particularly Daniel Varin (M.Sc.) and Mario Lamontagne (Ph.D) who provided normal weight individual data for the completion of this present thesis. This thesis would not have been complete if it wasn't for their guidance and help. Many thanks also go to Soul Lee (M.Sc.) who helped my brother and me during our initial data collections. We owe much gratitude for the time she spent with us in helping us with the equipment and software. To all my fellow colleagues at the Biomechanics lab, I would like to thank everyone, especially Liam, Adam, Elizabeth, Li, Andrew, Kevin, Teressa, Giulia, and Geoffrey. I could not have made it without your friendship, help, and support.

Finally, I wish to express my warmest appreciation to my twin brother (a.k.a. my right-hand man) who stuck with me throughout my journey. It was because of us working together, which allowed both our data collection to go smoothly. I was extremely fortunate to have his help and also to be blessed in having a brother like Nok-Yeung.

And most importantly, I would like to dedicate this thesis to my parents for all their guidance, support, and love that they have provided me. Without both of your love and support, I would not have finished this thesis. Furthermore, I would not be the person I am today if it wasn't for their guidance.

"Our greatest glory is not in never falling, but in rising every time we fall."

-Confucius

TABLE OF CONTENTS

CHAPTER I: INTRODUCTION.....	7
1.1 Background of the Study.....	7
1.2 Research Question.....	9
1.3 Variables.....	9
<i>Independent Variables</i>	9
<i>Dependent Variables</i>	10
1.4 Hypothesis.....	11
1.5 Rationale.....	12
1.6 Limitations.....	13
CHAPTER II: LITERATURE REVIEW.....	15
2.1 Introduction.....	15
2.2 Stair climbing kinematics	18
2.3 Stair climbing kinetics	21
2.4 Stair climbing sex differences.....	24
2.5 Principles behind participant classification.....	26
CHAPTER III: METHODOLOGY.....	28
3.1 Participants.....	28
3.2 Instruments.....	29
3.3 Procedures.....	32
<i>Participant and equipment preparation</i>	32
<i>Marker placemen</i>	32
<i>Data collection and testing protocol</i>	34
3.4 Data Processing	35
3.5 Statistical Analysis.....	36
CHAPTER IV: RESULTS.....	37
4.1 Temporo-Spatial Parameters	37
4.2 Kinematics.....	39
4.3 Kinetics.....	47
CHAPTER V: DISCUSSION AND CONCLUSION.....	53
5.1 Temporo-Spatial Parameters.....	53
5.2 Kinematics.....	54
5.3 Kinetics.....	61
5.4 Limitations.....	66
5.5 Conclusion.....	69
REFERENCES.....	70

LIST OF FIGURES

Figure 1: Mean hip, knee and ankle joint angles at stair ascent (black) and descent (open-line) from published work.....	20
Figure 2: Mean hip, knee and ankle joint moments at stair ascent (black) and descent (open-line) subjects from published work.....	20
Figure 3: The three dimensional set-up of the testing area with the ten infrared cameras.....	30
Figure 4: Force plate set-up.....	30
Figure 5: Staircase apparatus.....	31
Figure 6: Anatomical landmarks of the University of Ottawa marker set for the motion capture during data collection.....	33
Figure 7: Typical ascent trial with right leading leg striking the first force plate on step 1 and then step 3.....	34
Figure 8: Typical descent trial with right leading leg striking the force plate on step 2 and then the ground.....	34

LIST OF TABLES

Table 1: Participant's average age, body mass, body height, and body mass index.....	37
Table 2: Mean and standard deviation for temporo-spatial parameters during stair climbing for normal weight, overweight, and obese participants.....	38
Table 3: Correlation (r) and r^2 values with F change values from regression analysis for the effects of body mass and sex on the temporo-spatial parameters.....	38
Table 4: Mean and standard deviation for sagittal peak joint angles ($^{\circ}$) during stair climbing for females and males.....	40
Table 5: Correlation (r) and r^2 values with F change values from regression analysis for the effects of body mass and sex on sagittal peak joint angles (n=51).....	41
Table 6: Mean and standard deviation for frontal peak joint angles ($^{\circ}$) during stair climbing for females (n=20) and males (n=25).....	42
Table 7: Correlation (r) and r^2 values with F change values from regression analysis for the effects of body mass and sex on frontal peak joint angles and ROM (n=51).....	47
Table 8: Mean & standard deviation for peak extensor and flexor moments during stair climbing.....	48
Table 9: Correlation (r) and r^2 values with F change values from regression analysis for the effects of body mass and sex on peak extensor and flexor moment of force data.....	48
Table 10: Mean & standard deviation for peak abductor and adductor moments during stair climbing.....	50
Table 11: Correlation (r) and r^2 values with F change values from regression analysis for the effects of body mass and sex on peak abductor and adductor moment of force data...	50

Chapter I

INTRODUCTION

1.1. Background

In today's society, stair climbing is a challenging task for some individuals, especially since it is a common activity frequently performed during our daily living. Obese and overweight individuals may have more difficulty ascending and descending stairs, since the forces on the lower extremities tend to be higher compared to level walking (Nordin & Frankel, 1989; Schipplein et al., 1991). Studies on kinematic and kinetic aspects of stair climbing have been vast and well documented in the literature for normal weight individuals (Andriacchi et al., 1980; Livingston et al., 1991; Propapadaki et al., 2002; Riener et al., 2002; Lin et al., 2005; Lin et al., 2005; Lu & Lu, 2006; Protopadaki et al., 2007). Few studies, however, have examined the effects of obesity on the biomechanics of the musculoskeletal and locomotor system during walking and stair-climbing (Wearing et al., 2006; Hills et al., 2002).

To the author's knowledge, only one study by Strutzenberger et al., (2011) has examined the kinetic aspects of stair climbing among obese children. It is important to study the aging population because this segment of the population has an even higher risk in developing osteoarthritis (OA) compared to other subgroups in the normal population (Devos-Comby et al., 2006). Approximately 50% of those who are aged 65 or over have OA (Osteoarthritis, 2003). It is important to address this gap in the literature because individuals with a high body mass index (BMI) may be at risk of developing OA due to joint loading, which accelerate the 'wear and tear' of the joints (Griffin & Guilak, 2005). Individuals with a high BMI may suffer from disabling degenerative diseases, such as osteoarthritis, which affects nearly 2 million Canadians (Statistics Canada, 2001). The knee, in particular, is a weight-bearing joint that is commonly affected (Lohmander et al., 2008). These individuals are in a way trapped in a vicious cycle where they

are unable to perform physical activity due to their mobility problems and may gain weight as the result. In terms of whether a cause-effect relationship exists between obesity and OA, there has been strong evidence that suggests a major link between obesity and the increase risk of knee and hip osteoarthritis (Lohmander et al., 2008). In an 11-year longitudinal study of 11,026 men and 16,934 women in Sweden, the researchers provided strong evidence of how obesity was associated with the incidence of OA in the knee and hip. Generally, those with a higher body mass index also tended to have a higher risk of OA. The results from the study suggest that the biomechanics of the lower extremities, including loading condition in joints and locomotion patterns, is associated with the development of OA (Powell, 2008).

In summary, osteoarthritis is a growing health concern among the obese (Wearing et al., 2006; Chang et al., 2004; Chang & Sharma, 2007; Brady & Snieszek, 2003) and the elderly population (Devos-Comby et al., 2006). Individuals with a high BMI may be at risk of developing OA due to their body mass, which results in greater joint loading in the lower limb during stair climbing and the 'wear and tear' of their joints. Our health care system is paying the price with the rise in healthcare costs due to increase in number of health and other mobility related problems that are caused by obesity (Public Health Agency of Canada, 1998). Although there is strong evidence that suggests there is a very high correlation between having a high body mass index and the development of knee and hip OA, still few studies have examined how body mass influences the weight bearing joints during stair climbing. Moreover, there is also the need for studies to address whether there are sex differences in the biomechanics of the lower limb during stair climbing. Research on the effects of body mass on the lower extremity biomechanics during stair climbing would be of value because it may shed new light on mobility related problems, such as joint degeneration and OA, which are common among obese individuals.

1.3. Research Objectives

The purpose of this study was to examine the joint biomechanics of the lower extremity of normal weight, overweight, and obese individuals during stair ascent and descent. The primary research question aimed to address whether there were any differences in the temporo-spatial, kinematics and kinetics parameters of the hip, knee, and ankle joints between normal weight, overweight, and obese individuals during stair ascent and descent. Furthermore, the sex differences in the temporo-spatial, kinematics and kinetics parameters of normal weight individuals and overweight/obese individuals can be examined.

1.4 Variables

Independent Variable

The independent variables for the study were sex (2 levels: male and female) and body mass (3 levels: normal weight, overweight, and obese). The participants were eligible to participate in the study if they either have a normal body mass index (BMI), or a BMI within obese class I. According to the CDC (2000), those with a BMI from 18.5 to 24.9 are normal weight, while those with a BMI from 25.0-29.9 are overweight. Individuals with a body mass index from 30-34.9 are classified as obese class I.

INDEPENDENT VARIABLES	
Categories	Description
Body Mass	Normal weight Overweight Obese
Sex	Male Female

Dependent Variables

a) Temporo-spatial and Kinematic variables

The temporo-spatial parameters for the study were the stride time, single support time, double-support time, and clearance distance of each step during ascent and descent. The kinematic variables in this study included the hip, knee, and ankle joint angles in the frontal plane and sagittal plane. The peak joint angles were taken at each joint during ascent and descent.

b) Kinetic variables

The kinetic parameters were the moment of force at each joint in the lower limb. The joint moments for the lower extremity were based on the sagittal plane (x-direction) and frontal plane (y-direction). The average peak joint moments were calculated for each of the participants, and normalized by body mass (kg).

DEPENDENT VARIABLES	
Categories	Description
Temporo-spatial	Clearance distance (m) Stride time (s) Single support time (s) Double-support time (s)
Kinematics	Peak hip joint angles (°) Peak knee joint angles (°) Peak ankle joint angles (°)
Kinetics	Peak hip moment of force N•m/kg Peak knee moment of force N•m/kg Peak ankle moment of force N•m/kg

1.5. Hypothesis

Some published work has examined level walking among obese participants. Few studies have examined the biomechanics of the lower limb during stair climbing among overweight and obese participants. Obese individuals tend to show a slower walking speed, a longer stance phase duration, a shorter swing phase and a greater period of double-support compared to normal weight individuals (Spyropoulos et al., 1991; Hulens et al., 2003). Furthermore, it was found the obese participants' (39.5 ± 8.8 years; 123.4 ± 28.5 kg; 1.70 ± 0.11 m; BMI: 42.3 ± 7.7) neuromuscular function changed to produce gait patterns that resulted in lowered knee joint loading during level walking (DeVita & Hortobagyi, 2003). Based on the results from this study, it was hypothesized that similar to level walking, (i) the hip extension and ankle plantar flexion angles will be significantly higher among the overweight/obese participants when ascending the stairs, while their knee flexion angles will be significantly smaller compared to the normal weight participants when descending the stairs.

Mazlan et al. (2011) examined the 3D joint mechanics among 20 healthy normal weight subjects (10M & 10F, 23.4 ± 2.3 years, 1.6 ± 0.09 m, 58.45 ± 7.65 kg, and BMI: 22.4 ± 1.38 kg/m²) and 20 obese subjects (10M & 10F, 23.7 ± 2.2 years, 1.62 ± 0.08 m, 84.88 ± 9.36 kg, and BMI: 32.17 ± 1.46 kg/m²) during stair ascent. The study found the obese individuals adopted an altered movement strategy mainly at the hip compared to the normal weight individuals during stair ascent. The obese group had comparably higher hip joint moments than the normal weight group along all three planes of movement. Based on these findings, it was hypothesized that (ii) the hip adductor and knee extensor joint moment for the overweight/obese participants will be significantly higher than the non-obese subjects during stair ascent and descent, while their ankle moments in the sagittal and frontal plane will be similar to the normal weight subjects.

1.5. Rationale

In North America, the incidence rates of obesity are rising at a staggering rate (WHO, 1998; Stats Canada, 2006). According to a study by the Canadian Health Surveys, approximately 58.8% of Canadian adults (65.2% of men and 52.4% of women) were either overweight or obese (Statistics Canada, 2004). This study may provide insight into how body mass influences the biomechanics of the lower limb joint and the movement-related difficulties that were faced by the overweight and obese population.

Joint degeneration and knee osteoarthritis (OA) are common problems in overweight and obese people. In fact, obesity is an important risk factor for structural joint damage associated with OA, especially in the weight bearing joints such as the knee and hip (Lohmander et al., 2008). In an 11-year longitudinal study, Lohmander et al., (2008), found all measures of obesity including body weight, body mass index (BMI), and waist circumference were major risk factors for the development of OA in the knee and hip. The higher BMI of the subjects, the higher the risk the subjects had in developing OA. Moreover, the biomechanics of the lower extremities, including the loading condition in the joints and locomotion patterns, has been associated with the development of OA in obese individuals (Powell et al., 2005).

To date, studies on the joint biomechanics in stair climbing have predominantly focused on individuals of normal weight, particularly those without physical disabilities associated with obesity (Andriacchi et al., 1980; Livingston et al., 1991; McFadyen & Winter, 1988; Riener et al., 2002; Lin et al., 2005; Lu & Lu, 2006; Protopapadaki et al., 2007); few studies, however, have examined stair climbing (Wearing et al., 2006). The lack of studies on stair climbing among the overweight population is unfortunate because there is still a tremendous need for research in this area as more individuals are gradually aging and becoming overweight. Studies

in the past have found that the lower limb joints were exposed to high loads during walking (Ang et al., 1989; Le Veau et al., 1984). Overweight individuals would experience more loading at the joint because those with a heavier body mass would need to withstand the greater forces of gravity that are acting on their joint when they were walking, running, and climbing stairs. As shown in the past, the joint reaction force tended to be 3-5 times the body mass when walking (Nordin & Frankel, 1989), while stair climbing and running were associated with higher forces.

It is important to explore the impacts of being overweight and obese on the lower extremity biomechanics because it would shed light on the effects that body mass has on the locomotion and performance of obese individuals. Individuals with a high BMI are at risk of developing osteoarthritis due to joint loading, which accelerate the ‘wear and tear’ of the joints (Griffin & Guilak, 2005). Furthermore, this research would allow us to gain a better understanding of the reason why knee osteoarthritis is common mobility problem among obese individuals.

1.6. Limitations

It was important to remember that the experiment took place in a laboratory setting, which may not be representative of climbing the stairs in the real world. The experimental stair case only consisted of 3 steps, which may not fully reproduce the conditions that were faced by these individuals when they climb the stairs in the real world, which vary in height and tread depth.

Another limitation for the present study was the use of the inverse dynamic model in calculating the kinetic parameters from the force plate data during various activities including stair climbing. The kinematic data were one of the inputs in calculating the joint moments. Any

error resulting from movement of the markers or placement of the markers resulted in error in the kinematic calculations, and subsequently the accuracy of the kinetic data. Besides this limitation, another limitation to the inverse dynamic model was the fact the model assumed that the segments of the body are rigid structures (Robertson et al., 2004). This may not be the case during human movement since the tissue, bone, and ligament tend undergo deformation in more flexible structures such as the foot and trunk compared to more rigid structures as in the leg and thigh. As the result, the joint moment calculations for these more flexible structures were slightly less accurate compared to the more rigid structures (Robertson et al., 2004).

In terms of data collection, one of the most pressing matter that have yet to be addressed by researchers in the field of biomechanics was the issue surrounding movement from skin markers. Studies that have examined the biomechanics of locomotion and performance have noted that movement from skin artifact (Benoit et al., 2006; Wearing et al., 2006) and the progression angle (Messier et al., 1994) were major sources of error for the kinematic data among the obese individuals. As Wearing et al., (2006) pointed out, individuals with a high BMI tend to have a greater subcutaneous adipose tissue; hence, the use of skin-mounted markers to indicate the position and movement of skeletal structure is likely to cause error due to movement of the skin relative to the underlying anatomy (Wearing et al., 2006). To date, there has not been a viable solution as to minimize the amount of error from the skin markers by minimizing movement of the skin (Wearing et al., 2006).

Chapter II

REVIEW OF LITERATURE

2.1. Introduction

In North America, obesity is a growing epidemic not only in the United States, but also in Canada. According to Statistics Canada, two out of every three adults in Canada are overweight or obese (Statistics Canada, 2006). The high rates of obesity may not only be due to the rise in consumption of fast foods and junk food, but it may also be caused by physical inactivity (Catenacci, 2009). With the rise of the obesity, obese and overweight adults may have more difficulty in performing daily activities such as stair climbing due to their structural limitations and functional limitations (Hills & Wahlqvist, 1994; Riddiford et al., 1999; Hill et al., 2002).

Studies in the past on the kinematic aspects of stair climbing among normal weight individuals have noted the gait pattern is characterized by extension at the knee and hip (Riener et al., 2002). The knee and hip joints tend to extend forward during early stance phase to overcome the force of gravity, while the ankle joint plantar flexes as one moves from one step to another (Propadaki et al., 2002). Contrary to ascent, flexion occurs during descent at the hip and knee to control the force of gravity acting on the body (Riener et al., 2002; Lin et al., 2005). Studies have consistently reported that the knee and hip flexion angles tend to be greater during ascent than compared to descent (Andriacchi et al., 1980; Livingston et al., 1991; Propapadaki et al., 2002). The research surrounding the kinematics aspects of stair climbing among obese and overweight individuals has been limited. On the contrary, most of the research has been focused on the kinematics aspects of obese gait (DeVita & Hortobagyi, 2003; Messier et al., 1994) and sitting-to-standing (Sibella et al., 2003; Gali et al., 2000). DeVita & Hortobagyi (2003), for example, found obese individuals tended to reorganize their neuromuscular functions to produce

gait patterns that resulted in lowered knee joint loading. The obese participants in their study were also more likely to have approximately 5° more hip extension throughout stance phase, approximately 8° less knee flexion in early stance, and approximately 4° less knee flexion throughout stance compared to the normal weight participants. Furthermore, the obese subjects were also approximately 6° more plantar flexed throughout stance phase and approximately 7° more plantar flexed at toe-off.

In regards the kinetic aspects of during stair climbing, studies had been well documented in literature for normal weight individuals (Andriacchi et al., 1980; Livingston et al., 1991; McFadyen & Winter, 1988; Riener et al., 2002; Lin et al., 2005; Lu & Lu, 2006; Protopapadaki et al., 2007). Biomechanical studies have examined obese individuals during sitting-to-standing (Sibella et al., 2003) and walking (Spyropoulos et al., 1991; Messier et al., 1994; DeVita & Hortobagyi, 2003; Nantel et al., 2006; Browning, et al., 2007). Sibella et al., (2003) noted that the obese participants accomplished the sit-to-stand task by reducing their trunk flexion and reposition their feet backwards, which resulted in a lower hip joint moment and a greater knee joint moment compared to the normal weight participants. Furthermore, DeVita & Hortobagyi (2003) found that obese individuals tended to adopt an altered gait pattern that resulted in a lower knee joint loading. Few studies have examined the effects that one's body mass has on other forms of movement including stair climbing (Wearing et al., 2006; Hills et al., 2002). To the author's knowledge, only one study by Strutzenberger et al., (2011) has examined the loading pattern of the hip, knee, and ankle joint among normal weight and obese children during stair ascent and descent. It is important to note that the subjects were children ages 10-11. Hence, the lack of studies among aging population illustrates there is a need for future studies to examine stair climbing in the adult population, especially among the obese and overweight population.

In terms of sex differences during stair climbing, there have been few studies that have examined the differences in the joint biomechanics between males and females. Research in this area is still needed to examine whether the body fat distribution in males and female would influence the loading distribution pattern of the weight bearing joints during stair ascent and descent. Female individuals, for example, tend to have a higher lower extremity mass compared to male individuals (Chambers et al., 2010). The increased load in the lower extremity may place a greater demand on the weight bearing joints such as the knee. Studies on the kinematics and kinetics aspects of stair climbing on patients with knee osteoarthritis, for example, have noted female patients tend to experience greater loading than the male participants during stair ascent (Hughes et al., 2000). This finding was interesting because females individuals are believed to be twice as more likely to develop osteoarthritis of the knee than males (Felson et al., 1997). Research on the sex differences during stair climbing may provide new insight as to why females are more likely to develop osteoarthritis and also evidence for the association between loading distribution pattern and knee osteoarthritis.

Based on the review of the literature, it is evident there is still a need to examine the influence of increased body mass has on the kinematics and kinetics parameters of stair climbing. Moreover, it is unknown if there are sex differences in the biomechanics of the lower limb during stair climbing either in the normal weight population or in the overweight/obese population. This literature review will begin by providing a summary of the biomechanics of stair climbing in normal weight and overweight/obese individuals in terms of the:

- (i) Kinematics analysis of stair climbing
- (ii) Kinetics analysis of stair climbing
- (iii) Sex differences of stair climbing

2.2. Stair Climbing: Kinematic Analysis

One of the earlier studies on stair climbing found that hip flexion mostly occurred during swing phase of ascent (41.9°), while knee flexion occurred during descent (87.9°) (Andriacchi et al., 1980). More recent studies are consistent with these findings because as seen in studies with 10 normal weight males by Riener et al., (2002) and Lin et al., (2005), the hip tends to extend during most of stance phase, which later changes to hip flexion during the rest of swing phase in order to overcome the forces of gravity by lifting one's body from one step to another. Contrary to this, flexion at the knee occurred during descent in order to control the forces of gravity that are acting on the body.

In terms of the magnitude of the hip and knee joint angles, Prodapadaki et al., (2002) found that the subjects ($n = 33$) in their study had a significantly larger hip and knee joint angles during stair ascent compared to descent (Figure 1). During stair descent, there was significant differences at the knee during stance phase of descent as the knee tended to flex more than twice as much going from step to step (68.9°) as it did going from step to floor (28.9°). With regards to the angles at the ankles, Andriacchi et al., (1980) and Livingston et al., (1991) reported mean maximum plantar flexion angles of 25.6° and 30° , respectively; while Prodapadaki et al., (2002) reported maximum plantar flexion angles of 40.08° . The different results among the studies may be due to different subject height, step dimension, marker placement, & motion analysis system.

Riener, Rabuffetti and Frigo (2002) documented the lower extremity mechanics of stair negotiation among normal weight male participants. The focus of this research was to understand the influence that various staircase inclinations of 24° , 30° and 42° had on joint moments and powers. The researchers found stair inclination did have a significant effect on the joint angles, but its influence was relatively low (Riener et al., 2002). It important to remember the

participants were male individuals. There is still a need for studies to examine whether there are gender differences during stair climbing.

Lastly, the subjects' body height was thought to be one of the factors influencing the biomechanics of stair walking. Livingston et al., (1991) reported that shorter subjects (mean height 115.9 cm (SD 2.1) used greater mean maximum knee flexion angles (92 °-105 °) than taller subjects (mean height 171.6 cm SD 2.1) whose angles ranged from 83 ° to 96 °. Few studies have examined the effects that body mass has on the joint angles of obese and non-obese individuals during stair climbing. Among the limited studies that have examined obese gait, researchers have noted obese individuals tend to walk in an upright posture to reduce their hip and knee flexion angles (DeVita & Hortobagyi, 2003). Contrary to level walking, it may be interesting to note patients with knee OA tended to lean their trunk forward more than the control throughout stance of stair climbing (Assay et al., 2008). This technique or strategy has also been noted among patients with total hip arthroplasty (THA) who leaned forward during stair ascent, which resulted in a reduced hip flexion angle near the end of the gait cycle (Lamontagne, Varin, & Beaulieu, 2011). It is believed that the patients with knee OA lean forward as a way to reduce loading at the knee (Assay et al., 2008), while the THA patients lean forward to reposition the body as a way to increase their feeling of stability (Focher et al., 2008). It would be interesting for future studies to examine whether obese individuals adopt a similar strategy during ascent.

Based on the review of the literature on the kinematics analysis of stair climbing, it is evident that few studies have examined the kinematic parameters during stair climbing among overweight and obese participants. In the futures, there is a need for studies to fill in this gap in the literature by examining and comparing the difference in joint angles, speed, etc. among obese and overweight participants vs. normal weight participants when performing stair climbing.

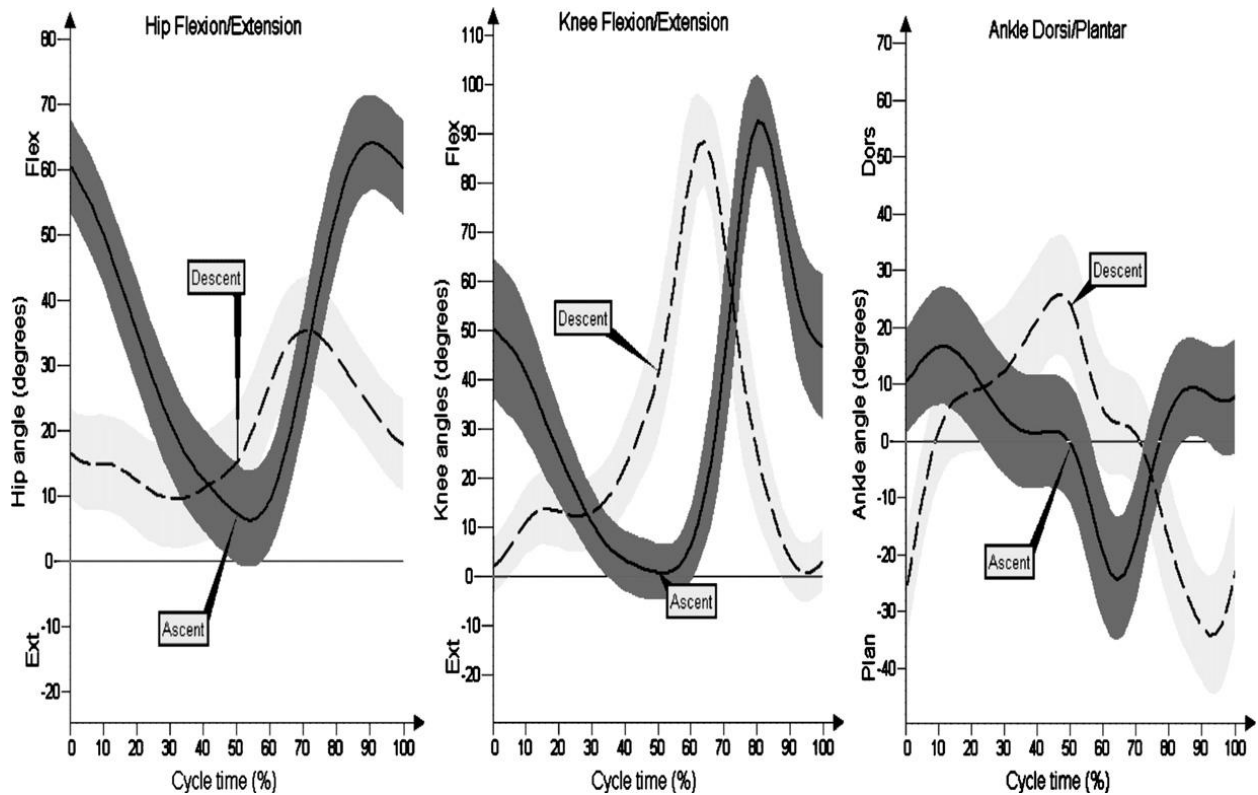


Figure 1: Mean hip, knee and ankle joint angles during ascent (black) and descent (open-line). The black line and open-line represent the mean during ascent and descent, while the dark and pale shades represent the standard deviations (SD) during ascent and descent (Protopapadaki et al., 2007).

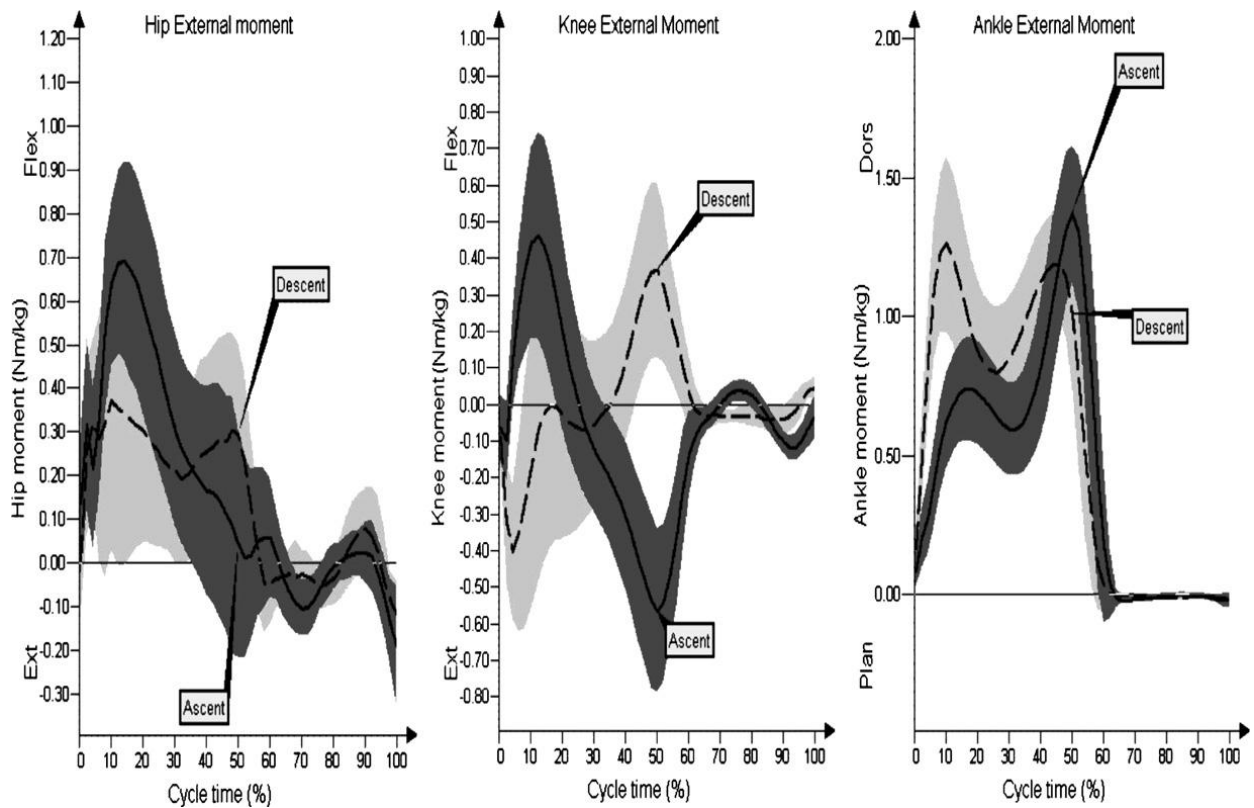


Figure 2: Mean hip, knee and ankle joint moments during ascent (black) and descent (open-line). The black line and open-line represent the mean during ascent and descent, while the dark and pale shades represent the standard deviations (SD) during ascent and descent (Protopapadaki et al., 2007).

2.3. Stair Climbing: Kinetic Analysis

Studies that have examined the kinetic properties of stair climbing have found that stair walking may be more demanding than level walking on the joints of the lower limb due to loading. As mentioned before, Andriacchi et al., (1980) examined the lower limb mechanics of stair climbing in ten normal weight male participants. The researchers found that the knee & hip joint moments were largest during descent (Andriacchi et al., 1980). It is important to note, however, that the researchers in the study calculated the joint moments by taking the cross product of the vector that was defined by the position of the joint centre and the vector defining the ground reaction force of the foot, which neglected the contributions from inertial terms and segment weight. This method was thought to be inaccurate and increases error (Wells, 1981). In a later study by Livingston et al., (1991), the researchers' results pointed out the importance of considering the subjects' height and age when examining stair walking data. Similar to Andriacchi, Livingston et al., (1991) reported higher knee moments during descent.

In terms of the hip and knee moments in the frontal plane, both Riener et al., (2002) and Lin et al., (2005) reported moments in normal weight individuals during ascent and descent. Riener et al., (2002) reported the hip and knee moments in the sagittal plane, while Lin et al., (2005) reported hip and knee moments in the frontal, sagittal, and transverse planes. Both studies reported abductor moments were required at both the hip and the knee for most of stance phase during ascent and descent. In the study by Lin et al., (2005), the researchers noted that one defining features in the knee moments of frontal plane was the fact that there were two peak abductor moments in the knee that characterized stair ascent and descent. And for the hip abductor moments, the peak was largest during stair descent. Research on the frontal joint moment of the hip and knee has generally reported the importance of the hip and knee abductors

were for stabilization. Nadeau et al., (2003) emphasized the importance of the hip abductors in controlling the pelvis during stair ascent and descent, while other studies such as Lamontange, Beaulieu, & Beaulé (2009) have also reported similar findings in regards to the hip abductor moments being important in pelvis and trunk stability for the THA patients during stair ascent and descent. At the knee level, both the Reiner et al., (2002) and Lin et al., (2005) findings were consistent with studies in the past including Andriacchi et al., (1980), Kowalk et al., (1996), who noted that knee abductor moment was required in early and late stance of descent in order provide propulsion and medial lateral stability. The structures that normally provide the knee moment includes the lateral collateral ligament and the ilio-tibial band of the medial side of the knee, which creates an abductor moment at the knee because the ground reaction force vector must pass medial to the knee joint centre (Kowalk et al., 1996).

In the sagittal plane, the hip produced an extensor moment during most of stance phase in order to lift the body during stair ascent, which later changed to flexor moment during the rest of swing phase (Reid et al., 2005; Riener et al., 2002). Contrary to this, the hip produced a flexor moment during descent rather than an extensor moment (Riener et al., 2002). At the knee, both Andriacchi et al., (1980; 1991) and Lin et al., (2005) found similar peak knee extensor/flexor moments curves during stair ascent and level walking, with peak of stair ascent begin almost 2 to 3 times larger than level walking. During ascent, the knee extensor moment gradually became smaller towards the end of swing phase (Riener et al., 2002; Lin et al., 2005). Contrary to ascent, walking down the stairs required a 2nd extensor moment at the knee to lower the body to the next step by controlling flexion at the knee (Reid et al., 2005). These findings have been shown by other studies including Kowalk et al., (1996), McFadyen & Winter, (1988), Salsich et al., (2001), and Riener et al., (2002). With a increased moment at the knee, this may cause greater loading

because the posterior cruciate ligament (PCL) may need to absorb the patellar tendon force and peak flexor force that is acting on the ligament during ascent (Lu & Lu, 2006). In contrast, the anterior cruciate ligament (ACL) may also need to withstand the higher forces during descent (Lu & Lu, 2006). Hence, walking up and down the stair may be taxing on the lower limbs because the PCL and ACL may need to withstand the forces acting on the joints.

In terms of the ankle moment, both Beaulieu et al., (2007) and Riener et al., (2002) found there was a reduced plantar flexor moment at the ankle during descent among normal weight participants. The peak ankle plantar flexor moments for descent were significantly smaller than those for ascent and walking. Beaulieu et al., (2007) explained that the reduce ankle plantar flexor moment could be attributed to the double-peak support moments that were produced during stair descent, which resulted in an increase in knee extensor moments that were significantly higher to level walking.

For kinetics analysis of stair climbing, it is evident that there have been numerous studies that have examined stair climbing among normal weight participants, but very few have examined stair climbing among overweight and obese participants. Although it is known that stair climbing is a more demanding task on normal weight individuals, it is important to reemphasize that this task may be more demanding for obese individuals, since the higher biomechanical loading conditions that they experience in the lower limb has been shown to be associated with the development of OA (Powell et al., 2005).

In summary, the studies showed that among normal weight participants was that stair climbing was more strenuous task than level walking as the structures in the knee joint need to withstand high contact and shear forces during weight bearing, with the compressive loads reaching 2-3 times the compared to level walking. While for obese individuals, their joint

reaction forces in the lower extremity joints tend to be higher compared to normal weight people. (Browning, et al., 2007; Hulens et al., 2003). Sibella et al., (2003) also noted there was a heightened knee joint moment that was almost doubled among the obese adults compared to the non-obese adults during a sitting-to-stand task. Few studies have examined whether these heightened knee joint moment were attributed to sex differences in terms of body fat distribution. The current study will be the first to address this gap in literature and also to make a distinction the loading patterns at the weight bearing joints between males and females.

2.4. Stair climbing: Sex Differences

In regards studies on sex differences in stair climbing, there have been few studies that have examined the sex differences that may exist in the joint kinematics of stair climbing among a group of osteoarthritis patients and normal weight individuals. Among the limited studies, Hughes et al., (2002) found females knee osteoarthritis patients (ascending 96.5°; descending 89.9°) had a 6 to 8 degree greater peak knee flexion angle compared to the male patients (ascending 88.5°; descending 83.5°). Though the study did provide a kinematic analysis of the sagittal plane angles, however, it did not provide an analysis for the frontal plane. This was unfortunate because after all, it is along the frontal plane where most knee disorders and lower limb injuries were believed to have the highest rate of occurrences (Messier et al., 1996). Obese individuals may be at risk of developing varus misalignment or ‘bow legged’ syndrome due to their excess body weight (Gibson et al., 2010). It is believe that the varus knee alignment is a mediating factor that predisposes a person to medial compartment knee OA (Sharma et al., 2010; Cerejo et al., 2002; Brouwer et al., 2007; Sharma et al., 2001), and a person’s added body weight (Gibson et al., 2010) can lead to varus knee joint alignment. The loading distribution

pattern at the knee joint may lead to the development of osteoarthritis of the knee, which is especially common among female individuals (Felson et al., 1997).

Besides these kinematics studies, there have also been few that have examined the kinetic aspects of stair climbing in terms of the sex differences that may exist between the obese individuals and normal weight individuals. Studies on the effects BMI has on postural control have found males generally tend to have a greater trunk and upper extremity mass, while females tend to have a greater lower extremity mass (Chambers et al., 2010). The fat distribution of an individual is an important consideration from a biomechanical perspective because adiposity may move a person's centre of mass forward and hence, affect his or her postural stability in response to the perturbation (Corbeil et al., 2002). Males tend to have an android body type (apple-like body shape) that is concentrated in their thorax-abdominal region, while females tend to have a gynoid type (pear-like body shape) with greater adipose tissue in their lower extremity (Clark, 2004). With a greater mass in either region, their fat distribution may affect their joint moments and loading at the lower extremity. Patients with knee osteoarthritis (OA), for example, have noted a significantly higher ($p=0.0325$) knee extensor moment among the females patients ($0.24 \text{ N}\cdot\text{m}/\text{kg} \pm 0.19$) compared to the male patients ($0.18 \text{ N}\cdot\text{m}/\text{kg} \pm 0.16$) during stair ascent (Hughes et al., 2000). The authors' findings were interesting because it provided evidence regarding the influence that joint loading has on knee osteoarthritis, which is believed to be twice as more common among women than men (Felson et al., 1997).

Based on the review of the literature, there is still a need for future studies to examine the influence that one's body mass and sex plays in the kinematics and kinetics aspects of stair climbing. Hence, the primary objective of the study was to examine the effects of increased body mass on the kinematics and kinetics of the hip, knee, ankle during stair climbing. This

paper also aims to examine the influence of sex and whether there were any sex differences regarding the kinematic and kinetic aspects of the lower extremity during stair ascent and descent among a group of normal weight and obese/overweight participants.

2.5. Subject Classification for body mass index (BMI)

Over the years, the body mass index (BMI) is one of the most commonly used techniques to determine whether an individual is overweight or underweight. But in more recent studies, this method has been shown to be unsuitable for those who are muscular (i.e., athletes), pregnant and over the age of 65 (Sizer & Whitney, 2006). In regards to children's BMI, the body mass index may also be unsuitable for this segment of the population due to their difference in size and developmental factors.

According to the Centre of Disease Control's (2000), those with a BMI of less than 18.5 are underweight, while individuals with a BMI of 18.5 to 24.9 are classified as normal weight. Individuals with a BMI of 25.0 to 29.9 would be classified as overweight, while those with a BMI of 30.0 and above would be classified as obese (starting from obese I, obese II, etc.). The problem with using BMI, however, is the fact that the value does not indicate the percentage of fat in the individual. Hence, a person with a greater muscle mass, as mentioned before, may have a higher BMI even though they may have a smaller percentage of body fat.

Besides the BMI and IOTF classification, another common way to classify the participants' weight would be to measure their waist-to-height ratio (WHtR). This value is calculated simply by dividing one's waist size by one's height (Clymer, 2010). Normally, a healthy waist circumference for men is no larger than 102 centimeters (40 inches), while for women it should be no larger than 88 centimeters (35 inches) (Sizer & Whitney, 2006). By

dividing the individual's waist size with their height, this measured value will be more representative of the individuals' total fat distribution.

Of all these techniques, the most accurate techniques would be to use instruments that are designed specifically to measure body composition and fat distribution. The dual energy X-ray absorptiometry (DXA), for example, measures two beams of X-ray energy as they pass safely through body tissues, and provides clinicians an assessment of the patients' total body fatness, fat distribution, and bone density (Sizer & Whitney, 2006). Another method to assess body fatness would be to use the bioelectrical impedance test, which involves passing harmless electrical charges through the body in order to measure body fatness (Sizer & Whitney, 2006). Lastly, the underwater weighing technique and the fatfold test are two other common techniques that used in the laboratory or clinical setting to assess body fatness. Depending on the availability and feasibility of the equipment, the DXA scan would be the prefer method to be used to classify the participants. Since the participants in the study will primarily be adults, the BMI would also be the most suitable and practical measurement techniques to be used to assess body fatness.

Chapter III

METHODOLOGY

3.1. Participants

In all, twenty normal weight individuals, 9 males and 11 females, (61.2 ± 6.0 years; 163.8 ± 7.7 cm; 59.5 ± 7.9 kg), twenty one overweight, 14 males and 7 females, (59.4 ± 6.0 years; 170.4 cm ± 9.8 ; 78.9 ± 11.4 kg), and eleven obese individuals, 3 males and 8 females, (58.1 ± 6.0 years; 166.7 ± 8.6 cm; 93.8 ± 12.8 kg) were recruited to participate in this study. The participants were eligible to participate in the study if they were between the ages of 50-75 years and had a BMI within 18.5 to 34.9.

Prior to the start of data collection, the participants were classified into three groups: the normal weight group, overweight, and obese group based on their BMI. Those with a BMI of 18.5 to 24.9 were classified as normal weight, while individuals with a BMI of 25.0 to 29.9 were classified as overweight (CDC, 2000). And those with a BMI of 30.0-34.9 were classified as obese class I (CDC, 2000). It has been shown a person's body mass tends to roughly vary 5-15% of body weight during the day (about ± 1 kg in a person with 60 kg) (Lehikoinen, 1987). It was calculated that 1 kg was equal to 0.32 BMI. Hence, individuals who had a BMI within 24.7 to 25.3 were excluded because they were between normal weight and overweight according to the CDC's classification for BMI. In addition to this, individuals who had a BMI within 29.7 to 30.3 were excluded because they were within the borderline for overweight and obese I. A total of 7 participants were excluded because they fell within the borderline of either normal weight or overweight and overweight or obese.

Participants who suffered from neuromuscular disorders, musculoskeletal injuries, cardiorespiratory, and weight fluctuations in the past 6 months were excluded from the study. This study was approved by the University of Ottawa research ethics committee and each of the

participants was required to sign an informed consent form. For further information as to the principles behind the weight classification, please refer back to the section entitled *principles behind subject classification*. To determine the number of participants that will be needed for the study, a power analysis was performed during an earlier pilot study by Law & Li, (2011).

3.2. Instrumentation

Motion Analysis System

Ten infrared, high speed, optical cameras (Vicon MX-13, Oxford Metrics, oxford, UK) captured at 200 Hz the 3D trajectories of 43 reflective markers placed on the participant's body based on the University of Ottawa Motion Analysis Model (UOMAM, a modified version of Plug-in-Gait model (VICON, Oxford Metrics, Oxford, UK) during the stair climbing trials. The cameras were either hanging from the ceiling or resting on a tripod, and positioned so that all of the markers were captured within the testing area.

Prior to the start of data collection, the cameras were calibrated in two parts: a dynamic calibration followed by a static calibration. A dynamic calibration was performed by using a T-shaped (240 mm) wand with 3 reflective markers at the end. The wand was waved around for a certain period of time in order to establish the recording volume, which the cameras capture at least 3000 frames with the 3 visible markers. Afterwards, static calibration was performed. This part of the calibration was performed using an L-shaped frame (ErgoCal, 14 mm), which was placed at the centre of the capture volume to set the origin of the global coordinate system. The X axis was the axis for the anterior/posterior direction in which flexion and extension movement of limbs occurred, while the Y axis was for lateral/medial direction in which adduction and abduction occurred, and the Z axis was for the vertical direction in which internal and external rotation occurred.

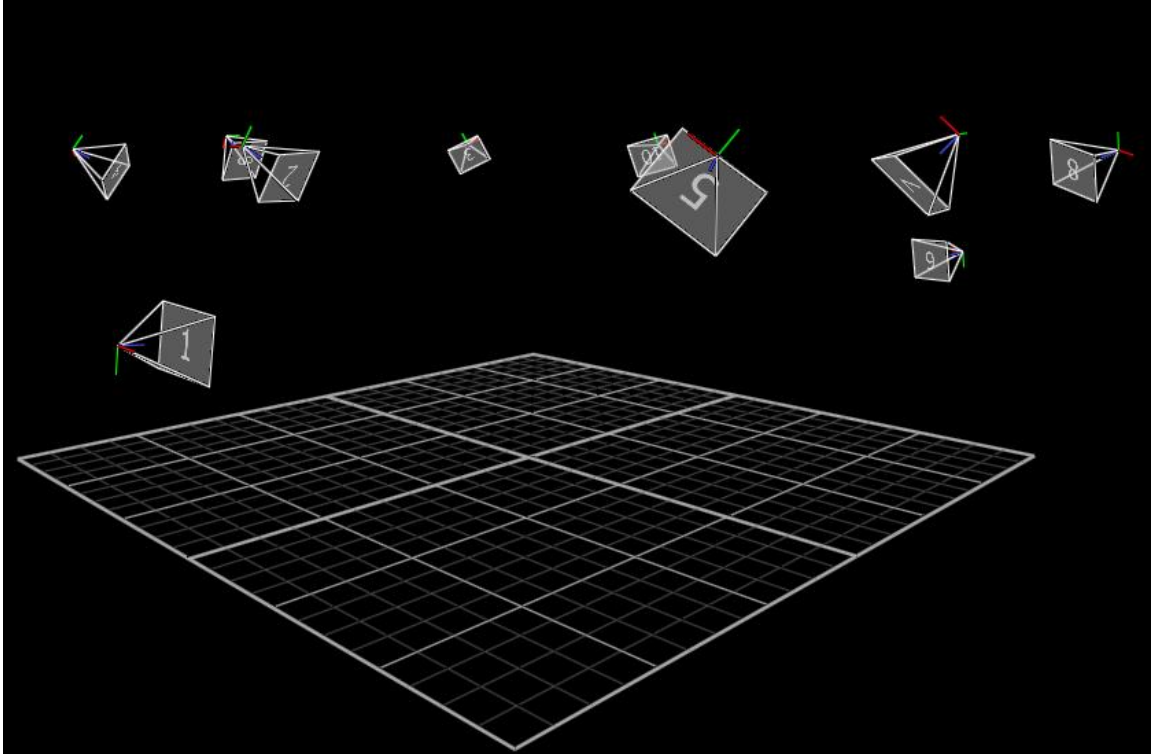


Figure 3: The three dimensional set-up of the testing area with the ten infrared cameras.

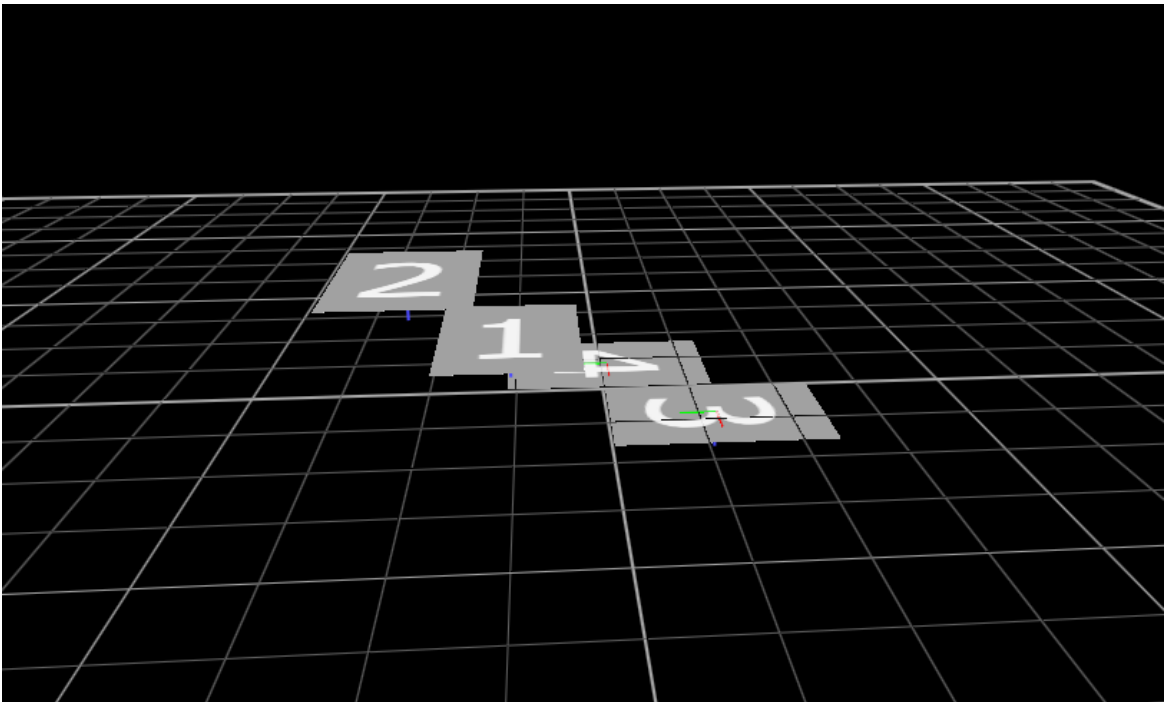


Figure 4: Force plate set-up. (1 & 2: models 9286AA, Kistler Instruments Corp. Winterhur, Switzerland; 3 & 4: FP, 4060-08, Bertec Corporation, Columbus, OH, USA)

Force Plates

The experimental staircase comprised of three steps 17.8 cm high and 28 cm deep, with the first and second steps embedded with portable force plates (Model 9286AA, Kistler Instruments Corp, Winterhur, Switzerland). Four force plates, two portable Kistler built into the staircase and two Bertec (Model FP 4060-08, Bertec Corporation, Columbus, OH, USA) built on the ground, were used record the ground reaction force at 1000 Hz.

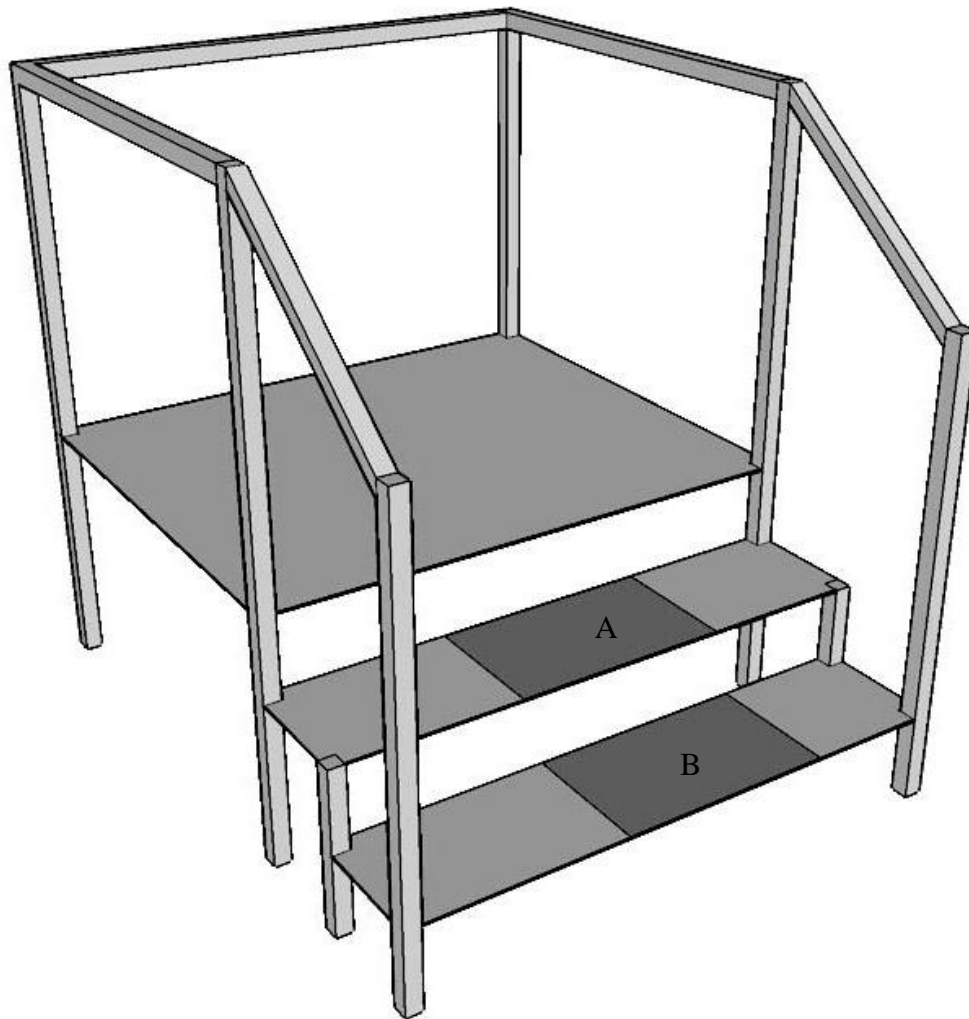


Figure 5: Staircase apparatus. Kistler force A and B are located on the first two steps. (Source: Varin, D. (2011). *Kinematics and Kinetics of Total Hip Arthroplasty Patients during Gait and Stair Climbing* (Masters Dissertation). Retrieved from: uOResearch Thesis and Dissertation database.)

3.3. Protocols

Participant and Equipment Preparation

Prior to the arrival of the participant, the equipment and cameras were started up and calibrated. Once the participant arrived, the participant was briefed about the purpose of the experiment, the study's objectives, and the procedure that was followed by the researchers. After the participant was provided with this information, he or she was asked to sign a consent form. The person administering the form ensured that the participant was aware that the forms remained anonymous and that he or she had the right to withdraw from the study at any time during the experiment when he or she wished to do so.

Before the start of data collection, the participant was asked to change into a body suit or tight fitting clothing to reduce movement of the reflective markers and then his/her anthropometric data were collected. The ankle width (cm), knee width (cm), and leg length (cm) for both the right and the leg were measured and recorded, along with their height (cm) and weight (kg) as well as waist circumference. The participant's anthropometric data were later entered on into Vicon Motion Analysis System for the calculation of the moment of force.

Marker Placement

In all, there were 43 reflective markers that were placed on the participants' body based on the anatomical landmarks that were outlined by the University of Ottawa Motion Analysis Model (UOMAM). Wristbands with reflective markers were provided to the participants. All of the important landmarks were located through palpation.

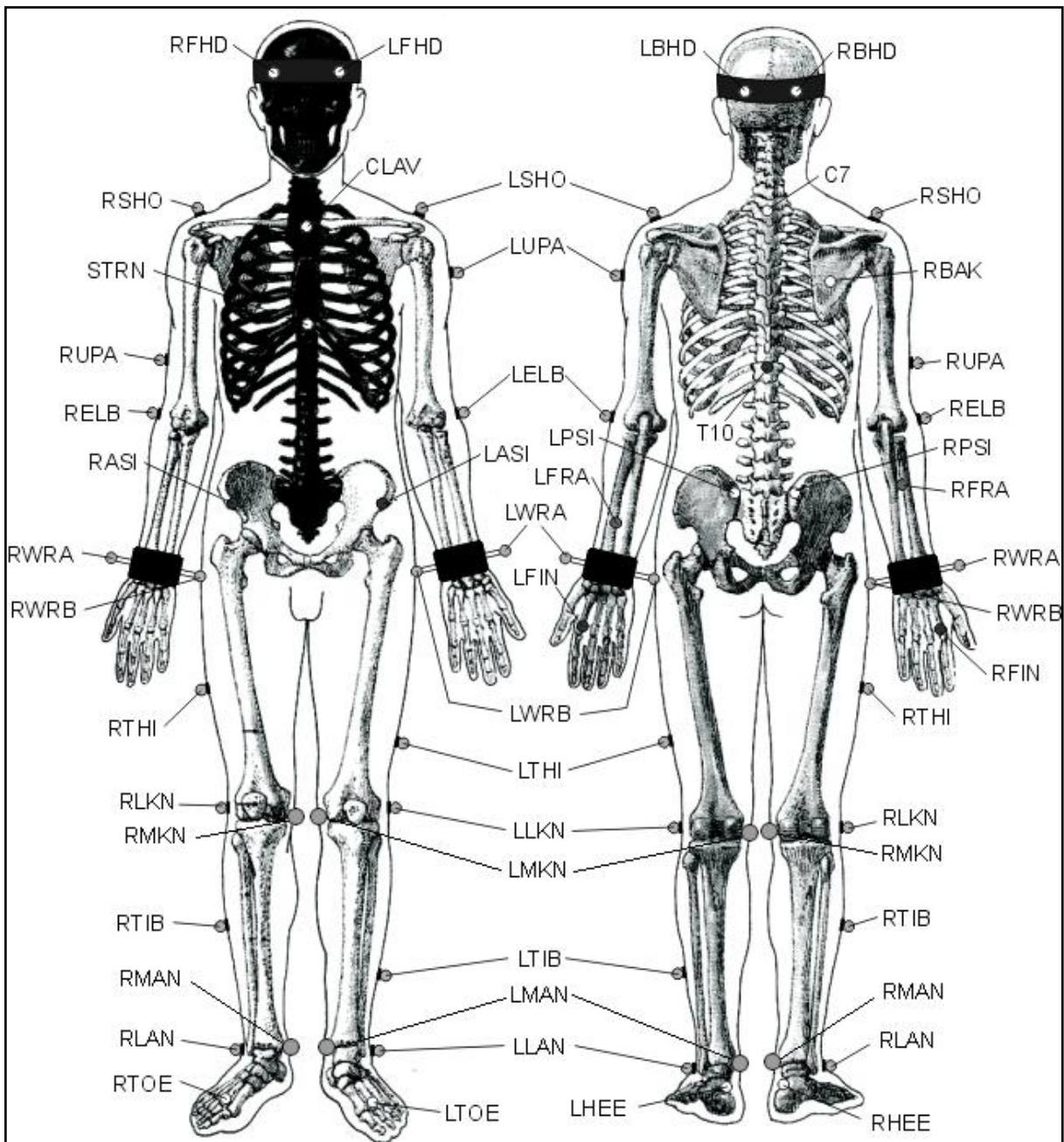


Figure 6: Anatomical landmarks of the University of Ottawa marker set for the motion capture during data collection

Data Collection and Testing Protocol

Once all of the required procedures prior to data collection were completed, a static trial of the participant was collected for 5 seconds to allow the cameras to read each of the reflective markers and to create a model in the Vicon Motion Analysis System. After this step has been completed, the dynamic trials proceeded.

During the data collection process, the participants in the study were allowed to first practice ascending and descending the stairs at their self-selected pace. When the participant was ready, the participant was asked to ascend the staircase in a similar manner with their right foot striking the initial force plate on the first step and then the third step (Fig. 7). While during descent, the participants were asked to start the descent with their right foot striking the force plate on the second step, and then the force plate located on ground (Fig. 8). In all, the participants in the study were asked to ascend and descend the stairs at a comfortable speed for a total of 5 trials with their right leg as the leading leg.

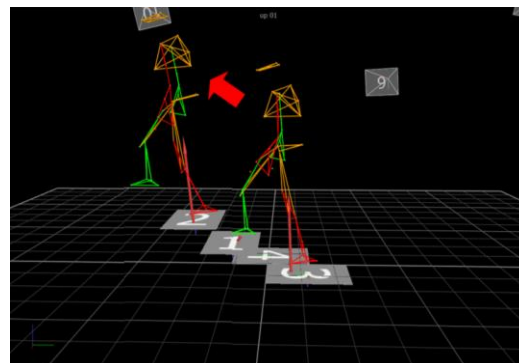
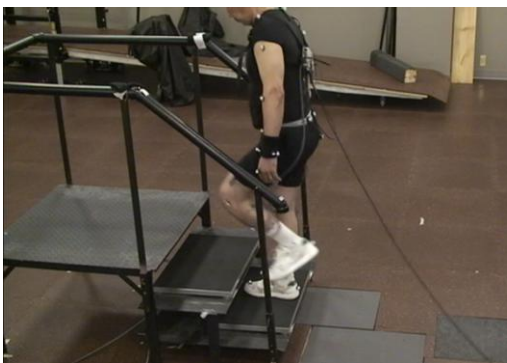


Fig.7: Typical ascent trial with right foot striking the first force plate on step 1 and then step 3

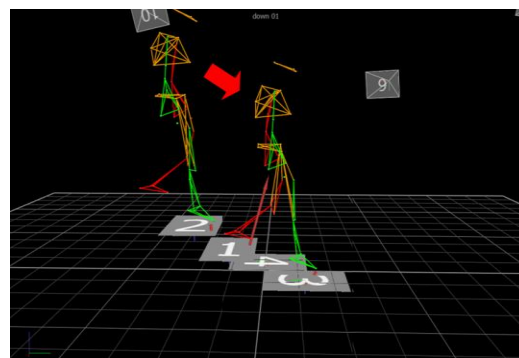
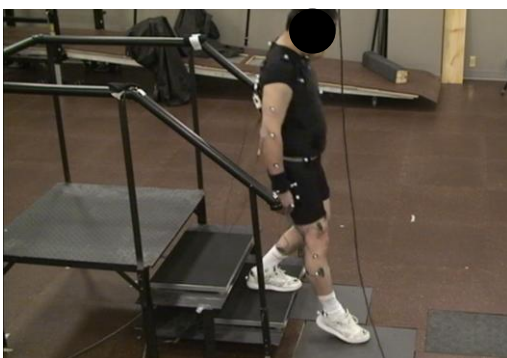


Fig.8: Typical descent trial with right foot striking the force plate on step 2 and then the ground

3.4. Data Processing

The stair climbing data for the participants were analyzed based two consecutive strides for the right leg. The stride period was normalized to the gait cycle (%) for stair climbing. The period in which heel-strike and toe-off occurred were visually inspected by examining the position of the virtual marker on the heel and the toe of the participant as they made contact with the ground or left the ground, respectively.

The three-dimensional coordinates of the reflective markers were collected during the locomotion task. VICON Nexus (v1.7.1) and the UOMAM model were used to calculate the hip, knee, and ankle angles for the frontal and sagittal planes. Once the joint angles were computed, the data were exported from Nexus to Excel (Microsoft, Washington, USA) where the maximum angle, minimum angle, and range of motion at each joint in all three planes were determined.

In regards to the kinetic data, the ground reaction forces were filtered using an 4th order 7Hz Butterworth filter to eliminate the slight oscillation of the staircase. The moment of the hip, knee, and ankle were calculated based on inverse dynamics model. The moment of force at each joint were calculated based on the subject's anthropometric measurements and the UOMAM model. Similar to the joint angles, the moment of force data were exported from Nexus to Excel (Microsoft, Washington, USA) where it was normalized by the participants' body mass (BM) to allow within subject comparison. The joint angles and moment data were based on the definitions that were defined by the UOMAM model. All of the trials for the study were cropped, normalized according to a 100% gait cycle, and finally averaged for a total of 5 trials in each of the participant.

3.5. Statistical Analysis

Prior to performing any statistical analysis, the data were first visually inspected by the researcher for any outliers. All the data were expressed as a mean \pm standard deviation (SD). The mean was calculated by taking the average of the five trials of stair climbing for each participant, and then a grand average was used to calculate the average of all of the participant's temporo-spatial, kinematic, and kinetic data.

A student's version Statistical package for Social Science (SPSS) version 20.0 software for Windows (SPSS Science, Chicago, Illinois) was used for the statistical analysis. The independent variables in the study were: "sex" (2 levels: male and female) and "mass" (3 levels: normal weight, overweight, and obese). To avoid the risk of Type I errors, a two-way MANOVA analysis was used instead of a two-way ANOVA analysis to determine if there were any significant differences between the sexes and between the body mass groups. The two-way MANOVA analysis was also used to determine whether there was a significant interaction between "sex" and "body mass" on the dependent variables. The dependent variables were the temporo-spatial parameters, joint angles, range of motion, and joint moment of force. When there was no significant interaction and no main effect of gender, the data were pooled for the males and females so a one-way ANOVA analysis and Tukey's Post-hoc test was performed to further investigate whether there was a significant difference in the masses. The one-way ANOVA analysis and Tukey's Post-hoc test was not performed on the factor of sex, since there were only two levels. Lastly, a linear regression analysis was used to investigate the possible influence of sex and BMI on the relation between the dependent variables. The linear regression was based on the total studied population (n=52), while the MANOVA analysis was based on a subset of the population (n=45). The level of significance was set at $p < 0.05$ for all statistical tests.

Chapter IV

RESULTS

All data are presented as means and standard deviations (SD). Table 1 provides the participants' information and their physical characteristics. The data were from 19 normal weight participants (BMI: 22.1 kg/m²), 18 overweight participants (BMI: 27.4 kg/m²), and 8 obese participants (BMI: 33.3 kg/m²) for the MANOVA analysis. Significant differences were found in the participants' body mass ($p < 0.05$) and body mass index ($p < 0.05$) between the three groups. There were no significant differences noted in the participants' body height ($p = 0.073$) (Table 1).

Table 1: Participants' information average age, body mass, body height, and body mass index

Group	Participants	Age (years)	BM* (kg)	BH (cm)	BMI* (kg/m ²)
Normal	n=19 (M: 8; F:11)	61.4 ± 6.1	59.5 ± 7.8	163.8 ± 7.9	22.1 ± 1.8
Overweight	n=18 (M:14; F:4)	59.7 ± 6.2	81.3 ± 10.2	172.1 ± 9.3	27.4 ± 1.3
Obese	n=8 (M:3; F:5)	60.3 ± 5.6	93.3 ± 9.9	167.6 ± 10.0	33.3 ± 2.5

M, male; F: female; BM, body mass; BH, body height

* $p < 0.05$: indicates a significant difference between the three groups

4.1. Temporospacial Variables

The MANOVA analysis did not find any significance interaction between mass and sex, ($F(16) = 1.151$, $p = 0.330$). Furthermore, the participants' body mass ($F(16) = 1.435$, $p = 0.153$) and sex ($F(8) = 1.326$, $p = 0.266$) did not have a significant influence on the temporospacial parameters. Since there was no significant interaction and no main effect of sex, the data for the male and female participants were pooled so a one-way MANOVA and Tukey's Post-hoc test could be performed. Table 2 presents the mean and standard deviation of the temporospacial parameters for the normal weight, overweight, and obese group.

Table 2: Means and standard deviations for temporo-spatial parameters during stair climbing for normal weight (n=19), overweight (n=18), and obese participants (n=8).

	Stride Time (s) Mean \pm SD	Double-support (s) Mean \pm SD	Single Support (s) Mean \pm SD	Clearance (m) Mean \pm SD
Ascent				
Normal	1.48 \pm 0.28	0.39 \pm 0.12	0.51 \pm 0.09	0.80 \pm 0.05
Overweight	1.64 \pm 0.27	0.47 \pm 0.14	0.52 \pm 0.06	0.80 \pm 0.07
Obese	1.61 \pm 0.19	0.46 \pm 0.07	0.53 \pm 0.07	0.78 \pm 0.05
Descent				
Normal	1.40 \pm 0.35	0.26 \pm 0.11	0.61 \pm 0.14	0.84 \pm 0.04
Overweight	1.50 \pm 0.36	0.32 \pm 0.12	0.63 \pm 0.15	0.82 \pm 0.03
Obese	1.44 \pm 0.16	0.33 \pm 0.03	0.61 \pm 0.09	0.86 \pm 0.09

The results from the regression analysis were also consistent with the MANOVA analysis. No significant differences were noted in the F values that would indicate an association between the effects of sex and mass on the stride time, single support time, and clearance distance. The regression analysis did, however, find a nearly marginable significance ($p=0.043$) in the F values that indicated an association between the double-support and the effects of body mass during ascent (Table 3).

Table 3: Correlation (r) and r^2 values with F change values from regression analysis for the effects of body mass and sex on the temporo-spatial parameters (n=51)

Temporo-spatial	Ascent					
	r gender	r BMI	r^2 gender	r^2 BMI	p value gender	p value BMI
Stride time (s)	0.073	0.213	0.005	0.050	0.610	0.139
Double support (s)	-0.020	0.286	0.000	0.083	0.887	0.043*
Single support (s)	0.115	0.103	0.013	0.024	0.420	0.480
Clearance distance (m)	-0.027	-0.235	0.001	0.056	0.850	0.100
Descent						
Stride time (s)	0.183	0.077	0.033	0.039	0.199	0.600
Double support (s)	0.054	0.260	0.003	0.070	0.704	0.060
Single support (s)	0.224	-0.013	0.050	0.051	0.114	0.907
Clearance distance (m)	-0.271	0.247	0.073	0.136	0.055	0.068

*, $p < 0.05$

4.2. Kinematics

The MANOVA analysis did not find any significant interaction between mass and sex in the peak joint angles ($F(48)=1.072$, $p=0.387$) and range of motion ($F(24)=0.716$, $p=0.815$) during ascent and descent. Sex did have a significant effect on the peak joint angles ($F(24)=4.393$, $p=0.002$) and range of motion ($F(12)=4.386$, $p=0.001$) during ascent and descent. And the participants' body mass did not show any significant effect on the peak joint angles ($F(34)=1.264$, $p=0.239$) and range of motion ($F(24)=1.210$, $p=0.272$).

Sagittal Plane:

Hip Joint

There was no significant difference noted between the male and female participants in terms of the peak joint angles and ROM in the sagittal plane during ascent and descent (Table 4).

Knee Joint

The female participants had a significantly smaller knee extension angle than the males during descent ($p=0.012$). The peak knee extension angle for the female participants was 4.2° , while the males had a peak angle of 7.0° ; a difference of approximately 3° (Fig 5). The ROM for the knee joint was also significantly larger ($p<0.05$) in the sagittal plane for the female participants (96.2°) compared to the male participants (90.3°) during descent (Table 4). Similar to the MANOVA analysis, the regression analysis found the effect of sex to be a statistically significant. The correlation coefficient for the peak extension angle during descent was $r(51)=0.329$, ($p=0.018$), which was a weak positive correlation. The r^2 values were 0.108 for gender and 0.171 for BMI (Table 5).

Ankle Joint

The male participants plantar flexed their ankles less compared to the female participants during ascent ($p < 0.05$) and descent ($p = 0.004$) (Table 4 and Fig 6). The female participants also used a significantly larger sagittal ROM when ascending the stairs ($p = 0.007$) and descending the stairs ($p = 0.003$) (Table 4 and Fig 6). The regression analysis found statistical significance in the effect that sex had on the differences found in the peak ankle plantar flexion angles during ascent $r(51) = 0.61$ ($p < 0.0001$) and descent $r(51) = 0.52$ ($p < 0.001$), which were both moderately positive correlations (Table 5).

Table 4: Means and standard deviations for peak joint angles and range of motion ($^{\circ}$) in the sagittal plane during stair climbing for females ($n=20$) and males ($n=25$).

		Gender				
		Female	Male	p-value		
Sagittal Plane	Ascent	Hip Flexion	70.2 \pm 7.3	67.4 \pm 4.7	0.066	
		Hip Extension	8.8 \pm 6.1	7.9 \pm 6.2	0.385	
		Hip ROM	62.8 \pm 4.2	60.0 \pm 4.8	0.092	
	Ascent	Knee Flexion	99.1 \pm 6.3	95.7 \pm 5.1	0.138	
		Knee Extension	7.3 \pm 5.4	7.6 \pm 6.5	0.753	
		Knee ROM	92.3 \pm 8.6	88.2 \pm 5.6	0.088	
	Descent	Ankle	DF	11.3 \pm 4.1	14.5 \pm 5.6	0.366
			PF*	-23.7 \pm 5.3	-15.6 \pm 3.7	0.000
			ROM*	35.9 \pm 5.2	31.2 \pm 5.7	0.007
		Hip	Flexion	42.7 \pm 9.2	41.3 \pm 5.6	0.495
			Extension	12.2 \pm 7.5	12.3 \pm 5.5	0.528
			ROM	30.5 \pm 4.3	29.1 \pm 3.6	0.847
Knee	Flexion	97.6 \pm 5.6	95.4 \pm 4.6	0.091		
	Extension*	4.2 \pm 3.4	7.0 \pm 3.3	0.012		
	ROM*	96.2 \pm 5.6	90.3 \pm 3.8	0.000		
Ankle	DF	33.7 \pm 5.1	35.0 \pm 6.6	0.789		
	PF*	-29.9 \pm 5.0	-22.1 \pm 7.9	0.004		
	ROM*	64.5 \pm 3.9	59.1 \pm 7.5	0.003		

DF = dorsiflexion; PF = plantar flexion; ROM = range of motion

* $p < 0.05$: indicates a significant main effect of gender (male and female)

Table 5: Correlation (r) and r² values with F change values from regression analysis for the effects of body mass and sex on the peak joint angles of the sagittal plane (n=51)

<i>Angles (°)</i>	Ascent					
	r gender	r BMI	r ² gender	r ² BMI	p value gender	p value BMI
Hip flexion peak	-0.221	-0.004	0.049	0.049	0.120	0.997
Hip extension peak	-0.071	0.205	0.005	0.048	0.621	0.149
Knee flexion peak	-0.302	-0.089	0.091	0.098	0.031*	0.541
Knee extension peak	-0.053	0.219	0.003	0.051	0.712	0.124
Ankle dorsiflex. peak	0.323	0.157	0.105	0.128	0.021*	0.264
Ankle plantar flex.peak	0.606	0.075	0.367	0.371	0.000*	0.566
Descent						
Hip flexion peak	-0.113	0.170	0.013	0.042	0.431	0.230
Hip extension peak	0.012	0.236	0.000	0.056	0.935	0.099
Knee flexion peak	-0.265	0.224	0.070	0.122	0.060	0.098
Knee extension peak	0.329	0.255	0.108	0.171	0.018*	0.063
Ankle dorsiflex. peak	0.108	0.077	0.012	0.017	0.449	0.601
Ankle plantar flex.peak	0.521	0.009	0.272	0.272	0.000*	0.986

*, p< 0.05

Frontal Plane:

Hip joint

No significant differences in the peak hip adduction-abduction angles were found between the two gender groups during stair ascent and descent (Table 6). The joint angles profiles showed the hip was required to adduct during early stance phase, which changes to abduction during the swing phase (Fig 3a). The hips were required to abduct to tilt the pelvis angle so the contralateral side of the leg would swing properly. The female participants used a significantly larger range of motion along the frontal plane of the hip compared to the males to ascend the staircase (p=0.006) (Table 6). The regression analysis noted that gender contributed significantly to the model with hip frontal ROM as the dependent variable and sex as the independent variable for both ascent (p=0.015) and descent (p=0.003). The correlation coefficients were $r(51) = 0.34$ for ascent and $r(51) = 0.40$ for descent, which were both positive weak correlations in terms of the effects that sex has on the dependent variable (Table 7).

Knee joint

The participants' body mass did not influence the frontal peak angles of the knee during ascent and descent. A significant effect of sex, however, was noted in the peak valgus angles during descent (Table 6). The female participants had a significantly larger peak valgus angle (0.2°) compared to the males (3.2°) when descending the stairs; the difference was found to be significant ($p=0.002$) (Fig 7). The regression analysis among the total studied population found statistically significant of the effects of sex that was positively correlated with the differences noted in the peak valgus angles at the knee, $r(51) = 0.51$ ($p<0.001$) (moderate strength) (Table 7).

Table 6: Mean and standard deviation for frontal peak joint angles and range of motion ($^\circ$) of joint during stair climbing for females ($n=20$) and males ($n=25$).

		Gender				
		Female	Male	p-value		
Frontal Plane	Hip	Adduction	7.8 ± 4.6	4.6 ± 4.6	0.076	
		Abduction	-9.1 ± 3.4	-8.4 ± 3.6	0.702	
		ROM*	17.3 ± 3.2	13.2 ± 4.5	0.006	
	Ascent	Knee	Valgus	-2.7 ± 4.7	2.3 ± 4.3	0.150
			Varus	8.6 ± 17.0	15.7 ± 15.3	0.064
			ROM	17.3 ± 9.4	19.1 ± 10.9	0.564
	Ankle	Adduction*	6.8 ± 4.8	2.5 ± 2.5	0.001	
		Abduction	-1.9 ± 1.0	-1.6 ± 1.7	0.329	
		ROM*	9.5 ± 4.3	6.8 ± 2.7	0.017	
	Hip	Adduction	7.8 ± 4.6	4.6 ± 4.6	0.108	
		Abduction	-9.1 ± 3.4	-8.4 ± 3.6	0.084	
		ROM	14.4 ± 4.0	14.7 ± 4.2	0.437	
Descent	Knee	Valgus*	0.2 ± 5.6	3.2 ± 4.8	0.002	
		Varus	13.0 ± 16.1	21.6 ± 14.0	0.226	
		ROM	16.5 ± 10.5	15.4 ± 11.7	0.630	
Ankle	Adduction	4.8 ± 5.6	8.9 ± 6.1	0.108		
	Abduction	-1.1 ± 1.6	-0.3 ± 1.0	0.084		
	ROM	12.8 ± 3.6	12.8 ± 4.8	0.882		

*, $p<0.05$

Ankle joint

The peak ankle adduction joint angles during ascent were also significantly different between the male and female participants. Interestingly, the female participants were more likely to adduct their ankles (6.8°) more than the male participants (2.5°) during ascent (p=0.001) as seen in Table 6 and Fig 8. Sex contributed significantly to the model with peak adduction joint angle as the dependent variable and body mass index as the independent variable, $r(51) = -0.53$ (p<0.0005) (Table 7). During descent, no significant differences were noted between the males and females in the peak joint angles at their ankle joints. A significant difference was found in the ankle joint ROM along the frontal planes between the males and females for ascent (p=0.017); the difference in ROM was approximately 3° (Table 6).

Table 7: Correlation (r) and r² values with F change values from regression analysis for the effects of body mass and sex on peak joint angles and ROM in the frontal plane (n=51)

<i>Angles and ROM (°)</i>	Ascent					
	r gender	r BMI	r ² gender	r ² BMI	p value gender	p value BMI
Hip adduction peak	-0.391	-0.069	0.153	0.157	0.005*	0.636
Hip abduction peak	0.070	-0.458	0.005	0.216	0.627	0.001*
Knee varus peak	0.348	0.213	0.121	0.165	0.012*	0.122
Knee valgus peak	0.328	0.314	0.108	0.203	0.019*	0.020*
Ankle abduction peak	0.182	-0.027	0.033	0.034	0.201	0.835
Ankle adduction peak	-0.526	0.200	0.277	0.320	0.000*	0.087
Hip frontal ROM	0.338	0.279	0.114	0.119	0.015*	0.642
Knee frontal ROM	0.067	0.188	0.005	0.093	0.639	0.035*
	Descent					
Hip adduction peak	-0.217	-0.144	0.047	0.067	0.126	0.317
Hip abduction peak	-0.202	-0.426	0.041	0.220	0.156	0.002*
Knee varus peak	0.298	0.245	0.089	0.147	0.034*	0.077
Knee valgus peak	0.513	0.169	0.263	0.289	0.000*	0.191
Ankle abduction peak	0.357	-0.108	0.127	0.140	0.010	0.404
Ankle adduction peak	0.395	-0.177	0.156	0.190	0.004	0.165
Hip sagittal plane	0.040	-0.072	0.002	0.064	0.783	0.079
Hip frontal ROM	0.404	0.348	0.164	0.165	0.003*	0.756
Knee frontal ROM	0.129	0.257	0.017	0.125	0.368	0.018*

ROM = range of motion

*, p< 0.05

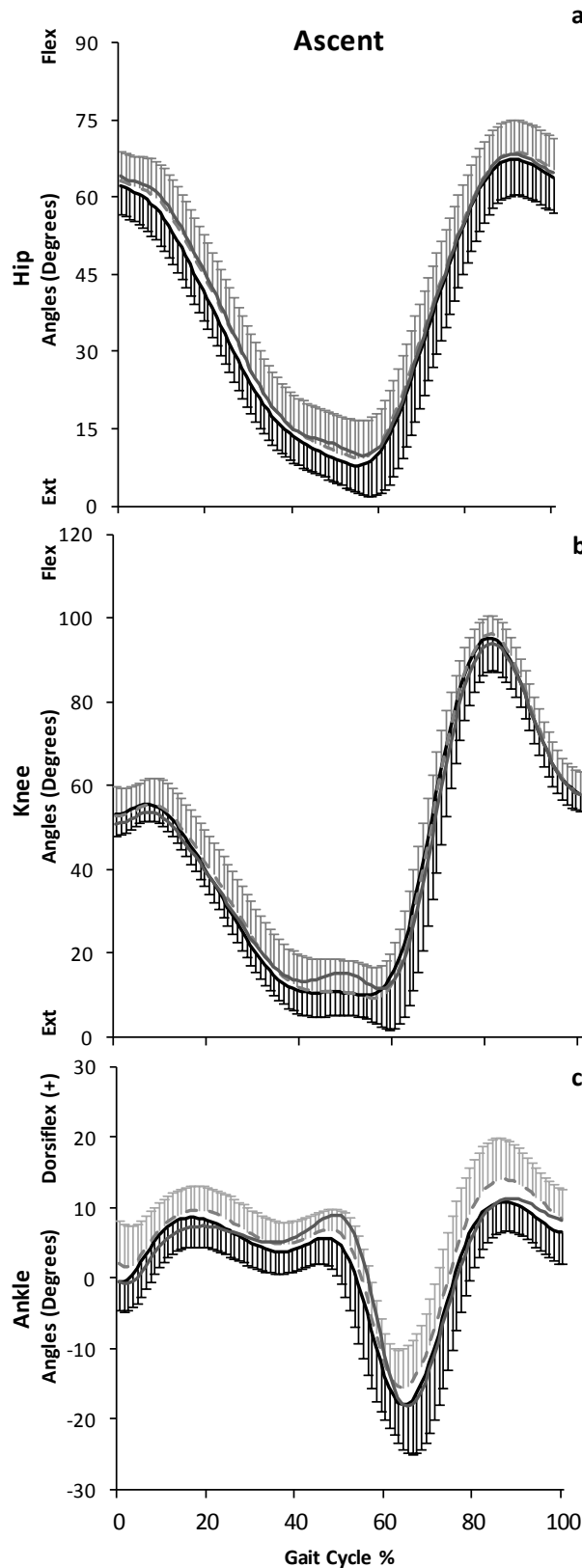


Fig 1: Mean and standard deviation of hip, knee, and ankle joint angles in sagittal plane during stair ascent for normal (black), overweight (open line), and obese (grey) subjects in a gait cycle. (a) Hip flex-ext angles (b) knee flex-ext angles, & (c) ankle plantar & dorsiflexion angles

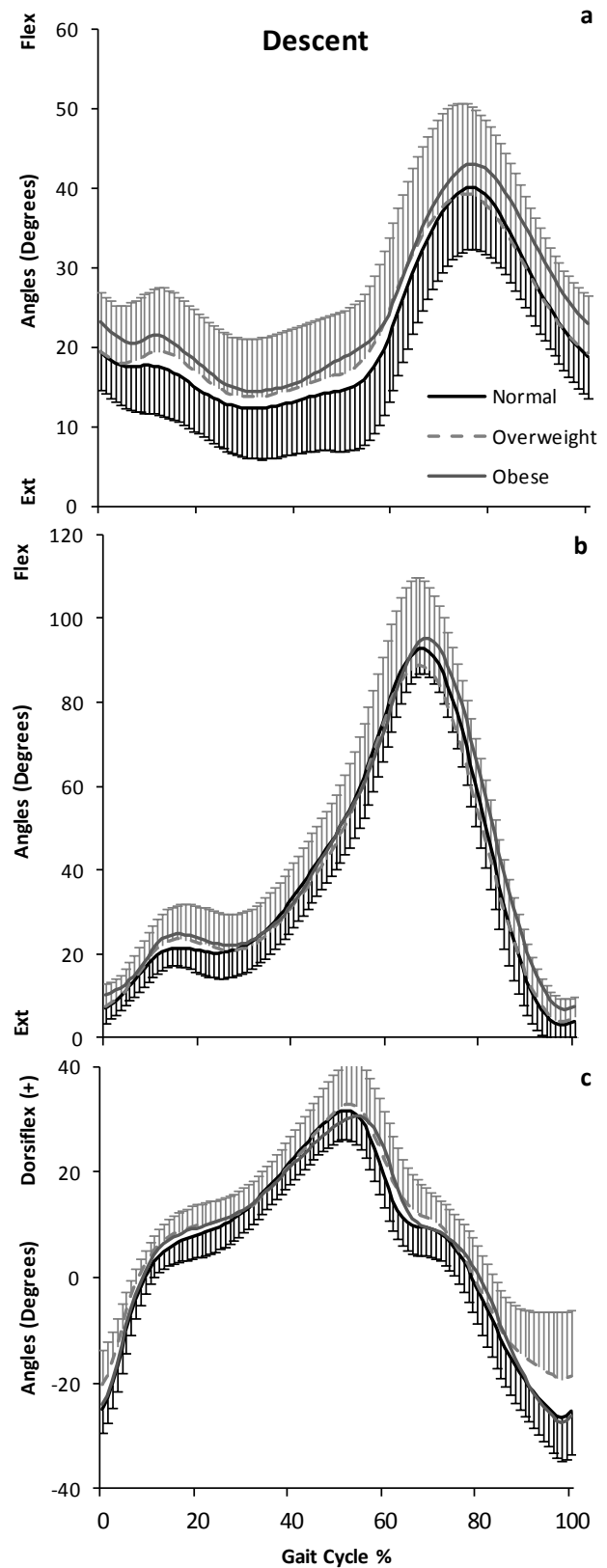


Fig 2: Mean and standard deviation of the hip, knee, and ankle joint angles in sagittal plane during stair descent for normal (black), overweight (open line), and obese (grey) subjects in a gait cycle. (a) Hip flex-ext angles (b) knee flex-ext angles, and (c) ankle plantar & dorsiflexion angles

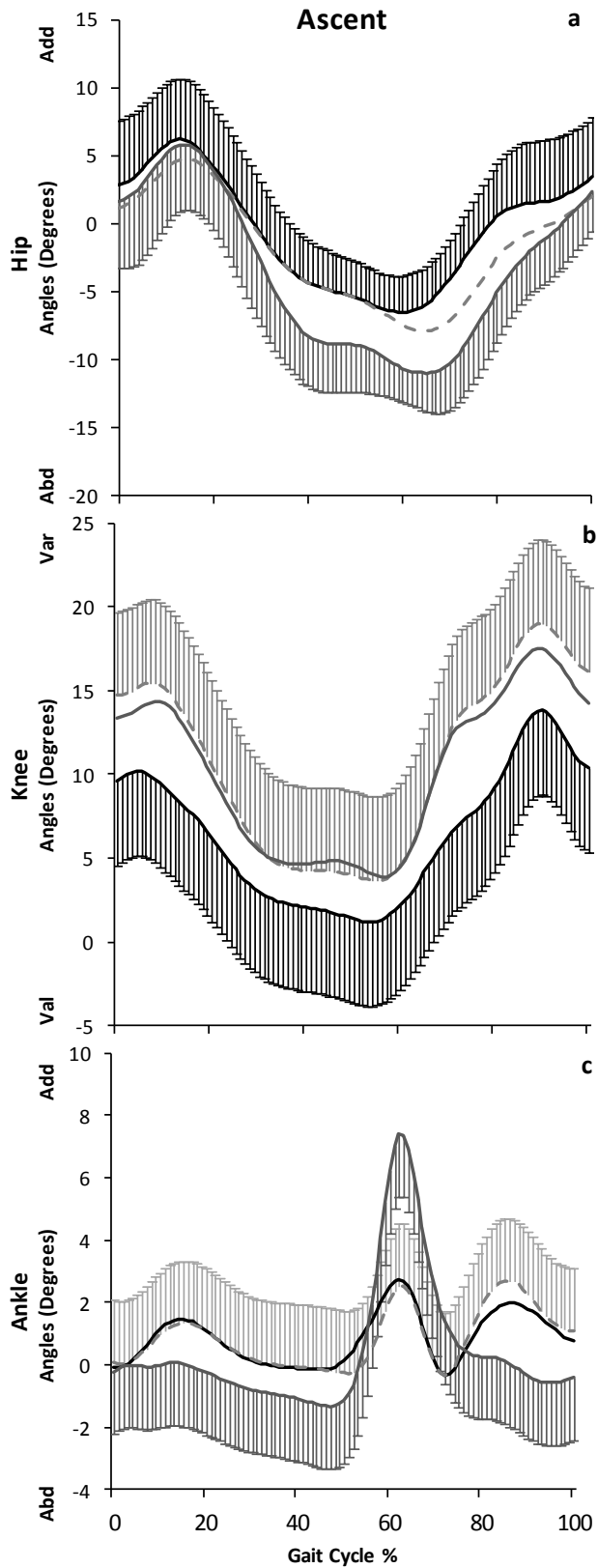


Fig 3: Mean and standard deviation of the hip, knee, and ankle joint angles in frontal plane during stair ascent for normal (black), overweight (open line), and obese (grey) subjects in a gait cycle. (a) Hip ab-add angles (b) knee varus-valgus angles, & (c) ankle abd-add angles

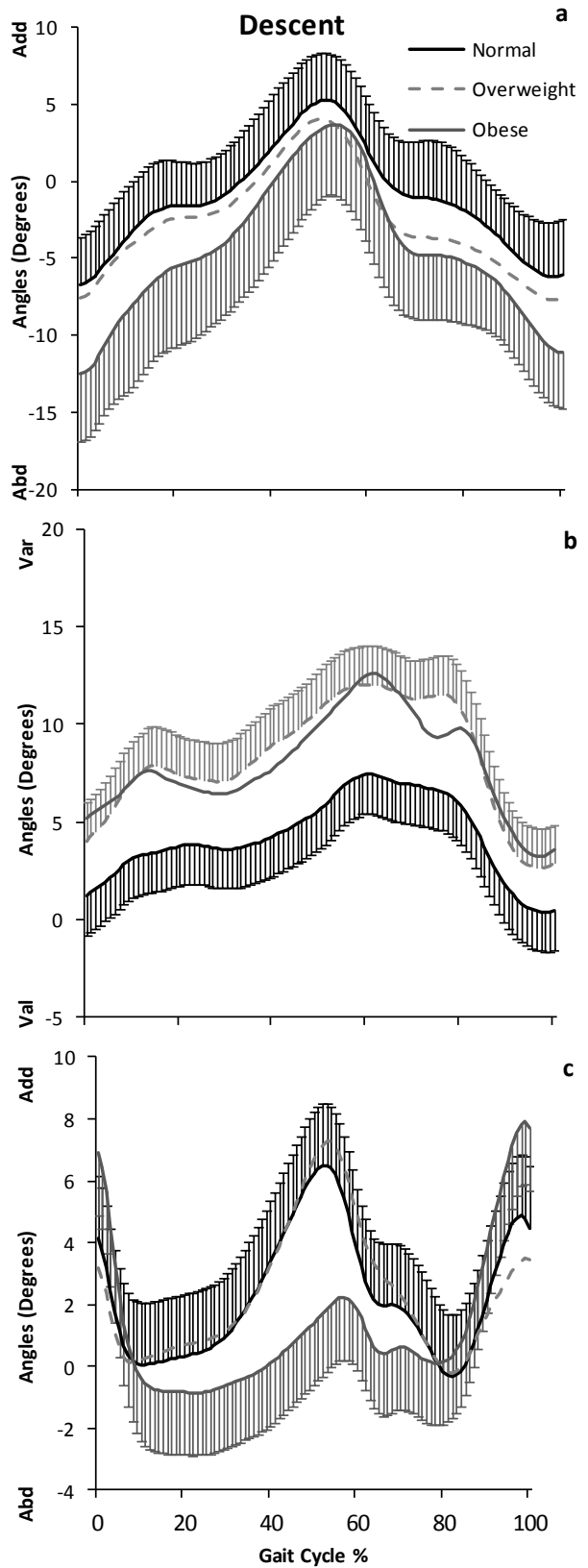


Fig 4: Mean and standard deviation of the hip, knee, & ankle joint angles in frontal plane during stair descent for normal (black), overweight (open line), and obese (grey) subjects in a gait cycle. (a) Hip ab-add angles (b) knee varus-valgus angles, & (c) ankle ab-adduction angles

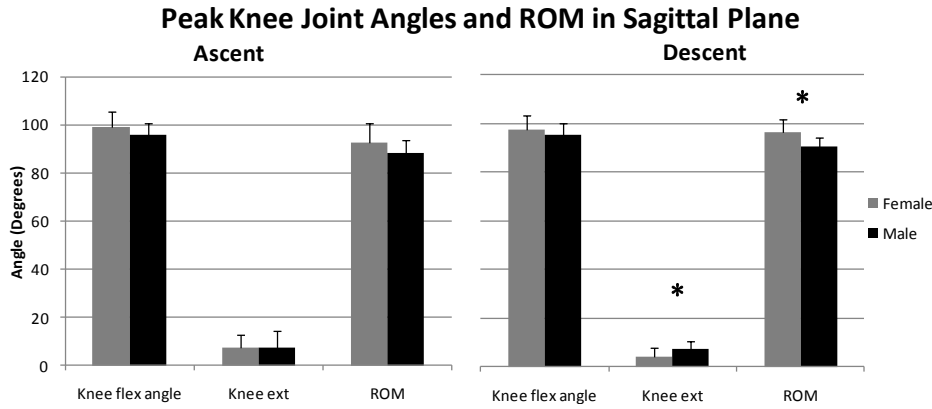


Fig 5: Peak knee joint angles and Range of Motion (ROM) during stair ascent and descent for the sagittal plane

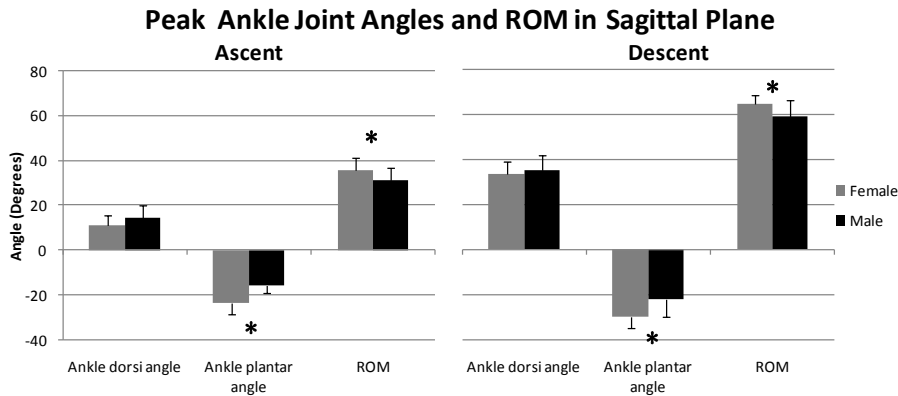


Fig 6: Peak ankle joint angles and Range of Motion (ROM) during stair ascent and descent for the sagittal plane

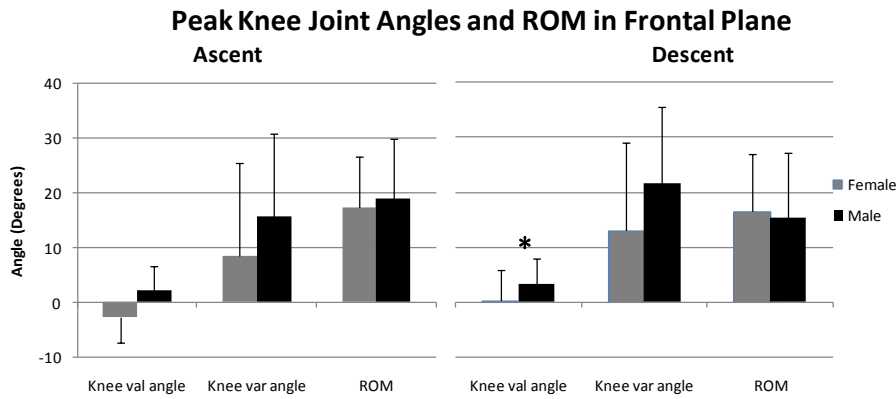


Fig 7: Peak knee joint angles and Range of Motion (ROM) during stair ascent and descent for the frontal plane

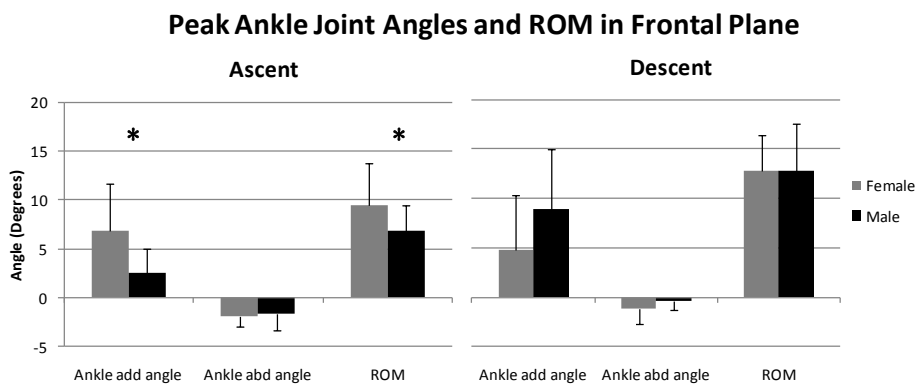


Fig 8: Peak ankle joint angles and Range of Motion (ROM) during stair ascent and descent for the frontal plane

4.3. Kinetics

In regards the kinetic data, the MANOVA revealed there was no significant interaction between sex and mass ($F(34) = 0.594$, $p = 0.943$). The MANOVA also indicated body mass had a significant influence on the joint moments ($F(34) = 1.836$, $p = 0.026$), irrespective of sex ($F(17) = 1.730$, $p = 0.110$). Since there was no interaction or effect of sex, the data for the males and females was pooled for the ANOVA and post-hoc test.

Sagittal Plane:

Hip joint

No significant differences were noted between the groups in terms of their peak hip extensor moments during ascent. The peak hip flexion moment among the obese individuals ($0.42 \text{ N}\cdot\text{m}/\text{kg}$) was found to be significantly higher than the overweight group ($0.22 \text{ N}\cdot\text{m}/\text{kg}$) when ascending the stairs ($p = 0.031$) (Table 8). Both the peak hip extensor and flexor moments during descent were not significantly different.

Knee joint

The peak knee extensor moments were quite similar when all three groups were ascending the stairs (Table 8). The overweight and obese groups had larger knee extensor moments ($-1.05 \text{ N}\cdot\text{m}/\text{kg}$) and ($-0.99 \text{ N}\cdot\text{m}/\text{kg}$), respectively, than the normal weight group ($-0.94 \text{ N}\cdot\text{m}/\text{kg}$) when ascending the stairs (Fig. 9b). Besides this finding, it was interesting to note that the initial peak knee extensor moment during stance phase of descent was significantly larger ($p = 0.026$) in the overweight group compared to the normal weight group, irrespective of sex (Fig 10b). The overweight group had a peak knee extensor moment of $-0.98 \text{ N}\cdot\text{m}/\text{kg}$, while the normal weight group had a knee moment of $-0.70 \text{ N}\cdot\text{m}/\text{kg}$ (Table 8).

Ankle joint

The peak plantar flexor moment was noted in both groups near the end of stance phase (50%) where the right ankle joint of the leading leg was responsible for performing a toe-off to lift the body from one step to the next during ascent (Fig. 9c). Contrary to ascent, the ankle joint was required to initially plantar flex when pushing off of the top step and then dorsiflex when performing a heel-strike on the second step (Fig. 10c).

Table 8: Means and standard deviations for the flexor and extensor peak joint moment (N•m/kg) during stair climbing for normal weight (n=19), overweight (n=18), and obese participants (n=8).

				Body Mass		
				Normal	Overweight	Obese
Sagittal Plane	Ascent	Hip	Flexor*	0.26 ± 0.18	0.22 ± 0.17	0.42 ± 0.20 ^b
			Extensor	-0.72 ± 0.17	-0.70 ± 0.17	-0.61 ± 0.20
		Knee	Extensor	-0.94 ± 0.29	-1.05 ± 0.35	-0.99 ± 0.33
			Ankle	PF	-1.20 ± 0.23	-1.25 ± 0.15
	Descent	Hip	Flexor	0.26 ± 0.12	0.22 ± 0.09	0.27 ± 0.10
			Extensor	-0.04 ± 0.32	-0.05 ± 0.39	-0.03 ± 0.27
		Knee	Extensor*	-0.70 ± 0.29 ^a	-0.98 ± 0.30	-0.86 ± 0.42
			Ankle	PF	-1.03 ± 0.13	-1.00 ± 0.18

PF = plantar flexor

*, p<0.05: indicates a significant effect of mass (normal, overweight, and obese)

^a, p<0.05: the normal weight vs. overweight group

^b, p<0.05: the overweight vs. obese group

Table 9: Correlation (r) and r² values with F change values from regression analysis for the effects of body mass and sex on flexor and extensor moment of force (n=51)

Moment	Ascent					
	r	r	r ²	r ²	sig F	sig F
	gender	BMI	gender	BMI	gender	BMI
Hip extension max	-0.329	0.192	0.108	0.147	0.018*	0.147
Hip flexion max	-0.584	0.130	0.342	0.361	0.000*	0.236
Knee extension max	-0.016	-0.126	0.000	0.016	0.909	0.385
Ankle plantar flexion	0.079	0.228	0.006	0.058	0.583	0.112
Descent						
Hip extension max	-0.364	-0.061	0.132	0.135	0.009	0.680
Hip flexion max	-0.382	-0.038	0.146	0.147	0.006*	0.806
Knee extension max	0.071	-0.145	0.005	0.026	0.622	0.311
Ankle plantar flexion	0.196	0.040	0.038	0.040	0.168	0.791

*, p< 0.05

Frontal Plane:

Hip joint

The hip was required to abduct during early stance phase to raise the pelvis, which allows the contralateral side of the leg to swing properly during ascent (Fig.11a). No significant differences were noted between the groups of the different body masses in the peak hip abductor moments when ascending and descending the stairs (Table 10).

Knee joint

The knee varus-valgus moment curves for all three groups were similar in shape in terms of having two notable peaks during ascent and descent (Fig. 11b and 12b). The peak valgus moment showed a significantly larger peak ($p=0.036$) in the overweight group ($-0.52 \text{ N}\cdot\text{m}/\text{kg}$) compared to the obese group ($-0.27 \text{ N}\cdot\text{m}/\text{kg}$) during descent, irrespective of sex (Table 10).

Ankle Joint

Lastly, the moment of force of the ankle in adduction-abduction curves for the obese and normal weight group were similar in shapes and peak (Fig. 7c and Fig. 8c). No significant differences were noted in the ankle joint moment during ascent. During descent, the obese group had a significantly larger ankle abduction moment than the normal weight ($p=0.031$) and overweight ($p=0.002$) as seen in Table 10. The correlation coefficient was $r(51) = -0.29$, $p=0.030$ (Table 11).

Table 10: Means and standard deviations for the adductor and abductor peak joint moments (N•m/kg) during stair climbing for normal weight (n=19), overweight (n=18), and obese participants (n=8).

			Body Mass			
			Normal	Overweight	Obese	
Frontal Plane	Ascent	Hip Abductor	-0.44 ± 0.18	-0.35 ± 0.14	-0.32 ± 0.18	
		Knee	Valgus	-0.44 ± 0.19	-0.40 ± 0.21	-0.29 ± 0.13
			Varus	-0.15 ± 0.11	-0.13 ± 0.13	-0.09 ± 0.08
			Ankle	Adductor	--	--
		Abductor		-0.14 ± 0.10	-0.16 ± 0.07	-0.20 ± 0.06
	Descent	Hip Abductor	-0.82 ± 0.24	-0.80 ± 0.21	-0.63 ± 0.24	
		Knee	Valgus*	-0.44 ± 0.25	-0.52 ± 0.20	-0.27 ± 0.20 ^b
			Varus	-0.17 ± 0.17	-0.22 ± 0.15	-0.09 ± 0.11
			Ankle	Adductor	0.02 ± 0.23	0.02 ± 0.026
		Abductor*		-0.12 ± 0.08	-0.09 ± 0.06	-0.21 ± 0.11 ^{ab}

*p<0.05: indicates a significant effect of mass (normal, overweight, and obese)

^a p<0.05: indicates a significant difference between the normal weight vs. obese group

^b p<0.05: indicates a significant difference between the overweight vs. obese group

Table 11: Correlation (r) and r² values with F change values from regression analysis for the effects of body mass and sex on adductor and abductor moment of force (n=51)

Moment	Ascent						
	r		r ²		p value		
	gender	BMI	gender	BMI	gender	BMI	
Hip abduction max	0.245	0.237	0.060	0.115	0.083	0.092	
Knee valgus max	-0.088	0.225	0.008	0.059	0.538	0.113	
Knee varus max	0.059	0.139	0.003	0.023	0.681	0.337	
Ankle adduction max	--	--	--	--	--	--	
Ankle abduction max	-0.125	-0.288	0.016	0.097	0.383	0.042*	
	Descent						
	Hip abduction max	0.128	0.329	0.016	0.123	0.372	0.019*
	Knee valgus max	-0.263	0.214	0.069	0.017	0.062	0.116
	Knee varus max	-0.073	0.174	0.005	0.036	0.610	0.223
	Ankle adduction max	0.455	-0.046	0.207	0.210	0.001*	0.686
	Ankle abduction max	0.309	-0.288	0.095	0.181	0.027*	0.030*

*p< 0.05 indicates the sig F change value was significant

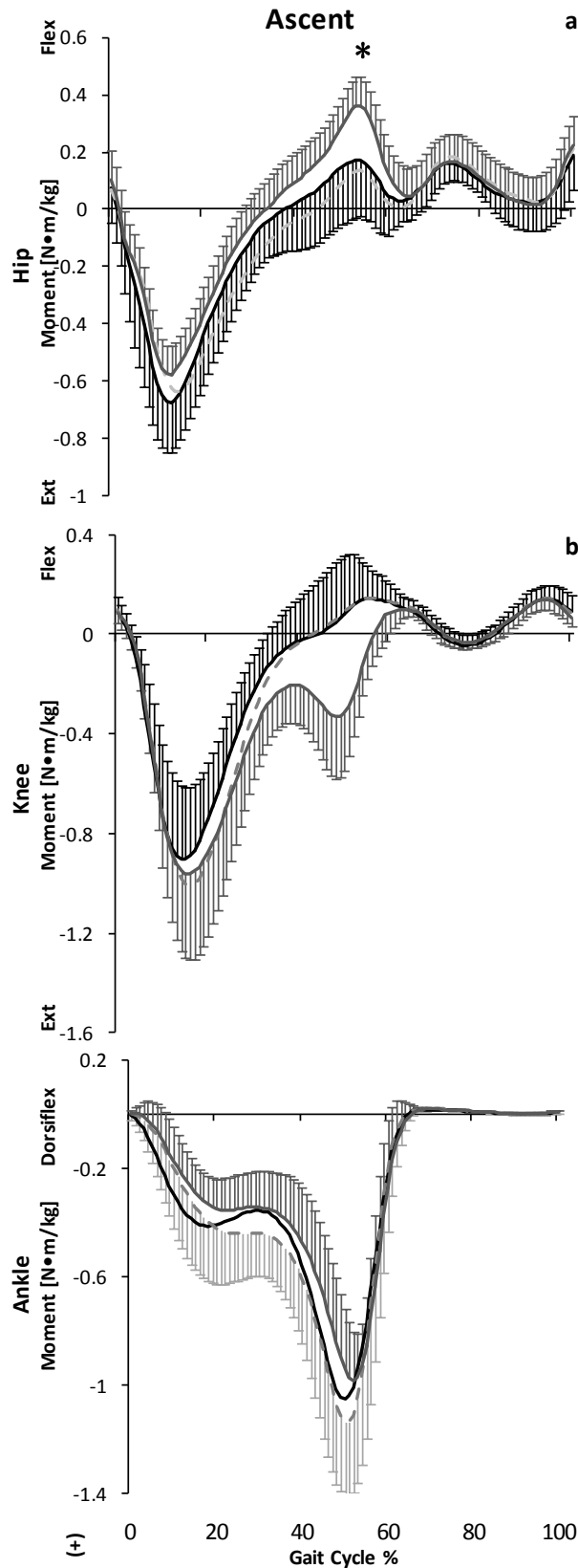


Fig 9: Mean and standard deviation of the hip, knee, and ankle joint moments during stair ascent for normal (black), overweight (open line), and obese (grey). (a) Hip flexion-extension moment, (b) knee flexion-extension moment, and (c) ankle plantar flexion and dorsiflexion

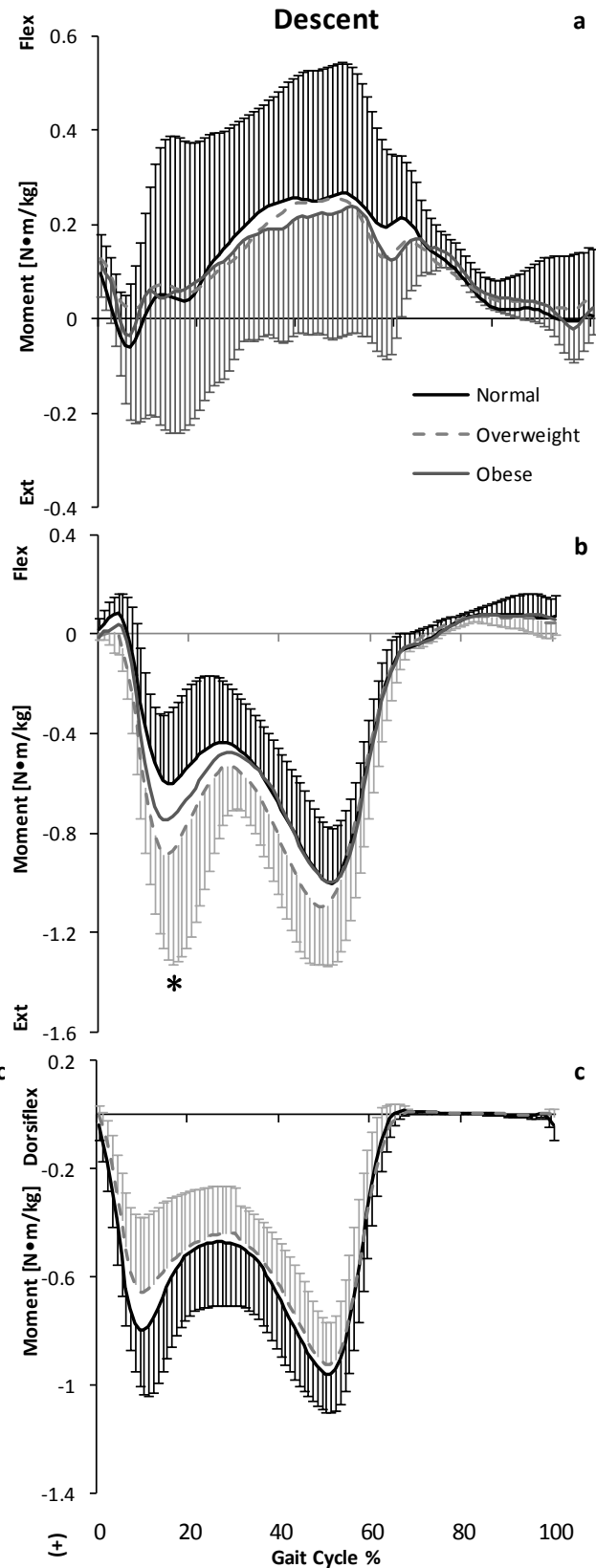


Fig 10: Mean and standard deviation of the hip, knee, and ankle joint moments during stair descent for normal (black), overweight (open line), and obese (grey). (a) Hip flexion-extension moment, (b) knee flexion-extension moment, and (c) ankle plantar flexion and dorsiflexion moment

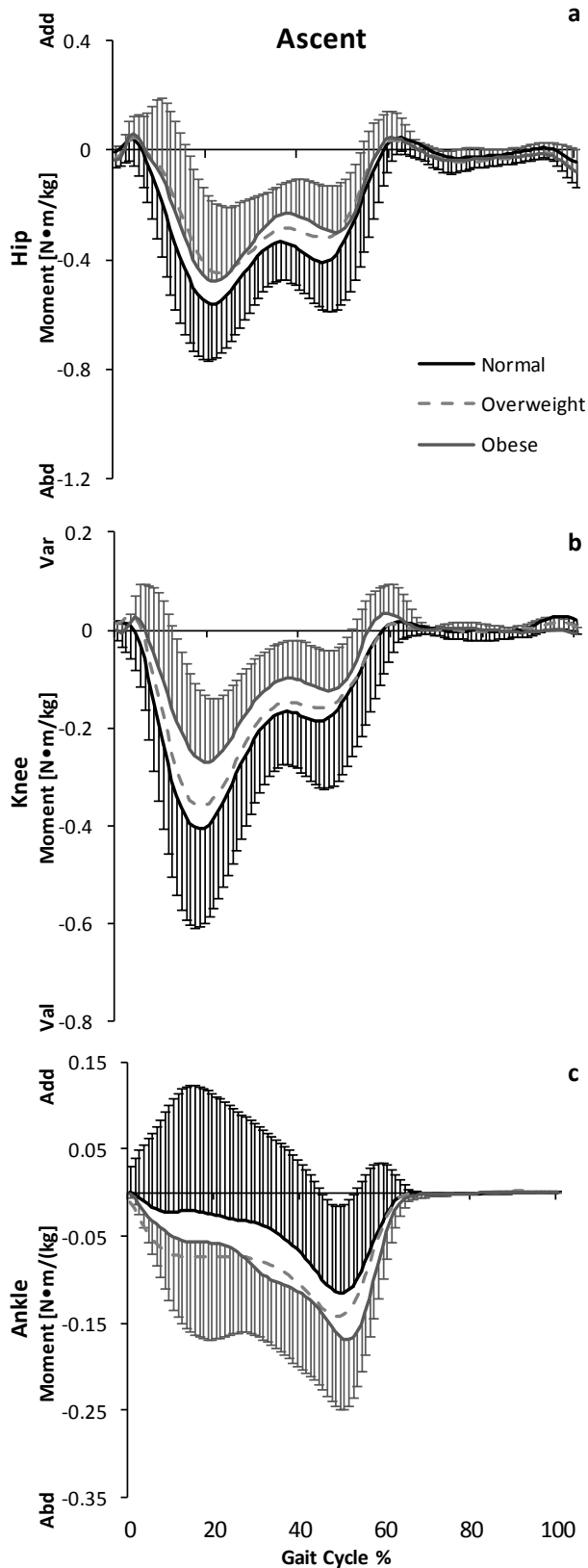


Fig 11: Mean and standard deviation of the hip, knee, and ankle joint moments during stair ascent for normal (black), overweight (open line), and obese (grey). (a) Hip adduction-abduction moment (b) knee valgus-varus moment, and (c) ankle adduction and abduction moment

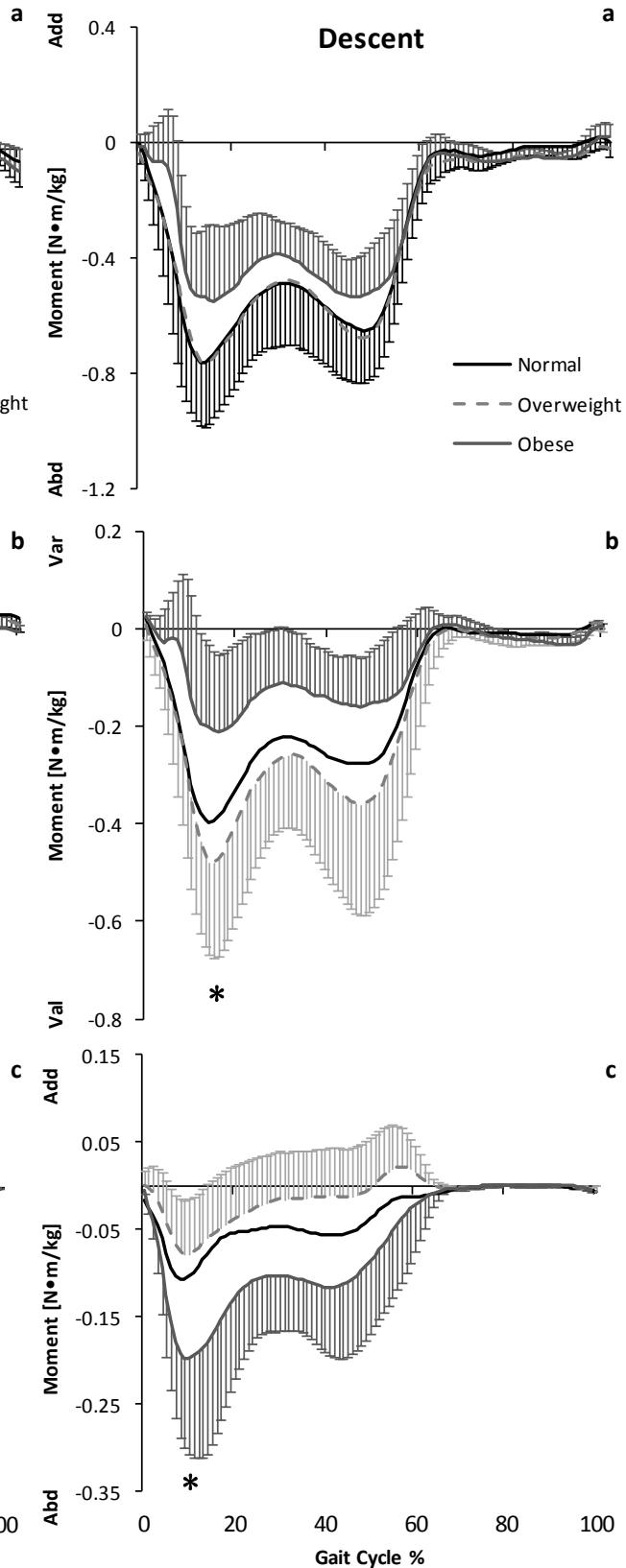


Fig 12: Mean and standard deviation of the hip, knee, and ankle joint moments during stair descent for normal (black), overweight (open line), and obese (grey). (a) Hip adduction-abduction moment (b) knee valgus-varus moment, and (c) ankle adduction and abduction moment

Chapter V

DISCUSSION AND CONCLUSION

The purpose of the present study was to examine the effects of one's body mass and sex on the kinematics and kinetics of the lower limb for a group of normal weight, overweight, and obese participants during stair ascent and descent. Although there have been studies that have examined stair climbing in the normal weight population, this study was unique in providing a biomechanical analysis of the temporal-spatial parameters, kinematics, and kinetics of the lower limb for the overweight and obese population during stair ascent and descent. The study revealed sex had a significant influence on the peak joint angles and range of motion (ROM), while the participants' body mass did not have a significant influence on these variables. Instead, the study found the peak joint moment of force of the lower limb were influenced by body mass, irrespective of the effects of sex.

5.1. Temporo-Spatial Parameters

During stair ascent and descent, the male and female participants did not showed any significant differences in the temporo-spatial parameters. Moreover, body mass did not significantly influence the stride time, single support time, double-support time, and clearance distance. The results from the present study suggested all participants, regardless of their sex and body mass, did adopt similar gait strategies when ascending and descending the stairs. The findings of the temporo-spatial variables for the present study were consistent with the ones found by past studies on obese locomotion. Similar to the study by Syropoulos et al., (1991) and Hulens et al., (2003), the present study found the obese and overweight participants spent a longer time than the normal weight participants in double-support, but also in single support time during descent. One of the possible reasons for the longer periods of single support and double-

support in the present study might be due to the age of the participants between the current study and the past studies.

Past studies on level walking have found that elderly individuals spent more time in double-support compared to young adults (Winter et al., 1990). The authors believe there were three possible explanations for the differences in the double-support (DS) time between the two age groups. The first was that the elderly increased their double-support time and reduced their dorsiflexion angle during heel-strike to improve their restabilizing time. Another explanation for the longer double-support time could have been due to the elderly group might have felt more comfortable walking with a shorter stride length and a slower velocity, which resulted in a weaker push-off and a longer double-support time. Finally, the elderly participants lower limb muscles' may have been weaker compared to the younger participants, which resulted in a shorter single support and a longer double-support.

In regards to the participants' clearance distances, it is also important to remember the participants were required to ascend and descend the same staircase. All of the participants were required to step the same distances when they were stepping from the first step to the third step during ascent or stepping from the second step to the ground during descent. As a result, no significant differences were found between the normal weight, overweight, and obese participants in terms of their clearance distances during stair ascent and descent (Table 2).

5.2. Kinematics

Sagittal Plane:

Hip joint

Initially, it was hypothesized that the hip extension angle would be significantly larger among the overweight and obese participants during stair ascent. Based on the results from the

study, this hypothesis was not supported. Contrary to the initial hypothesis, no significant differences were noted between the normal weight, overweight, and obese participants. Furthermore, there were no significant differences found between the male and female participants in terms of their peak hip extension angles and ROM in the sagittal plane (Table 4). The hip joint profiles for the normal weight, overweight, and obese participants were consistent with the curves reported in past studies (Fig. 1a and Fig. 2a). The participants had to extend the hip of their leading leg forward in order to lift their body from the ground to the first step by overcoming the forces of gravity during stair ascent (Andriacchi et al., 1980; Livingston et al., 1991; Propapadaki et al., 2002; Riener et al., 2002; Lin et al., 2005). The lack of significant differences between the males and females in terms of their peak hip flexion and extension angles were somewhat unexpected. Studies that have compared the gait patterns between normal weight males and females individuals have noted females individuals tend to flex their hips more than males during level walking due to their greater anterior pelvic tilt (Kerrigan, Todd, & Croce, 1998; Cho, Park, & Kwon, 2004). In addition to this, it was expected that the female participants would require a greater peak hip flexion angle to ascend the stairs due to their difference in height, which has been shown to be correlated with their stride length (Murray, Kory, & Sepic, 1970; Murray, Drought, & Kory, 1964). But as seen in Table 4, no significant differences were found in the peak hip joint angles and ROM along the sagittal plane. The values that were reported were consistent with results from past studies that reported the ROM along the sagittal plane for the hip joint was ~60-65° for normal weight subjects (Nadeau et al., 2003; Protopapadaki et al., 2007). The results suggest the peak hip joint angles and ROM in the sagittal plane were not influence by the effects of sex and body mass.

Knee joint

Initially, it was also hypothesized that similar to level walking; the knee flexion angles in the overweight and obese group would be significantly smaller compared to the normal weight participants when descending the stairs. From Table 4, it is evident that the hypothesis was not supported as no significant differences were found between normal weight, overweight, and obese group in terms of their peak knee flexion angles. Contrary to what was initially hypothesized, a sex difference between the male and female participants was found. The female participants had a significantly smaller knee extension angle than the male during descent ($p=0.012$), irrespective of the participants' body mass (Table 4). Differences in peak knee extension angle may have been due to the differences found in terms of the participants' muscular strength and anatomy. As shown in studies on level walking, female individuals tend to have a significantly smaller knee extension angle compared the males during initial contact and also a greater knee flexion angle in pre-swing (Kerrigan et al., 1998). As mentioned before, the females may have been required to flex their hips and knees more in order to compensate for their difference in height when they are ascending the stairs (Livingston et al., 1991). Kerrigan et al., (1998) believed the longer stride length that results due to the greater hip flexion angle did not account for the reduced peak knee extension angle. Instead, the researchers believed the difference in the knee extension were due to intrinsic gender differences in walking dynamics. The females were required to flex their knee at pre-swing in order to place the leg on the next step, which was consistent with the findings by Nadeau et al., (2003). No significant differences, however, were found in terms of the subjects' height, peak knee flexion angles, and ROM during ascent. On the contrary, significant differences were found between the males and females in terms of their ROM for the knee in the sagittal plane during descent (Table 4). The range of

motion along the sagittal plane for the knee joint was 96.2° for the female participants and 90.3° for the male participants during stair descent. The range of motion of the knee flexion angles that were found in the present study were similar to the ones that were reported by past researchers on healthy normal weight individuals (~94 °) (Nadeau et al., 2003; Protopapadaki et al., 2007). The results suggest that the participants did not suffer from any mobility problems that may limit their range of motion in the knee. If this was not the case, the participants may have experienced limited mobility in their knee or restriction in their range of motion. Studies on patients with knee osteoarthritis have noted a mild restriction of motion (Startzell et al., 2002; Collopy et al., 1977).

Ankle joint

Initially, it was hypothesized that the ankle plantar flexion angles would be significantly higher among the overweight/obese participants when ascending the stairs. From the results, the hypothesis was not supported as no significant effect of mass was found in the peak ankle joint angles of the sagittal plane during ascent. Instead, the female participants had a significant larger peak plantar flexion angle compared to the male participants during ascent ($p < 0.05$) and descent ($p = 0.004$) (Table 4). At the ankle level, the profiles for the ankle joints angles were consistent with the ones found in past literature. Similar to the findings by Andriacchi et al., (1980) and Livingston et al., (1991), the joint profiles showed the ankle was required to plantar flex in order to perform a toe-off as one moves from the ground to the step or from a step to another step. During ascent, the female participants had a peak plantar flexion angle of -23.7° at their ankle joints, while the male participants had a peak plantar flexion angle of -15.6°. This finding was also similar during descent as the female participants had a peak angle of -29.9°, while the males had a peak angle of -22.1°. As mentioned before, the ankle was required to perform plantar flexion in

order to push-off the ground towards the end of stance phase, while the tibialis anterior was required to dorsiflex. The range of motion found in the ankle joint for the sagittal plane was 35.9° for the females and 31.2 ° for the males when ascending the stairs, a difference of approximately 5° ($p < 0.05$). Furthermore, the female participants also had a significantly larger ($p = 0.004$) ROM along the sagittal plane of the ankle joint when descending the stairs. The ROM for the ankle joint that were presented in the present study were similar to the values reported by McFayden & Winter (1998) and Protopapadaki et al., (2007), which were ~21-35 ° along the sagittal plane. The difference in the peak angles between the male and female participants may suggest sex differences in the muscular strength. The correlation coefficients from the regression analysis were $r(51) = 0.61$ ($p < 0.0001$) for ascent and $r(51) = 0.52$ ($p < 0.0001$) for descent, which both indicate moderate positive correlations (Table 5). The r^2 values for the model were 0.367 for ascent and 0.272 for descent, which meant the model could be used to explain approximately 36.7% and 27.2% of variance found in the angles were due to sex. Unfortunately, the present study did not conduct an analysis of the muscle activity of the lower limb to determine whether the differences found in the joint angles could be attributed to sex differences in muscular strength. This may be an area that may need to be addressed by future studies.

Frontal Plane:

Hip joint

Along the frontal plane, the hip tended to abduct to raise the pelvis, which allows the contralateral side of the leg to swing properly (Spyropoulos et al., 1991). There were no significant differences noted in the frontal peak joint angles of the hip in terms of the effects of sex and mass (Table 6). The only significant differences that were noted between the two gender

groups were the female participants had a significantly larger ($p=0.006$) ROM along the frontal plane of the hip compared the males when ascending the stairs (Table 6). This current finding might suggest no altered movement strategies were adopted by the studied population that would result in sex or mass differences in the kinematics data of the hip joint along the frontal plane.

Knee joint

The joint angles profiles showed all three groups were required to abduct their knees when they were ascending the stairs (Fig. 3b). The joint angle profiles between the normal weight, overweight, and obese participants were similar in shape and peak values when ascending. No significant differences in terms of the effects of body mass were noted. What may be interesting to note was the female participants had a significantly larger peak valgus angle (0.2°) compared to the males (3.2°) when descending the stairs; the difference was found to be significant ($p=0.002$) (Table 6). This finding was somewhat unexpected because there've been studies in the past that believed women greater the age of 50 were more likely at risk of osteoarthritis (OA) than men (Dowdy et al., 1998; Davis et al., 1990; Saase et al., 1989) because of the valgus misalignment at the knee, which resulted in a larger Q angle and pain at the knee (Mohammad-Jaffar et al., 2007). Others believed it was the varus misalignment that caused higher loading on the medial compartment than the lateral compartment of the knee, which may lead to medial compartment OA (Sharma et al., 2010; Cerejo et al., 2002; Brouwer et al., 2007; Sharma et al., 2001). Furthermore, a person's BMI is also believed to influence the severity of the misalignment (Gibson et al., 2010). Though the differences in the frontal joint angles may be clinically small, the effects that the change in the joint angle could be detrimental to loading at the knee, which may lead to long-term mobility problem like osteoarthritis (Miyazaki et al., 2002; Oliveria et al., 1999; Powell et al., 2005; Andriacchi et al., 2004) and valgus/varus

deformities like “knock-knee” and “bowleg” syndrome that are common among the obese population (Gibson et al., 2010).

Ankle joint

Significant differences in the peak adduction angles were noted between the males and females (Table 6). The female participants had a significantly larger ($p=0.001$) peak ankle adduction angle (6.8°) than the male participants (2.5°) when ascending the stairs. The linear regression found sex significantly contributed to the differences in the peak adduction angles as the $r(51) = -0.53$ ($p=0.000$) indicating a moderate negative correlation. The inversion-eversion movement of the foot-ankle complex may suggest that the female participants were trying to readjust their gait as a compensatory mechanism. From a biomechanical perspective, excess movements of the foot-ankle complex in the frontal plane may change the individuals' centre of mass (COM) relative the person's base of support (Mian, Thom, Narici, & Baltzopoulos, 2007).

From the kinematic findings, it was evident that significant sex differences in the joint angles were found in the hip, knee, and ankle joint. One of the possible explanations for this may have been due to the differences in terms of height. Shorter individuals, for example, may need to flex their knees more in order to compensate for their difference in height when they are ascending the stairs. Another possible explanation for the differences in joint angles may be due to the differences in muscular strength. Therefore, there is a need for future studies to examine the muscle activity of the lower limb during stair climbing, especially for females and males of different body mass. Lastly, the participants in the study may have adopted altered movement pattern in terms of their kinematic parameters when they were ascending or descending the stairs as a way to compensate changes in their COM to maintain their balance and stability.

5.3. Kinetics

Sagittal Plane:

Hip joint

In terms of the kinetic data, the study found the peak joint moment of force for the hip, knee, and ankle were influenced by the participants' body mass. Sex did not have a significant influence on the peak joint moment of force. In the sagittal plane, the joint moment profiles showed the hip was required to extend forward to lift the body from the ground to the first step by overcoming the forces of gravity (Fig 9a). The hip extensor moment for the normal weight, overweight, and obese groups were not significantly different. The hip flexor moment, however, were significantly higher for the obese group (0.42 N•m/kg) compared to the overweight group (0.22 N•m/kg) when ascending the stairs, $p=0.031$. There were no significant differences noted in the peak hip flexor moments for the three groups during descent as seen in Table 8. Both the normal weight and obese group had similar hip extensor moments perhaps because they were healthy and did not have any notable mobility problems. The finding was consistent with the studies on healthy normal weight population that noted hip extensor moment occurred during stance phase, which later changed to flexor moment during the rest of swing phase (Reid et al., 2005). Contrary to ascent, the hip produced a flexor moment during descent (Riener et al., 2002).

Knee joint

It was hypothesized that the knee extensor moment would be higher among the obese group compared to the normal weight during ascent and descent. Based on the results from the study, it was evident that the hypothesis was fully supported. The peak knee extensor moments were found to be significantly larger among the obese participants than the normal weight participants during descent ($p=0.026$) (Table 8). The results from the sagittal knee moment for

the normal weight, overweight, and obese groups were consistent with the findings from studies on stair climbing on the normal weight population (Costigan et al., 2001; Riener et al., 2002; Nadeau et al., 2003; Lin et al., 2005; Protopapadaki et al., 2007; Beaulieu et al., 2008). Similar to the results from past studies, the knee extensor moment gradually became smaller towards the end of swing phase (Riener et al., 2002; Lin et al., 2005). As seen in Fig. 9b, the overweight and obese group had a larger peak extensor moment of $-1.05 \text{ N}\cdot\text{m}/\text{kg}$ and $-0.99 \text{ N}\cdot\text{m}/\text{kg}$, while the normal weight group had a peak extensor moment of $-0.94 \text{ N}\cdot\text{m}/\text{kg}$ ($p=0.982$). The increased body mass may result in higher loading at the weight bearing joint such as the knee, which may have some implications on the structures of the knee. The structure that is required to absorb the patellar tendon force and peak flexor force that is acting on the ligament during ascent is the posterior cruciate ligament (PCL) (Lu & Lu, 2006).

Contrary to ascent, walking down the stairs required a second peak extensor moment at the knee in order to lower the body by controlling flexion at the knee. This finding has been reported by other researchers including Kowalk et al., (1996), McFadyen and Winter, (1988), Salsich et al., (2001), and Riener et al., (2002). Descending the stairs may place more loading at the knee, which may result in a higher moment due to the force of gravity that is acting on the person as one is climbing down. The second peak knee extensor moments were similar for the normal weight group and for the obese group (Fig 10b). It is interesting to note, however, the overweight group had a significantly higher initial peak knee extensor moment at weight acceptance ($-0.98 \text{ N}\cdot\text{m}/\text{kg}$) than the normal weight group ($-0.70 \text{ N}\cdot\text{m}/\text{kg}$) when they were descending the stairs ($p=0.026$) (Table 8). The higher loading at knee may have some implications on the amount of stress that is acting on the anterior structures of the knees. Along the anterior side of the knee, the anterior cruciate ligament may need to withstand the greater

forces that are acting on the knee (Lu & Lu, 2006). Injury to this ligament may cause degeneration of the joint or limited movement (Lu & Lu, 2006). Furthermore, damage to the articular surfaces of the knee may lead to knee osteoarthritis (OA), which may result in restricted movement (Griffin & Guilak, 2005). It is still uncertain whether there is a clear link between obesity and osteoarthritis, but there are studies that suggest mechanical loading is associated with the development of osteoarthritis (McAlindon et al., 1991) and have suggested that obesity may be a determining factor (Powell et al., 2005).

Ankle joint

It was hypothesized that the ankle plantar flexor moments for both the obese and normal weight group would be similar during ascent and descent. From Table 8, it was evident that the hypothesis was fully supported as both the peak plantar flexor moment for the obese and non-obese groups were similar during ascent and descent. The finding was consistent with studies in the past on the normal weight population as researchers noted that the ankle joint was required to plantar flex during ascent, while the peak ankle plantar flexor moment was reduced during descent (Beaulieu et al., 2007; Riener et al., 2002). The ankle joint is required to plantar flex during stair ascent and descent in order to perform a toe-off as one goes from the ground to the step or from a step to the ground (Andriacchi et al., 1980; Livingston et al., 1991).

Frontal Plane:

Hip joint

In the frontal plane, it was hypothesized that the hip adductor moment for the obese subjects will be significantly higher than the non-obese subjects during stair ascent and descent. From the results, it was evident that the initial hypothesis was not supported. During ascent, the

right side of the hip was required to abduct in order to raise the pelvis on the contralateral side of the participants' body during the early stages of stance phase (Fig 11a). This lateral tilt of the pelvis was necessary in order to assist the swinging leg to avoid the initial step (Nadeau et al., 2003). Contrary to the initial hypothesis, the overweight (-0.35 N•m/kg) and obese group (-0.32 N•m/kg) had a smaller hip abductor moment compared to the normal weight group (-0.44 N•m/kg) (Table 10). There were no significant differences that were noted between the hip abductor moments for the obese and normal weight group during descent as both the shape and peaks for the two groups were similar in shape and sizes (Fig. 12a). As mentioned before, the participants in the study were generally healthy and did not suffer any mobility problems. This may have been one of the reasons why there were no significant differences found in the hip abductor moment. If this was not the case, there may have been more notable differences in that could have been found in the hip abductor moments. Studies in the past on patients with hip arthroplasty, for example, have found they had weaker hip abductor muscles which may make stair climbing more difficult (Perron et al., 1998).

Knee joint

Similar to the hip moment curve, the knee moment curves along the frontal plane were characterized by abductor (valgus) moments of the knee. The curves for the knee joint moment were consistent with the ones found by Riener et al., (2002) and Lin et al., (2005) on the normal weight population. As noted in the study by Lin et al., (2005), one defining feature in the knee moments of frontal plane was the fact that there were two peak moments in the knee that characterized stair ascent and descent. As seen in Fig 11b and 12b, both the obese and normal weight group had an initial peak valgus peak during early stance phase and also later on near the start of swing phase. Surprisingly, the peak valgus moment was found to be significantly larger

($p=0.036$) in the overweight group ($-0.52 \text{ N}\cdot\text{m}/\text{kg}$) compared to the obese group ($-0.27 \text{ N}\cdot\text{m}/\text{kg}$) as seen in Table 10. The results were somewhat unexpected because as predicted by Nadeau et al., (2003), stair climbing normally is expected to produce higher amount of stress that results in a higher knee abductor moment that is noted in the early stance phase as compared to level walking. Andriacchi et al., (1980) and Kowalk et al., (1996) noted that the knee abductors were required during early and late stance phase of descent in order provide propulsion and medial lateral stability. The structures that normally provide the knee abductor moment includes the lateral collateral ligament and the ilio-tibial band of the medial side of the knee, which creates an abductor moment at the knee because the ground reaction force vector must pass medial to the knee joint centre (Kowalk et al., 1996). Hence with the higher joint loading at the knee, this task may be more challenging for those with mobility problems such as knee osteoarthritis or ‘bow leg’ syndrome (Gibson et al., 2010). Approximately 76% of obese individuals have an existing varus alignment at the onset of knee OA or will develop a varus alignment with disease progression (Felson et al., 2004). It is believe that the varus knee alignment is a mediating factor that predisposes a person to medial compartment knee OA(Sharma et al., 2010;Cerejo et al., 2002; Brouwer et al., 2007; Sharma et al., 2001), and a person’s added body weight (Gibson et al., 2010) can lead to varus knee joint alignment. Also, BMI has a shown to be correlated with the severity of the misalignment in this segment of the population (Gibson et al., 2010).

Ankle joint

Along the frontal plane, however, there were significant differences noted between the groups as the obese group tended to abduct their ankles more than the normal weight ($p=0.031$) and overweight ($p=0.002$) during descent (Table 10). With the exception of the ankle abductor moment, the findings from the present study did not find any other significant difference.

5.4. Limitations

One of limitations for the present study would be the use of the BMI classification system. This measurement has been in widespread use in many studies because the information required (body weight and height) is easy to collect, inexpensive, safe, and practical (Gallagher et al., 1996). Although this measurement has been widely used in many clinical settings, many of the medical literature have suggested this measurement may provide inaccurate measure of fatness since it only takes into account the weight and height of a person (Garn, Leonard & Hawthorne, 1986; Smalley et al., 1990; Gallagher et al., 1996; Yusuf et al., 2005; McCarthy et al., 2006). Hence, this measurement may provide misleading information that does not distinguish between lean tissue and adipose tissue; i.e., the difference between fat, muscle, bone, and other soft tissue. In the end, BMI may overestimate the body fat content for those with more lean body mass (i.e., athletes and military personnel) and underestimate for those with less lean body mass (Prentice & Jebb, 2001; Sizer & Whitney, 2006). The dual-energy X-ray scan may provide a more accurate measure of body composition, but unfortunately this technology was not used for the present study.

Besides this limitation, it is also important to note that the use of the BMI measurement in defining obesity does not account for the variations during the day. It has been shown that during the day, a person's BMI tends to vary roughly 5-15% of body weight (about ± 1 kg in a person with 60 kg) (Lehikoinen, 1987). For this reason, the data for the participants that fell within the 'borderlines' of being normal weight or overweight and overweight or obese were excluded for the present study. Moreover, there has been issue with the BMI measurement in regards to its sensitivity in defining which participants were obese. In the study by Romero-Corral et al., (2008), the researchers noted that while BMI may have high specificity in regards

to defining whether a person's obese ($\geq 30 \text{ kg/m}^2$), the measurement showed an unacceptable low sensitivity for detecting body fatness, with more than half of their obese subjects being labeled as normal or overweight by BMI. Whether it may have been due to the participant recruitment or the BMI criteria that was used to classify the participants, the sample sizes for the specific populations in the present study were small; especially the obese group ($n=8$) and the obese male and females participants were not matched in number. As a result, the small sample may not be reflective of this segment of the general population.

Findings from the medical literature also suggest it is not just the amount of fat that matters but the location or distribution of that fat. Male individuals, for example, tend to have more adipose tissue that is concentrated near their thorax abdominal region, whereas females tend to have a greater adipose tissue in their lower extremity (Clark, 2004). The increase level of adipose may affect the muscular strength of obese individuals in regards to their mobility and their postural control during stair climbing. Studies on the muscular strength of obese individuals, for example, have found that though obese individuals tend have increased knee extensor strength, their absolute knee flexion strength tends to be either similar or reduced when compared with non-obese individuals due to the infiltration of adipose tissue (Hulen et al., 2003; Delmonico et al., 2007). Muscle strength is associated to challenging locomotion, such as stair climbing. Therefore, it was also possible that a person with a high BMI resulting from his or her larger muscle mass may show better performance in stair climbing compared to an individual who was overweight or obese resulting from his or her fat tissue. There is a still a need for future studies to examine not just the amount of fat but also how the distribution of fat may influence mobility and muscular strength of obese individuals during stair climbing, since currently this is one of limitations for the present study.

In regards to the equipment, the experimental staircase consisted of only three steps. The number of steps that was used during each trial of stair climbing could be a potential limitation, since it may not be representative of climbing the stairs in the real world, which tend to vary in height and tread depth. One of the most pressing matter that have yet to be addressed by researchers in the field of biomechanics is the issue surrounding movement from skin markers. Any error resulting from movement of the markers or placement of the markers may result in error in the kinematic calculations, and subsequently the accuracy of the kinetic data. There is still a need for future studies to address this issue as there is still no viable solution as to minimize the amount of error from the skin markers by minimizing movement of the skin (Wearing et al., 2006).

Furthermore, the model for the principles of inverse dynamics assumes that the segments of the body are rigid structures (Robertson et al., 2004). This may not be the case during human movement since the tissue, bone, and ligament tend undergo deformation in more flexible structures such as the foot and trunk compared to more rigid structures as in the leg and thigh. As the result, the joint moment calculations for these more flexible structures may be slightly less accurate compared to the more rigid structures (Robertson et al., 2004).

Lastly, this study did not provide an analysis of the muscle activity of the lower limb during stair ascent and descent. This is one of the limitations for the present study as there have been few studies that have examined the muscle activity of overweight and obese individuals during stair climbing. Obese and overweight individuals may have greater adipose tissue than compared to normal weight individuals. With a greater level of adipose tissue, the signal that is collected from the obese participant may be 'noisier' than the signal that is collected from the normal weight participant. There is still a need for future studies to address this area of research.

5.5. Conclusion

In summary, older than 50 years obese people (BMI range from 30 to 34.9) had a significant change in their joint kinetics during stair climbing compared to age matched normal weight people. With regards of the effects of mass, body mass had a significant influence on the knee and ankle joint moment of force when descending the stair. During descent, the increased body mass in overweight participants may place a greater demand on the weight bearing joint at the knee due to the higher initial peak knee extensor moment at weight acceptance. Furthermore, the participants' higher body mass also caused the obese participants to abduct their ankles more than the normal weight and overweight participants to compensate for their larger mass during descent.

Sex had a significant influence on the peak valgus angles of the knee joint as the female participants tended to abduct their knees more than the male participants during descent regardless of body mass. This finding may provide a possible explanation for the reason why osteoarthritis of the knee is more common in women than men. The female participants were also more likely to plantar flex their ankles more compared to the males during ascent and descent, while the peak adduction angles in the female participants were also larger during ascent. Lastly, no significant effects of mass and sex were noted in the temporo-spatial parameters. The findings from the present study suggest that body mass resulted in significant impact on the joint kinetics of the lower limb during stair climbing, while sex differences were presented in the joint angles and range of motion of the lower limb.

References:

- Ang, E.J., Goh, C.J.H., Nicol, A.C., & Paul, J.P. (1989). Effects of load carriage on the lower limb. XII International Congress of Biomechanics Proceedings. Los Angeles: University of California, 1989.
- Andriacchi, T.P. & Scipplein, O.D., (1991). Interaction between active and passive knee stabilizers during level walking. *Journal of Orthopaedic Research*, 9, 113-119.
- Andriacchi, T.P., Andersson, G.B.J, Fermier, R.W., & Stern, D. (1980). A study of lower-limb mechanics during stair-climbing. *The Journal of Bone and Joint survey*, 62, 749-757.
- Andriacchi, T.P., Mundermann, A., Smith, R.L., Alexander, E.J., Dyrby, C.O., & Koo, S.A. (2004). A framework for the in vivo pathomechanics of osteoarthritis at the knee. *Annals Biomedical Engineering*, 32(3), 447-57.
- Assay, J.L., Mundermann, A., & Andriacchi, T.P. (2008). Adaptive pattern of movement during stair climbing in patients with knee osteoarthritis. *Journal of Orthopedic Research*, 27, 325-329.
- Barrett, D.S., Cobb, A.G., Bentley, G. (1991). Joint proprioception in normal, osteoarthritic and replaced knees. *Journal of Bone Joint Surgery*, 73,53-56.
- Bassey, E.J., Fiatarone, M.A., Oneill, E.F., Kelly M., Evans, W.J., & Lipsitz, L.A. (1992). Leg extensor power and functional extensor power and functional performance in very old men and women. *Clinical Science*, 82, 321-327.
- Beaulieu, F.G., Pelland, L., & Robertson, G.E. (2006). Kinetic analysis of forwards and backwards stair descent. *Gait & Posture*, 27, 564-571.

- Benoit, D. L., Ramsey, D. K., Lamontagne, M., Xu, L., Wretenberg, P., & Renstrom, P. (2006). Effect of skin movement artifact on knee kinematics during gait and cutting motions measured in vivo. *Gait & Posture*, 24(2), 152-164.
- Blimkie, C.J.R., Sale, D.G., & Bar-Or, O. (1990). Voluntary strength, evoked twitch contractile properties and motor unit activation of knee extensors in obese and non-obese adolescent males. *European Journal of Applied Physiology*, 61, 313-318.
- Borges, O. (1989). Isometric and isokinetic knee extension and flexion torque in men and women aged 20-70. *Scandinavian Journal of Rehabilitation Medicine*, 21, 5-53.
- Bowsher, K.A. & Vaughan, C.L. (1995). Effect of foot-progression angle on hip joint moments during gait. *Journal of Biomechanics*, 28, 759-762.
- Brady, T.J. & Sniezek, J.E. (2003). Implementing the National Arthritis Action Plan: New Population-based approaches to increasing physical activity among people with arthritis. *Arthritis & Rheumatism*, 49(3), 471– 476.
- Brandt, K.D., Heilman, D.K., Slemenda, C., et al., (2000). A comparison of lower extremity muscle strength, obese, and depression scores in elderly subjects with knee pain with and without radiographic evidence of knee osteoarthritis. *Journal of Rheumatology*, 8, 1937-1946.
- Browning, R.C. & Kram, R. (2007). Effects of obesity on the biomechanics of walking at different speeds. *Medicine & Science in Sports & Exercise*, 39(9),1632-1640.
- Brouwer, G.M., van Tol, A.W., Bergink, A.P., et al. (2007). Association between valgus and varus alignment and the development and progression of radiographic osteoarthritis of the knee. *Arthritis Rheumatism*, 56(6), 1204-1211

- Collopy ,M.C. Murray, M.P., Gardner, G.M., DiUlio, R.A., & Gore, D.R. (1977). Kinesiologic measurements of functional performance before and after geometric total knee replacement: one year follow-up of twenty cases. *Clinical Orthopaedic and Related Research*, 126, 196-202.
- Carter, D.R. & Wong, M. (2003). Modeling cartilage mechanobiology. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 358, 1461-71.
- Catenacci, J., Hill, J., & Wyatt, H. (2009). The Obesity Epidemic. *Clinics in Chest Medicine*, 30(3), 415-444.
- Centre for Disease Control and Prevention. (2000). 2000 CDC Growth Charts for the United States: Methods and Development. Retrieved October 25, 2010 from: http://www.cdc.gov/nchs/data/series/sr_11/sr11_246.pdf
- Cerejo, R., Dunlop, D.D., Cahue, S. et al., (2002). The influence of alignment on the risk of knee osteoarthritis progression according to baseline state of disease. *Arthritis Rheumatism*, 46(10), 2632-2636.
- Chambers, A.J., Sukits, A.L., McCrory, J.L., & Cham, R. (2010). The effect of obesity and sex on body segment parameters in older adults. *Clinical Biomechanics*, 25, 131-136.
- Chang, A., Hayes, K., Dunlop, D., Hurwitz, D., Song, J., Cahue, S., Genge, R., & Sharma, L. (2004). Thrust during ambulation and the progression of knee osteoarthritis. *Arthritis & Rheumatism*, 50(12), 3897-3903.
- Chang, A. & Sharma, L. (2007). Overweight: advancing our understanding of its impact on the knee and the hip. *Annals of Rheumatic Disease*, 66, 141-142.
- Cho, S.H., Park, J.M. & Kwon, O.Y. (2004). Gender differences in three dimensional gait analysis data from 98 healthy Korean adults. *Clinical Biomechanics*, 19, 145-152.

- Clark, K. (2004). Balance and strength training for obese individuals. *ACSM'S Health Fitness Journal*, 8, 14-20.
- Clymer, J. (2010). Body-mass index (BMI), waist-to-hip ratio (WHtR), basal metabolic rate (BMR), body fat & surface area Wiloughby ideal waist & weight. Retrieved, May 19, 2011, <http://home.fuse.net/clymer/bmi/>
- Cole, T.J., Bellizzi, M.C., Flegal, K.M., & Dietz, W.H. (2000). Establishing a standard definition for child overweight and obesity worldwide: international survey. *British Medical Journal*, 320, 1-6.
- Collopy ,M.C. Murray, M.P., Gardner, G.M., DiUlio, R.A., & Gore, D.R. (1977). Kinesiologic measurements of functional performance before and after geometric total knee replacement: one year follow-up of twenty cases. *Clinical Orthopaedic and Related Research*, 126, 196-202.
- Costigan, P.A., Deluzio, K.J., & Wyss, U.P. (2002). Knee and hip kinetics during normal stair climbing. *Gait and Posture*, 16, 31-37.
- Cress, M.E., Thomsas, D.P., & Johnson, J. (1991). Effects of training on VO_{2max} thigh strength and muscle morphology in septuagenarian women. *Medical and Science in Sports and Exercise*, 23, 752-758.
- Davis, M.A., Etinger, W.H., Neuhaus, J.M. (1990). Obesity and osteoarthritis of the knee: evidence from the National Health and Nutrition examination Survey. *Seminars in Arthritis Rheumatism*, 20, S34-S41.
- Delmonico, M.J., Harris, T.B., Visser, M., Park, S.W., Controy, M.B., Velasquex-Mieyer, P., Boudreau, R., Manini, T.M., Nevitt, M., Newman, A.B., Goodpaster, B.H., (2009). Longitudinal study of muscle of muscle strength, quality and adipose tissue infiltration. *American Journal of Clinical Nutrition*, 90, 1579-1585.

- Dempster, W.T., Gabel, W.C., & Felts, W.J.L. (1959). The anthropometry of manual workspace for the seated subject. *American Journal of Physiological Anthropometry*, 17, 289-317.
- DeVita, & P. Hortobagyi, T. (2003). Obesity is not associated with increased knee joint torque and power during level walking. *Journal of Biomechanics*, 36, 1355-1362.
- Devos-Comby, L., Cronan, T., Roesch, S.C. (2006). Do exercise and self-management benefit patients with osteoarthritis of the knee? A meta-analytic review. *The Journal of Rheumatology*, 33 (4),744-756.
- Dowdy, P.A., Cole, B.J., Harner, C.D. (1998). Knee arthritis in active individuals. *The Physician and Sports Medicine*, 26, 43-54.
- Durkin, J.L., Dowling, J.J. (2003). Analysis of body segment parameters differences between four unman populations and the estimation errors of four popular models. *Journal of Biomechanical Engineering*, 125, 515-522.
- Fotch, B.C., Rejeski, W.J., Ambrosius, W.T., Katula, J.A., & Messier, S.P. (2005). Exercise, self-efficacy, and mobility performance in overweight and obese older adults with knee osteoarthritis. *Arthritis & Rheumatism*, 53 (5), 659-665.
- Gali, M., Crivellini, M., Sibella, F., Montesano, A., & Bertocco, P. (2000). Sit-to-stand movement analysis in obese subjects. *International Journal of Obesity and Related Metabolic Disorder*, 24,1488-1492.
- Gallagher, D., Visser, M., Sepulveda, D., Pierson, R.N., Harris, T., & Heymsfield, S.B. (1996). How useful is body mass index for comparison of body fatness across, age, sex, and ethnic group, *American Journal of Epidemiology*, 143 (3), 228-239.
- Garn, S. M., Leonard, W.R., & Hawthorne, V.M. (1986). Three limitations of the body mass index. *American Journal of Clinical Nutrition*, 44, 996-997.

- Gibson, K., Sayers, S.P. Minor, M.A. (2010). Measurements of varus/valgus alignment in obese individuals with knee osteoarthritis. *Arthritis Care & Research*, 62(5), 690-696.
- Griffin, T.M. & Guilak, F. (2005). The Role of Mechanical Loading in the Onset and Progression of Osteoarthritis. *Exercise and Science Sport Review*, 33(4), 195-200.
- Hills, A.P., & Wahlqvist, M.L. (1994). *Exercise and Obesity*. London: Smith-Gordon & Co.
- Hills, A.P., Hennig, E.M., Byrne, N.M., & Steele, J.R. (2002). The biomechanics of adiposity-structural and functional limitations of obesity and implications for movement. *Obesity Review*, 3, 35-43.
- Hortobagyi, T., Mizelle, C., Beam, S., & DeVita, P. (2003). Old adults perform activities of daily living near their maximal capabilities. *Journals of Gerontology*, 58, 453-460.
- Hughes, V.A., Roubenoff, R., Wood, M., Frontera, W.R., Evans, W.J., Fiatarone Singh, M.A. (2004). Anthropometric assessment of 10-y changes in body composition in the elderly. *American Journal of Clinical Nutrition*, 80, 475-482.
- Hulens, M., Vansant, G., Laysens, R., Claessens, A.L., Muls, E. & Brumagne, S. (2001). Study of differences in peripheral muscle strength of lean versus obese women: an allometric approach. *International Journal of Obesity*, 25, 676-681.
- Hulens, M., Vanasant, G., Claeseens, A.L., Lysens, R., & Muls, E. (2003). Predictors of 6-minute walk-test results in lean, obese, and morbidly obese women. *Scandinavian Journal of Medicine & Science in Sports*, 13, 98-105.
- Janssen, I., Mark, A.E. (2006). Separate and combined influence of body mass index and waist circumference on arthritis and knee osteoarthritis. *International Journal of Obesity*, 30, 1223-1228.

- Kaufman, K.R., Hughes, C., Morrey, B.F., Morrey, M. & An, K.N. (2001). Gait characteristics of patients with knee osteoarthritis. *Journal of Biomechanics*, 34, 907-915.
- Kenny, C. (1997). Radial displacement of the medial meniscus and Fairbank's sign. *Clinical Orthopaedic Related Research*, 339, 163-173.
- Kerrigan, C., Todd, M.K., Croce, U.D. (1998). Gender Differences in Joint Biomechanics During Walking. *American Journal of Physical Medicine & Rehabilitation*, 77(1), 2-7.
- Kirkwood, R.N., Culham, E.G., & Costigan, P. (1999). Hip moments during level walking, stairclimbing, and exercise in individuals aged 55 years or older. *Physical Therapy*, 79(4), 361-370.
- Kitagawa, K. & Miyashita, M. (1978). Muscle strength in relation to fat storage rate in young men. *European Journal of Applied Physiology*, 38, 189-196.
- Ko, S., Stenholm, S., Ferrucci, L. (2010). Characteristic gait patterns in older adults with obesity- results from the Baltimore Longitudinal Study of Aging. *Journal of Biomechanics*, 43, 1104-1110.
- Kowalk, D.L., Duncan, J.A., & Vaughan, C.L. (1996). Abduction-adduction moments at the knee during stair ascent and descent. *Journal of Biomechanics*, 29 (3), 383-388.
- Lai, P.P., Leung, A.K., Li, A.N., Zhang, M. (2008). Three dimensional gait analysis of obese adults. *Clinical Biomechanics*, 23 (Suppl.1), S2-S6.
- Lamontagne, M., Varin, D., & Beaulé, P.E. (2011). Does the anterior approach for total hip arthroplasty better restore stair climbing gait mechanics? *Journal of Orthopaedic Research*, 1-6. doi: 10.1002/jor.21392

- Lamontagne, M., Beaulieu, M.L., & Beulé, P.E. (2009). Pelvis & Hip Joint Mechanics During Stair Ascent & Descent Following Total Hip Arthroplasty. *Gait & Posture* (Vol.30, p.S54).
- Law, N., Li, J., & Law, N. (2011). The moment of the hip and knee in obese and non-obese individuals during stair ascent and descent. *Portugese Journal of Sport Sciences*, 11(Suppl. 2), 523-526.
- Larsen, A.H., Sorensen, H., Puggaard, L., & Aagaard, P. (2009). Biomechanical determinants of maximal stair climbing capacity in healthy elderly women. *Scandinavian Journal of Medicine & Science in Sports*, 19, 678-686.
- Lehilkoinen, Esa. (1987). Seasonality of the Daily weight Cycle in Wintering Passerines and Its Consequences. *Ornis Scandinavica*, 18 (3), 216-226.
- LeVeau, B.F., & Bernhardt, D.B. (1984). Developmental biomechanics. *Physical Therapy*, 64, 1874-1882.
- Livingston, L.A., Stevenson, J.M., Olney, S.J. (1991). Stair climbing kinematics on stairs of differing dimensions. *Archives of Physical Medicine and Rehabilitation*, 72, 398-402.
- Lin, H.C., Lu, T.W., & Hsu, H.C. (2005). Comparison of joint kinetics in the lower extremity between stair ascent and descent. *Journal of Mechanics*, 21(1), 41-50.
- Lohmander, L.S., Gerhardsson de Verdier, M., Rollof, J., Nilsson, P.M., & Engstrom, G. (2011) Incidence of severe knee and hip osteoarthritis in relation to different measures of body mass: a population-based prospective cohort study. *Annals of Rheumatic Disease*, 68: 490-496.
- Loy, S.F., Holland, G.J., Mutton, D.L. (1991). Effects of stair climbing vs. running on treadmill and track running performance. *International Journal of Sports Medicine*, 12, 342.

- Loy, S.F., Conley, L.M., Sacco, E.R., Vincent, W.J., Holland, G.J., Sletten, E.G., & Trueblood, P.R. (1993). Effects of stair climbing on VO_{2max} and quadriceps strength in middle-aged females. *Medicine & Science in Sports & Exercise*, 26(2), 241-247.
- Lu, T.W. & Lu, C.H. (2006). Forces transmitted in the knee joint during stair ascent and descent. *Journal of mechanics*, 22(4), 289-297.
- Mazlan, M.H., Abu Osman, N.A., Wan Abas, & W.A.B. (2011). Hip 3D joint mechanics analysis of normal and obese individuals. BIOMED 2011, IFMBE Proceeding, 35, 161-166
- McCarthy, H. D., Cole, T.J., Fry, T., Jebb, S.A., & Prentice, A.M. (2006). Body fat reference curves for children. *International Journal of Obesity*, 30, 598–602.
- McFadyen, B.J. & Winter, D.A. (1988). An integrated biomechanical analysis of normal stair ascent and descent. *Journal of Biomechanics*, 21 (9), 733-744.
- McAlindon, T.E., et al., Level of physical activity and the risk of radiographic and symptomatic knee osteoarthritis in the elderly: The Framingham study. *American Journal of Medicine*, 1999. 106(2), 151-157.
- Messier, S.P. (1994). Osteoarthritis of the knee and associated factors of age and obesity: effects on gait. *Medicine & Science in Sports & Exercise*, 26(12),1446-1452
- Messier, S.P., Davies, A.B., Moore, D.T., Davis, S.E., Pack, R.J., & Kazmar, S.C. (1994). Severe obesity: effects on foot mechanics during walking. *Foot Ankle International*, 15, 29-34.
- Messier, S.P., Ettliger, W.H., Doyle, T.E., Morga, T., James, M.K., O'Toole, M.I. et al. (1996). Obesity effects on gait in an osteoarthritic population. *Journal of Applied Biomechanics*, 12, 161-72.

- Messier, S.P., Loeser, R.F., Miller, G.D., Morgan, T.M., Rejewski, W.J., Sevick, M.A., Ettinger, W.H., Pahor, M., & Williamson, J.D. (2004). Exercise and dietary weight loss in overweight and obese older adults with knee osteoarthritis. *Arthritis & Rheumatism*, 50(5), 1501-1510.
- Messier, S.P., Gutkunst, D.J., Davis, C. & DeVita, P. (2005). Weight loss reduces knee-joint loads in overweight and obese older adults with knee osteoarthritis. *Arthritis & Rheumatism*, 52(7), 2026-2032.
- Mian, O.S., Thom, J.M., Narici, M.V., & Baltzopoulos, V. (2007). Kinematics of stair descent in young and older adults and the impact of exercise training. *Gait Posture*, 25(1), 9-17.
- Miyatake, N., Fujii, M., Nashikawa, H., Wada, J. Shikata, K., Makino, H. & Kimura, I. (2000). Clinical evaluation of muscle strength in 20-79 years old obese Japanese. *Diabetes Research and Clinical Practice*, 48, 15-21
- Miyazaki, T., Wada, M., Kawahara, H., Sato, M., Baba, H., & Shimada, S. (2002). Dynamic load at baseline can predict radiographic disease progression in medial compartment knee osteoarthritis. *Annals of Rheumatic Disease*, 2002, 61(7), 617-22.
- Mohammad-Jafar, E., Mohammad-Hosseini, G., Farzad, A. & Hamid, N. (2007). "Q-angle: an invaluable parameter for evaluation of anterior knee pain". *Archives of Iranian medicine*, 10(1), 24-26.
- Nadeau, S., McFadyen, B.J., & Malouin, F. (2003). Frontal and sagittal plane analyses of the stair climbing task in healthy adults aged over 40 years: what are the challenges compared to level walking. *Clinical Biomechanics*, 18, 950-959.
- Nantel, J., Brochu, M., & Prince, F. (2006). Locomotor strategies in obese and non-obese children. *Obesity*, 14, 1789-94.

- Nordin, M., & Frankel, V. (1989). *Basic Biomechanics of the Musculoskeletal System*. Lea & Fabiger: Philadelphia, PA.
- Oliveria, S.A., Felson, D.T., Cirillo, P.A., Reed, J.I., & Walker, A.M. (1999). Body weight, body mass index and incident symptomatic osteoarthritis of the hand, hip, and knee. *Epidemiology*, 10, 161-6.
- Osteoarthritis. (2003). San Diego: Arthritis Foundation. San Diego Area Chapter.
- Pai, Y.C., Rymer, W.Z., Chang, R.W., Sharma, L. (1997). Effect of age and osteoarthritis on knee proprioception. *Arthritis and Rheumatism*, 40, 2260-2265.
- Powell, A. , Teichtahl, A.J. & Cicuttini, F.M. (2005). Obesity: a preventable risk factor for large joint osteoarthritis which may act through biomechanical factors. *British Journal of Sport Medicine*, 39, 4-5.
- Prentice, A.M. & Jebb, S.A. (2001). Beyond body mass index. *Obesity Review*, 2, 141-147.
- Protopapadaki, A., Drechsler, W.I., Cramp, M.C., Coutts, F.J., & Scott, O.M. (2007). Hip, knee, ankle kinematics and kinetics during stair ascent and descent in healthy young individuals. *Clinical Biomechanics*, 22, 203-210.
- Public Health Agency of Canada. (1998). Economic burden of illness in Canada. Retrieved May 18, 2011, from <http://ebic-femc.hc-sc.gc.ca>.
- Radin, E.L., Yang, K.H., Riegger, C., Kish, V.L., & O'Connor, J.L. (1991). Relationship between lower limb dynamics and knee joint pain. *Journal of Orthopaedic Research*, 9, 398-405.

- Ramarkrishnan, H.K., Kadaba, M.P. & Wooten, M.E. (1987). Lower extremity joint moments and ground reaction torque in adult gait. In *Biomechanics of Normal and Prosthetic Gait*, pp. 87-92 American Society of Mechanical Engineers.
- Reid, S.M., Lynn, S.K., Musselman, R.P., & Costigan, P.A. (2007). Knee biomechanics of alternate stair ambulation patterns. *Medicine & Science in Sports & Exercise*, 39 (11), 2005-2011
- Reeves, N.D., Spanjaard, M., Mohagheghi, A.A., Baltzopoulos, V. & Maganaris, C.N. (2009). Older adults employ alternative strategies to operate within their maximum capabilities when ascending stairs. *Journal of Electromyography and Kinesiology*, 19, e57-e68.
- Riddiford, D.L., Steele, J.R. Storlien, L.H., (1999). Does obesity affect the ability of prepubescent children to rise from a chair?. *Book of Abstracts for the International Society of Biomechanics VIIth Congress*. Calgary, Canada, 1999. Pg. 780.
- Riener, R., Rabuffeti, M. & Frigo, C. (2002). Stair ascent and descent at different inclinations. *Gait & Posture*, 15, 32-44.
- Rosentswieg, J., Verstraete, D., & Bassett, G. Stair climbing as a training modality for women (abstract). *Medical Science in Sports and Exercise*, 18, S28.
- Robertson, G.E., Cadwell, G.E., Hamil, J., Kamen, G. & Whittlesey, S.N. (2004). Research methods in biomechanics. Champaign, IL: Human Kinetics.
- Romero-Corral, A., Somers, V.K., Sierra-Johnson, J; Thomas, R J; Collazo-Clavell, M L; Korinek, J; Allison, T G; Batsis, J A et al. (2008). Accuracy of body mass index to diagnose obesity in the US adult population. *International Journal of Obesity*, 32 (6), 959-66.

- Roos, H., Adalberth, T., Dahlberg, L., & Stefan Lohmander, L. (1995). Osteoarthritis of the knee after injury to the anterior cruciate ligament of meniscus: the influence of time and age. *Osteoarthritis Cartilage*, 3, 261-267.
- Salsich, G.B., Brecker, J.H., Powers, C.M. (2001). Lower extremity kinetics during stair ambulation in patients with and without patellarfemorla pain. *Clinical Biomechanics*, 16, 906-912.
- Sasse, J.L.CM, Van Romunde, L.K., Cats, A., Vandenbroucke, J.P., Valkenburg, H.A. (1989). Comparison of radiological osteoarthritis in a Dutch population with that in 10 other populations. *Annals of the Rheumatic Disease*, 48, 271-280.
- Schipplein, O.D., & Andriacchi, T.P., Sugar, D.A. (1991). Interaction between active and passive knee stabilizers during level walking. *Journal of Orthopaedic Research*, 9(1), 113-119.
- Seniam.org, (2011). Sensor location: recommendation for sensor location for each individual muscle. Retrieved May 19, 2011, from <http://seniam.org/>
- Sharma, L., Song, J., Dunlop, D. (2010). Varus and valgus alignment and incident and progressive knee osteoarthritis. *Annals of Rheumatic Disease*: in press.
- Sharma, L., Song, J., Felson, D.T. (2001). The role of knee alignment in disease progression and functional decline in knee osteoarthritis. *JAMA*, 286 (2), 188-195.
- Sibella, F., Gali, M., Romei, M., Montesano, A., & Crivellini, M. (2003). Biomechanical analysis of sit-to-stand movement in normal and obese subjects. *Clinical Biomechanics*, 18, 745-750.
- Sizer, F. & Whitney, E. (2005). Nutrition: concepts and controversies (10th edition). Brooks Cole: California, U.S.

- Slemenda, C., Mazzuca, S., Brandt, K., Katz, B. (1996). Lower extremity lean tissue mass and strength predict increase in pain and in functional impairment in knee osteoarthritis. *Arth Rheum*, 29(9), S212. Abstract.
- Smalley, K. J., Knerr, A.N., Kendrick, Z.V., Colliver, J.A., & Owen, O.E. (1990). Reassessment of body mass indices. *American Journal of Clinical Nutrition*, 52, 405–408.
- Spyropoulos, P., Pisciotta, J.C., Pavlou, K.N., Cairns, M.A., & Simon, S.R. (1991). Biomechanical gait analysis in obese men. *Archives of Physical Medicine and Rehabilitation*, 72, 1065-1070.
- Startzell, J.K., Owen, D.A., Mulfinger, L.M., & Cavanagh, P.R. (2000). Stair negotiation in older people: a review. *Journal of American Geriatrics Society*. 48, 567-680.
- Statistics Canada. (2001). Arthritis in Canada: an ongoing challenge. Retrieved May 18, 2011, from http://www.acreu.ca/pdf/Arthritis_in_Canada.pdf
- Statistics Canada. (2006). It's your health. Retrieved December 14, 2010, from http://www.hc-sc.gc.ca/hl-vs/alt_formats/pacrb-dgapcr/pdf/iyh-vsv/life-vie/obes-eng.pdf
- Strutzenberger, G., Richter, A., Lang, D., & Schwameder, H. (2011). Effects of obesity on the biomechanics of stair-walking in children. *Gait & Posture*, 34, 119-125.
- Varin, D. (2011). *Kinematics and Kinetics of Total Hip Arthroplasty Patients during Gait and Stair Climbing* (Masters Dissertation). Retrieved from Dec. 12, 2012 from: http://www.ruor.uottawa.ca/en/bitstream/handle/10393/19723/Varin_Daniel_2011_these.pdf?sequence=1
- Warren WH. (1984). Perceiving affordances: visual guidance of stair climbing. *Journal of Experimental Psychology. Human Perception Performance*, 10, 683–703.

- Wearing, S.C., Hennig, E.M., Byrne, N.M., Steele, J.R. & Hill, A.P. (2006). The biomechanics of restricted movement in adult obesity. *Obesity Review*, 7, 13-24.
- Wells, R.P. (1981). The projection of the ground reaction force as a predictor of internal joint moments. *Bull Prothet Res*, 18(1), 15-19.
- Winter, D.A., Patla, A.E., Frank, J.S., & Walt, S.E. (1990). Biomechanical walking pattern changes in the fit and healthy elderly. *Physical Therapy*, 70, 340-347.
- Winter, D.A. (1995). Human balance and posture control during standing and walking. *Gait and Posture* 3: 193-214.
- Wolfson, L., Judge, J., Whipple, R., & King, M. (1995). Strength is a major factor in balance, gait, and the occurrence of falls. *Journal of Gerontology. Series A, Biological Science and Medical Science*, 50, 64-67,
- Woltring, H.J. (1978). A FORTRAN package for generalized cross-validatory spline smoothing and differentiation. *Advances in Engineering Software*, 8, 104-13.
- World Health Organization. Obesity: preventing and managing the global epidemic. Report of a WHO Consultation on Obesity. WHO: Geneva, 1998.
- Yusuf, S., Hawken, S., Ounpuu, S., Bautista, L., Franzosi, M.G., Commerford, P., Lang, C.C. (2005). Obesity and the risk of myocardial infarction in 27,000 participants from 52 countries: A case-control study. *Lancet* 366:1640–1649.

Appendix:



Université d'Ottawa • University of Ottawa

Faculté des sciences de la santé Faculty of Health Sciences
École des sciences de l'activité physique School of Human Kinetics

Consent Form

Title of the study: Locomotion Performance in People with Different Body Mass Index

Principal Investigator: Jing Xian LI _____, PhD
Associate Professor
School of Human Kinetics, Faculty of Health Science
University of Ottawa

INVITATION TO PARTICIPATE:

I am invited to participate in the abovementioned research conducted by Dr. Jing Xian Li and Dr. Mario Lamontagne of the School of Human Kinetics, Faculty of Health Sciences, University of Ottawa. The research is funded by the University of Ottawa.

PURPOSE OF THE STUDY:

I understand that the purpose of this study is to evaluate the functional capacity of the hip, knee, and ankle joints in old people with different body weights during daily activities such as level ground walking, sitting-to-standing, ascending and descending stairs.

ELIGIBILITY:

To be able to participate in this study, I must be between 50 to 75 years old and have no 1) cardiovascular disease or stroke; (2) moderate to severe hypertension (resting blood pressure >144/94 mm Hg); (3) body weight fluctuation [>2.27 kg (5 lbs)] in the previous six months]; and (4) hormone therapy during the previous six months.

PARTICIPATION:

I will complete a form about my biography and exercise habits, and musculoskeletal disorders. The study involves one session of measurements. It will last approximately 2-3 hours during which my movement of ground walking, sitting-to-standing and upstairs and downstairs walking will be recorded using video cameras.

RISKS:

The risk of falling during ascending and descending walking in elderly is higher than young people. To diminish the risk of falling during ascending and descending walking, a harness has been equipped in the laboratory and I will be asked to wear the harness during my ascending and descending walking. In this way, my safety is secured. Moreover, the researcher will assure me that there will be 2-3 minute breaks between each trial and that I may request to stop at any time if I need additional breaks.



Université d'Ottawa • University of Ottawa

Faculté des sciences de la santé Faculty of Health Sciences
École des sciences de l'activité physique School of Human Kinetics

DISADVANTAGES OF PARTICIPATING:

I understand that the primary disadvantage of participation will be the time required in the measurements of my movements.

BENEFITS:

I will not benefit directly from my participation in this research. However, I can know my movement performance. My contribution in this research will benefit to improve health care and health promotion.

CONFIDENTIALITY AND CONSERVATION OF THE DATA:

I understand that the data gathered from me will be used for research purposes only and my confidentiality will be ensured. I will be assigned an anonymous identification code that will be used throughout the research. The data (completed consent forms, testing notes and printed testing data) will be stored in a locked filing cabinet in the office of the researchers at the University of Ottawa. The electronic data will be kept in the computers of the researchers and will be password protected. Only the researchers will have access to the data. I understand that any published results will be presented with complete anonymity.

The data will be conserved for five years after the time of completing the research. By June 30, 2015 the electronic data will be deleted and the printed data will be shredded.

ANONYMITY:

Anonymity will be assured in the following manner: a code number system will be employed during the data collection, analysis, and reporting. I will not be identified in any reports or publications.

COMPENSATION:

I will receive a compensation of \$30.00 at the beginning of the session of evaluation of the functional capacity of the joints to help cover my travel and parking costs.

VOLUNTARY PARTICIPATION:

I am free to refuse participation and, if I choose to participate, I can withdraw from the study at any time for any reason.

I understand that I may ask questions regarding this study at any time and they will be answered. These questions may be addressed to Dr. Jing Xian Li.



Université d'Ottawa • University of Ottawa

Faculté des sciences de la santé Faculty of Health Sciences
École des sciences de l'activité physique School of Human Kinetics

MORE INFORMATION ABOUT THIS STUDY:

If I have any questions with regards to the ethical conduct of this study, I may contact the Protocol Officer for Ethics in Research, University of Ottawa, Tabaret Hall, 550 Cumberland Street, Room 159, Ottawa, ON K1N 6N5, tel.: (613) 562-5841 or ethics@uottawa.ca.

CONSENT:

I declare that I understand this study, the nature and degree of my participation and possible disadvantages and risks listed in this consent form. I have had the opportunity to ask all my questions concerning the different aspects of the study and have received responses to my satisfaction.

I voluntarily agree to participate in this study.

If I withdraw from the study, I want that:

___ the data gathered from me until the time of withdrawal be destroyed.

___ the data gathered from me until the time of withdrawal be nonetheless used for the study despite my withdrawal.

I agree that Dr. Jing Xian LI and Dr. Mario Lamontagne can keep my name and telephone number to contact me for any future study that she may be carrying out.

Yes _____

No _____

There are two copies of this consent form one of which is for me to keep.

Name of participant

Signature of participant

Date

Signature of researcher

Date

Participants Information

Project: Locomotion Performance in People with Different Body Mass Index

Date: _____

Researcher: _____

Disclaimer: *The information you provide in this survey is strictly confidential and will be used for research purposes only. We have no relationships with any manufacturers, distributor, or other businesses. And your names and addresses will not be distributed to any people.*

Biographical Information

1. Participant Name: _____
2. Age: _____
3. Gender (circle): MALE FEMALE
4. Telephone: _____
5. E-Mail Address: _____
6. Body weight (kg): _____
7. Body height (cm): _____
8. Which is your dominant leg (The one you kick with)? (circle):
 RIGHT
 LEFT
9. During a typical **7-Day period** (a week), how many times on the average do you do the following kinds of exercise for **more than 15 minutes** during your free time (write on each line the appropriate number).

12. Are you suffered any injuries or disorders of the lower extremities in the past 3 years?
- YES NO

If yes, please fill the table to give the detail information. Please circle your choice

Which side of the legs	a) Right b) left	Remark
Location of the injury or disorder	a) hip b) thigh c) knee d) calf e) ankle/foot f) toe	
Injured or disordered tissues	a) bone b) muscle c) tendon d) ligament e) other	
Medical diagnosis if you know		
If the injury affects your daily life	a) no b) little bit c) considerable	



I, _____, hereby confirm that I have participated in the study entitled **“Locomotion Performance in People with Different Body Mass Index”** that was conducted by Dr. Jing Xian Li of the School of Human Kinetics at the University of Ottawa. For this reason, I am entitled to receive the monetary compensation of thirty dollars as stipulated in the consent form of this study.

School of Human Kinetics
University of Ottawa
125 University St.
Ottawa, Ontario, K1N 6N5
CANADA

Participant Signature : _____

Date : _____

Investigator Name : _____

Signature: _____

Date: _____