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BIOMECHANICS OF STAIRCASE EXERCISES

SAMI FARIS ALMASHAQBEH

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Name of Candidate: Sami Faris Mousa Al-Mashagbeh

Passport No: J305608

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Name:

Designation: Dr. Ting Hua Nong
Senior Lecturer
Department of Biomedical Engineering
Faculty of Engineering, University of Malaya
50603 Kuala Lumpur
Malaysia

ABSTRACT

Exercises provide many important health benefits to individuals. People should therefore be encouraged to change their lifestyle by including some kinds of physical activities into their daily routines. A staircase provides free and easy access as a tool for exercising. A wide variety of exercises have been proposed to be done on a staircase. Among them are walking up and down stairs with the hands behind the head, walking holding dumbbells, walking in cross-step manner, and lateral stepping. The joint-specific differences in the kinematics and kinetics patterns between such exercises and regular stair climbing may be used to target specific muscle groups of the lower extremity. On the other hand, the increase in weight associated with obesity is supposed to directly increase the knee load that subsequently leads to the development of knee osteoarthritis.

The kinematics and kinetics recordings of obese and slim adults walking and exercising on a four-step staircase were collected from 6-cameras, three-dimensional motion analysis system (Vicon MX, Oxford Matrices Ltd, UK) and a force platform (Kistler, model 9281CA) positioned on the second stair step, involving ascend and descend phases of regular stair walking, hands behind head, holding dumbbells, cross step forward, lateral stepping leading (the leg in interest is the leading limb), and lateral stepping trailing (the leg in interest is the trailing limb). Data processing and analysis were done using Vicon Nexus, Vicon Polygon, and Matlab. SPSS were used for all statistical analysis.

Based on the different loads that selected exercises exert on the lower extremity muscle groups in the sagittal and frontal plane and on the way obese people perform those exercises, it is found that the cross step forward and the lateral stepping (leading limb)

activities place greater demands on the hip extensors, and that the holding dumbbells activity places greater demands on the knee extensors and on the ankle dorsiflexors. In the frontal plane, the cross step forward and the lateral stepping (leading limb during descent and trailing limb during ascent) activities place greater demands on the hip abductors, and that the cross step forward and the lateral stepping (trailing limb during descent) activities place greater demands the knee abductors. These findings can be used to more effectively target specific lower-extremity muscle groups when recommending exercise for young individuals.

Obese individuals might adjust their gait characteristics in response to their heavy bodies to reduce or maintain the same load on the knee joint as the slim people. Therefore, obese people can safely perform the selected exercises as long as they do it at their self-selected speed.

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LIST OF ABBREVIATIONS

AS = Ascending.

CSF = Cross Step Forward.

DE = Descending.

H = Higher.

HBH = Hands Behind Head.

HDB = Holding Dumbbells.

L = Lower.

LSL = Lateral Stepping Leading.

LST = Lateral Stepping Trailing.

O = Obese.

RSW = Regular Stair Walking.

S = Slim.

SD = Slandered Deviation.

CHAPTER ONE: INTRODUCTION

1.1 Introduction

This chapter looks at the various staircase exercises in use today and defines the objectives, scope, and the importance of the current study.

1.2 Objectives Of Study

Exercises provide many important health benefits to individuals. People are, therefore, encouraged to change their lifestyle by including some kinds of exertive physical activities into their daily routines.

Stair climbing is one of the daily routines that most people undergo almost everywhere they go. There is a general belief that stair climbing is a useful physical activity that should be promoted to the public as an exercise for good health maintenance. Towards this end, many systems that provide means to simulate the action of stair climbing have been proposed. However, unlike these stair machines, a staircase provides free and easy access as a tool for exercising. This fact encourages trainers all over the world to propose some exercises that can be done on a staircase.

A wide variety of staircase exercises have been proposed. Among them are walking up and down stairs with the hands behind the head, walking holding dumbbells, walking in cross step manner, and lateral stepping. However, to our knowledge the biomechanics of those exercises has not been studied yet.

Studying the biomechanics of such exercises can provide very important and useful information. Although these exercises are multiple-joint exercises which stimulate several muscles group simultaneously, the joint-specific differences in the kinematics and kinetic patterns between such exercises and regular stair climbing may be used to target specific muscle groups of the lower extremity.

Obesity is considered as one of the important risk factors for development of knee osteoarthritis (Sturmer et al., 2000; Felson, 1988). The increase in weight associated with obesity is supposed to directly increase the knee loads that subsequently lead to the development of knee osteoarthritis (Felson, 1988; Felson and Zhang, 1998; Hochberg et al., 1995; Korner and Eberle, 2001).

The objectives of the current study are as follows:

- To determine the differences in the kinematics and kinetics patterns between the standard staircase exercises and regular stair climbing during ascending and descending a staircase.
- To identify how people who are obese perform when doing those exercises and to compare their performance to that of those who are slim.

The parameters considered are as follows:

- The temporal parameters (Cadence, foot off, stride time, and speed).
- Angles.
- Moments.
- Powers.
- Impulses.
- Total work.

The scope of the current study: The current research investigates the kinematics and kinetics of four types of the proposed exercises that can be done on a staircase by slim and obese people at their self selected speed. The included exercises are: walking up and down stairs with the hands behind the head, walking holding dumbbells, walking in cross-step manner, and lateral stepping.

The importance of the current study: This work provides pioneering research conducted on the biomechanics of staircase exercises, besides including the study of obese people doing stair climbing. The findings of the current study may be used to more effectively target specific lower-extremity muscle groups when recommending exercise for young individuals so that they can benefit from the stair at the office, in the home or at the shopping mall to build and maintain healthy bones, muscles, and joints.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The literature relevant to the current study is covered under three sections. The first section gives a review of the literature concerning the biomechanics of regular stair climbing. The second section looks at research done on stair climbing motion patterns. The last section presents some of the proposed staircase exercises and shows the importance of exercising and of the studying of the biomechanics of staircase exercises, especially the biomechanics of staircase exercises for obese people.

2.2 Regular Stair Climbing For Normal Subjects

The majority of stair biomechanics researches have concentrated on the patient population in order to compare between lower limb prosthetic designs (Schmalz et al., 2004; Schmalz et al., 2006; Venicek et al., 2007; Catani et al., 2003), total knee replacement designs (Andriacchi et al., 1982), and to determine the functional ability of different lower extremity disorders to perform this important daily living task (Hughes et al., 2000; Lin et al., 2006; Crossley et al., 2004; Thambyah et al., 2002; Salsich et al., 2005; Brechter and Powers, 2002). However, some of the researches have been conducted on the normal population. The aims of those studies were to compare stair climbing and level walking, stair ascent and descent, and to find out the effects stair inclination and subjects' height had on the lower extremity joints biomechanics. The following is a literature review of the regular stair climbing for normal population.

2.2.1 Stair climbing versus level walking

In general, stair climbing is more demanding for the lower extremity joints when compared to level walking. More demanding means "increase in the range of motion, moments, forces, and powers". In the sagittal plane, the knee, hip, and ankle go through greater range of motion. At the knee, Protopapadaki et al. (2007) reported maximum values ranging from 80 to 100 degrees for typical step configuration (slopes 30 to 35 degrees), or approximately 12 to 20 degrees more knee flexion than seen in level walking (Andriacchi et al., 1980; Livingston et al., 1991). At the hip, like the knee, increases in the range of 15 to 20 degrees had also been reported in the hip flexion during stair ascending (Andriacchi et al., 1980; Livingston et al., 1991). Also, an increase of the range of motion during stair climbing had been reported at the ankle joint (Protopapadaki et al., 2007; Andriacchi et al., 1980; Livingston et al., 1991).

The sagittal plane hip and knee moments have been shown to be greater than level walking (McFadyen and Winter, 1988; Nadeau et al., 2003; Andriacchi et al., 1980; Livingston et al., 1991). However, Anderacchi et al. (1980) and McFadyen and Winter (1988) had reported that the largest increase in sagittal plane moment in stair climbing occurs at the knee joint. On the other hand, the power generation and absorption is similar between stair climbing and level walking at the hip and ankle joints, and is mush greater at the knee (Riener et al., 2002). All of this suggests that the knee is largely responsible for managing increased demands associated with stair climbing.

In comparison to level walking, the frontal and transverse planes knee moments were similar (Costigan et al., 2002; Kowalk et al., 1996). However, Kowalk et al. (1996) observed two separate instances during stair climbing where extension moments were close to zero, but the abduction moments had values between 25 to 40 N.m. Thus, while abduction-adduction moments may not be larger than what is achieved for level walking, they are obviously functionally relevant, providing both propulsion and medio-lateral stability (Kowalk et al., 1996).

The net force at the knee is similar between level and stair walking in all planes (Costigan et al., 2002). However, the flexion angle where the moment and force peak is 20 deg. for level walking and 60 degrees for stair climbing. This is important because the higher flexion angle reduces the contact area for the articulating surface of the knee, which means higher stress and possibly more wear and tear (Costigan et al., 2002).

2.2.2 Stair ascent versus descent

Many differences have been detected between stair ascent and descent. At the knee and hip, greater flexion angles during stair ascent compared to descent have been reported (Protopapadaki et al., 2007; Andriacchi et al., 1980; Livingston at al., 1991). At the ankle as well, Andriacchi et al. (1980) and Protopapadaki et al. (2007) have reported greater dorsiflexion and plantarflexion angles during stair descent compared to ascent.

In the sagittal plane joints moments, variability in hip moments during stair ascent and descent is reported in the literature (Andriacchi et al., 1980; Costigan et al., 2002; McFadyen and Winter, 1988; Riener et al., 2002; Salsich et al., 2005). Protopapadaki et al. (2007) explained this variability by the position of the trunk. Different positions of the trunk may bring the line of ground reaction force anterior to or behind the hip, affecting the hip joint moment. At the knee, the higher external knee moments occurred while ascending stair (Protopapadaki et al., 2007; McFadyen and Winter, 1988; Salsich et al., 2005).Conversely, Anderacchi et al. (1980) and Kowalk et al. (1996) demonstrated the highest external knee moments occurring in normal subjects during descent. In the frontal plane knee joint moment, Kowalk et al. (1996) observed no difference between stair ascent and descent.

Power generation and absorption at the joints of lower limb have been reported for stair climbing (Riener et al., 2002; McFadyen and Winter, 1988). During ascent, all the joints generate energy. Power is generated at the hip and knee joints during the stance phase, mainly at the knee, to facilitate the raising of the contralateral limb to the next step. As soon as the cotralateral limb has approached the next step, during the late stance of the ipsilateral limb, large power generation occurring at the ankle supports the transfer of the body weight to the leading limb and reduces the need for higher hip and knee joints moments.

During descent, all the joints absorb energy. The energy associated with the initial contact of the stance phase is absorbed primarily at the ankle, with small peaks occurring at the hip and knee joints. However, the largest power absorption happens at the knee during late stance, in order to control the lowering of the contralateral limb from one step to the next. This knee power in absolute value is higher than the knee generation power during stair ascent.

2.2.3 Effect of stair inclination and subject's height

Two factors have been shown to have considerable effect on lower extremity joints biomechanics during stair climbing. These two factors are the subject's height and stair inclination. Livingston et al. (1991) investigated the effect of subject height on the knee, hip, and ankle kinematics during ascent and descent. Fifteen young women ranging in age from 19 to 26 years were divided into short, medium, and tall subject groups. Subject height appeared to influence knee motion during stair climbing. Shorter subjects use greater knee flexion angle than taller subjects during ascent and descent.

Dependencies of lower extremity joints kinematics and kinetics on stair inclination have been reported (Riener et al., 2002). Low but significant increase of joint angle and moments with increasing inclination was reported. However, power generation and absorption have the largest dependency on stair inclination. In general, absolute joint power increases with increasing staircase slope.

2.3 Stair Climbing Motion Pattern

In addition to studying the regular stair climbing, few researchers have studied some of the stair climbing motion patterns. The aim of these studies was to explain why the elderly and disabled people use alternative motion patterns during stair climbing, and to suggest some patterns that can be adopted by those people in order to make stair climbing more comfortable and a safer task. The following is a review of researches concerning stair climbing motion patterns.

Because of the pain, difficulty and the risk of fall that the elderly, injured, or physically impaired people face during stair climbing (particularly during descending), Beaulieu et al. (2007) had investigated backward stair descent as alternative strategy for descending stairs. Three descending conditions were studied: forward stair descent at self-selected speed, backward stair descent at self-selected speed, and slower forward stair descent at the same speed as backward stair descent. The findings of this research have shown reduction in the peak powers produced by the knee extensors during the critical single support phase of stair descent as compared to regular speed and slow forward stair descent. Additionally, backward stair descent has shown increases in the distance of the center of pressure from the stair edge, making it less likely for a slip to occur that might cause a fall, and this alternative strategy increases the foot clearance (toe and heel) during the swing phase, thus further reducing the chance of a fall. All of this suggests that backward stair descent permits safer and more comfortable stair descent when compared to regular forward stair descent.

In other research, Ried et al (2007) had studied the effects of step-by-step gait pattern on knee biomechanics. Step-by-step pattern is the placing of both feet on the same step before ascending or descending. This pattern of stair ambulation is usually forcefully adopted by the elderly and disabled population due to factors such as decreased muscle strength and joint diseases. Unlike the regular step-over-step gait in which each limb performs the same function at different times, the step-by-step pattern has a leading limb which is the limb that is responsible for the forward movement, and the other one which is called the trail limb as shown in **Figure 2.1**. The findings of this study have shown that, for the step-by-step gait pattern, the trail leg during ascent and the lead leg during descent have smaller net forces, moments, and powers in the sagittal plane when compared to regular step-over-step gait. These can, therefore, be referred to as the "resting limb" of the step-by-step gait pattern. Conversely, the lead leg during ascent and the trail leg during descent have similar sagittal plane forces, moments, and powers when compared to regular step-over-step gait. These can, therefore, be described as the "working limb" of the step-by-step gait pattern. These findings explain why the elderly and disabled people use the more painful leg as the resting one.

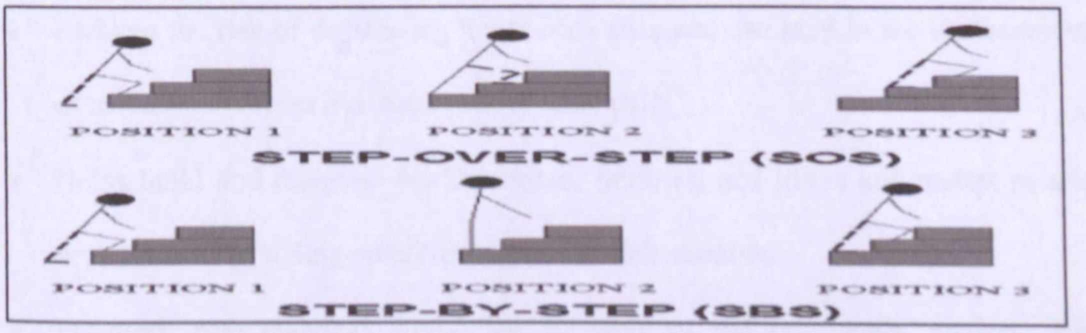


Figure 2.1: A schematic representation illustrating the gait cycles of (A) step-over-step (regular stepping pattern) and (B) step-by-step stepping (placement of both feet on the same step before ascending or descending) patterns analyzed during stair ambulation. Step-over-step dotted leg is the lead leg, and step-by-step dotted leg is the trail leg.

2.4 Staircase Exercises

Exercises provide many important health benefits to people. In general, individuals who are engaged in some form of physical activities, either through lifestyle or occupation, are likely to live longer and healthier, It is strongly recommended that all people be engaged in 15-30 minuets of moderate intensity physical activities on most days of the week, if not all. A review of the most recent scientific research collected by ACTIVE THE US SURGEON GENERAL (1996) indicates that there is clear evidence of many health benefits of regular physical activity, including:

- Reduces the risk of dying prematurely.
- Reduces the risk of dying from heart disease or stroke, which is responsible for one-third of all deaths.
- Reduces the risk of developing heart disease.
- Reduces the risk of colon cancer and type (2) diabetes by as much as 50%.
- Helps to prevent/reduce hypertension, which affects one-fifth of the world's adult population.
- Helps control weight and lowers the risk of becoming obese.
- Helps to prevent/reduce osteoporosis, thus reducing the risk of hip fracture in women.
- Reduces the risk of developing lower back pain and can help in the management of painful conditions like back pain or knee pain.
- Helps build and maintain healthy bones, muscles, and joints and makes people with chronic, disabling conditions improve their stamina.
- Promotes psychological well-being as well as reduces stress, anxiety, and depression.

- Helps prevent or control risky behaviors, especially among children and young people, e.g. use of tobacco, alcohol or other substances, unhealthy diet, or violence.

Based on these significant benefits of exercising or otherwise being physically active, people should be encouraged to change their lifestyle by including some sort of physical activities into their daily activity. Stair climbing is one of the daily tasks people encounter almost every where they go to. Researchers believe that stair climbing provides a useful model of the regular physical activity that should be promoted to the public (Eves et al., 2006). Many efforts have been made to encourage people to use the stairs (Eves et al., 2006; Boreham et al., 2000; Ilmarinen et al., 1979; Shenassa et al., 2008; Kerr et al., 2004; Kerr et al., 2001; Dolan et al., 2006; Edward, 1983). These efforts got great influence in people. For example, in the U.S., an estimated 4 million people, from young professionals to active grandparents, have joined stair climbing, with increase of more than 40 percent since the end of 1988 (Williams,1989). Many benefits have been reported for stair climbing, including:

- Stair climbing can be built-up across day time, making a significant contribution to the daily physical activity that is recommended for each day (Kerr, 2001). Furthermore, stair climbing requires less time to do the same intensity of workout otherwise. For example, 15 minutes of stair climbing is equivalent to 30 minutes of running (Health Canada, 2005).
- Research shows a lower risk of mortality in those people who climbed more than 55 flights of stairs each week (Paffenbarger et al., 1993).
- The risk of cardiovascular disease is lowered among those who are regular stair climbers (Boreham et al., 2005). A ten-year prospective study of middle-aged men

estimated that the energy expanded in vigorous activity that reduces coronary heart disease incidence by almost two thirds was equivalent to as little as 7 minutes a day of stair climbing (Yu et al., 2003).

- Stair climbing can improve the amount of "good cholesterol" (High-Density Lipoprotein (HDL) cholesterol) in the blood (Boreham et al., 2000).
- Stair climbing can reduce or control body weight. Edwards (1983) states that stair climbing require about 8-11 Kcal of energy per minute, which is high compared to other physical activities. Even two flights of stairs climbed per day can lead to 2.7 Kg weight loss over one year (Brownell et al., 1980).
- There is a strong association between stair climbing and bone density, in post-menopausal women (Coupland et al., 1999).
- Stair climbing activates dynamically large muscle groups of the lower extremities (Ilmarinen et al., 1979).
- Active stair climbers are more fit and have higher aerobic capacity (Ilmarinen et al., 1979).
- Since stair climbing increases leg power, it may be an important priority in reducing the risk of injury from falls in the elderly (Allied Dunber Survey, 1990).

Under the impression of the benefits that stair climbing has on the wellbeing of human health, many designs have been proposed of machines that simulate the real action of stair climbing. Almost all gymnasiums nowadays have at least one type of stair machines such as the machines shown in **Figure 2.2**. However, unlike stair machines, staircases are easy to access. It can be found almost everywhere, in workplaces, homes, malls, etc. All of these previously mentioned facts about stir climbing encouraged trainers all over the world to propose some exercises that can be done on a staircase.

Figure 2.2: Examples of stair machines

Wide verities of staircase exercises have been proposed, such as, walking up and down stairs with hands behind head, holding dumbbells, walking in cross step manner, or side stepping, as shown in **Figure 2.3**. The intensity of these exercises can be increased by increasing velocity, walking with a backpack, climbing large steps, and climbing two or three step at the time. However, the biomechanics of these exercises have not been studied yet.

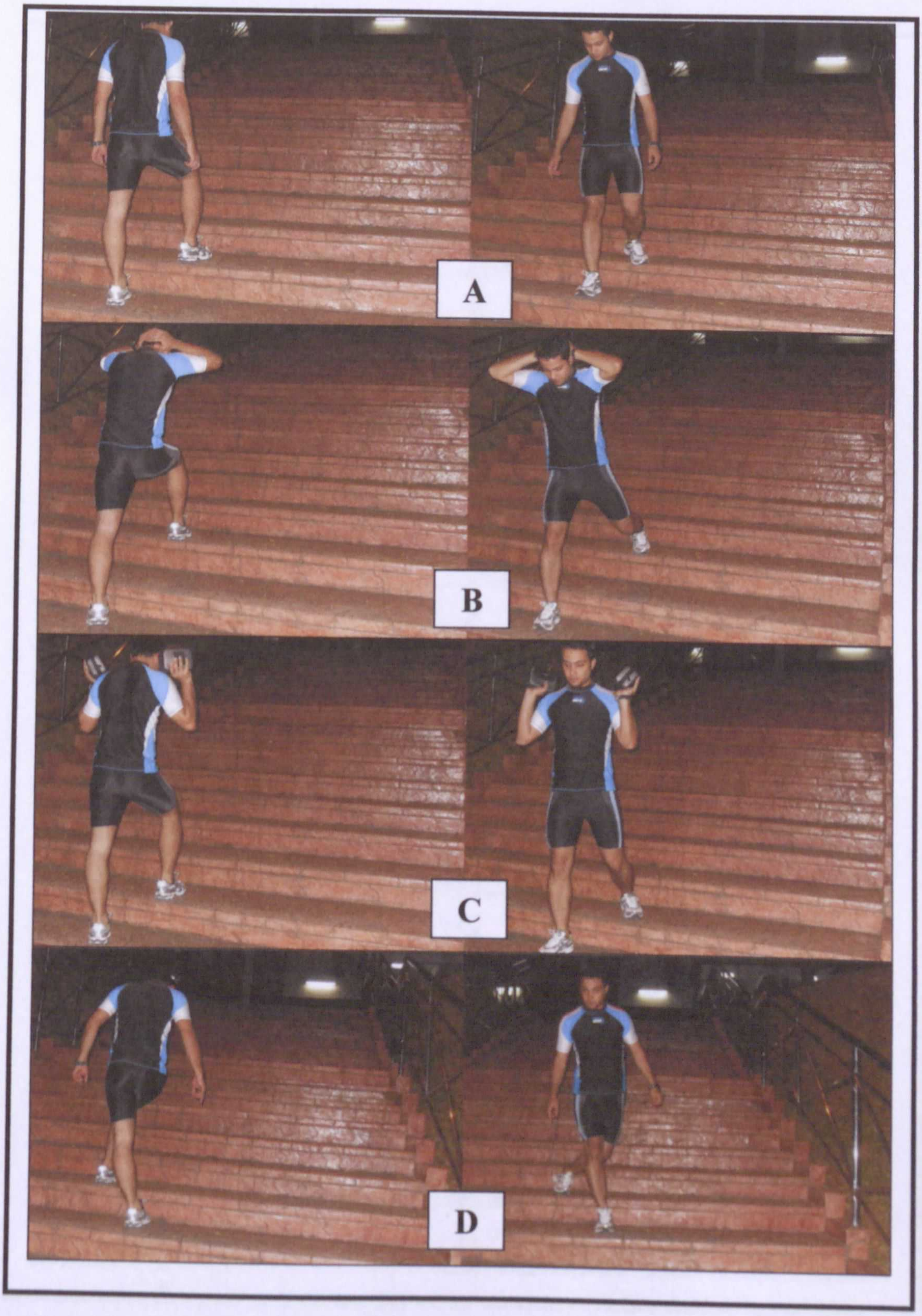
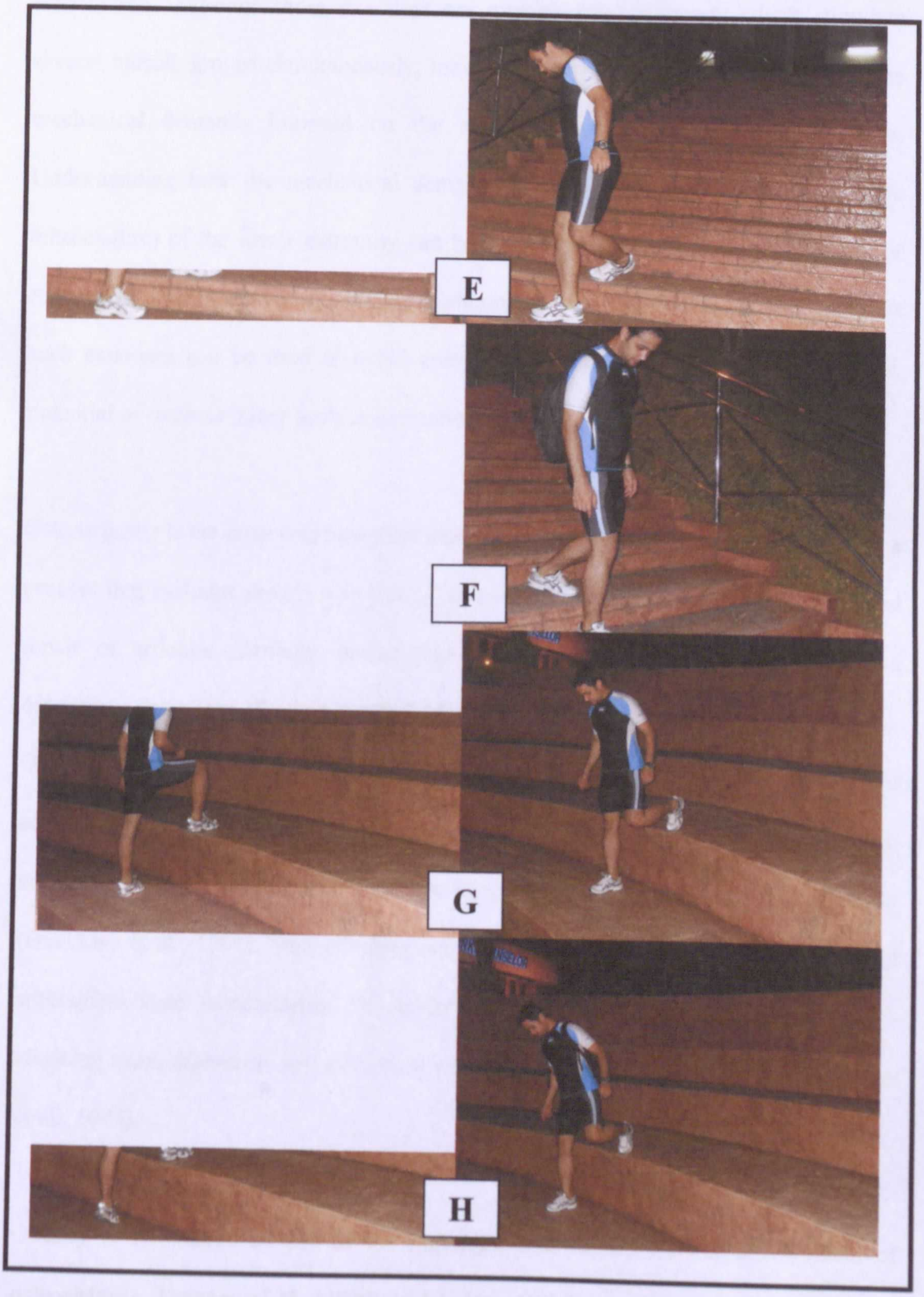


Figure 2.3: Staircase exercises **A**) regular stair walking. **B**) Hands behind head. **C**) Holding Dumbbells. **D**) Cross step forward.



Cont. Figure 2.3: Staircase exercises **E**) Lateral stepping. **F**) With backpack. **G**) Climbing large steps. **H**) Climbing large steps with backpack.

Studying the biomechanics of such exercises can provide very important and useful information. Although these exercises are multiple-joint exercises which stimulate several muscle groups simultaneously, they may allow for unequal distribution of the mechanical demands imposed on the ankle, knee, and hip joint musculature. Understanding how the mechanical demands are distributed across the joints (and musculature) of the lower extremity can be used to determine the appropriateness of each exercise (Flanagan et al., 2004). Furthermore, knowledge of the biomechanics of such exercises can be used to avoid doing the exercises that may increase the risk potential of overuse injury such as osteoarthritis.

Osteoarthritis is the most common joint disease which is caused by joint degeneration, a process that includes progressive loss of articular cartilage accompanied by attempted repair of articular cartilage, remodeling and sclerosis of subchondral bone, and osteophyte formation (Buckwalter and Mankin, 1997; Buckwalter and Martin, 1995). One major mechanism associated with pathogenesis of osteoarthritis is increased load across the articular cartilage (Mow et al., 1995; Radin et al., 1995). Osteoarthritis accounts for more trouble with stair climbing and walking than any other diseases (Guccione et al., 1994). Stair climbing activities but not walking increased the risk of subsequent knee osteoarthritis (Maalindon et al., 1999), and the jobs that require climbing stairs repeatedly are associated with high rates of knee osteoarthritis (Copper et al., 1994).

Obesity is considered as one of the important risk factors for the development of osteoarthritis. Sturmer et al. (2000) and Felson (1988) reported a strong association between obesity and bilateral knee osteoarthritis but no association between obesity and hip osteoarthritis. Researchers suggest that increased weight associated with obesity directly increases knee loads that subsequently lead to knee osteoarthritis (Felson, 1988; Felson and Zhang, 1998; Hochberg et al., 1995; Korner and Eberle, 2001). All of the previously mentioned studies show the importance of studying the biomechanics of staircase exercises for normal people who are slim and obese.

CHAPTER THREE: METHOD AND MATERIALS

3.1 Introduction

This chapter presents the method and materials used in the current study, including subjects, instrumentation, subject and system preparation, exercises procedures, motion analysis, and the statistical method used.

3.2 Subjects

Ten obese adults, 6 males and 4 females, and ten lean adults, 6 males and 4 females, volunteered for the study. Subjects' characteristics are listed in **Table 3.1** and **Table 3.2**. The groups were similar in height but the obese group had a larger mass and Body Mass Index (BMI). BMI was used to classify the participants. Obese subjects had BMI values of 30-43 $kg.m^{-2}$, and lean subjects had BMI values less than 25 $kg.m^{-2}$. The ranges of mass and BMI values for the obese male were 89 to 110 kg and 32.24 to 37.18 kg/m^2, and 75 to 85 kg and 31.62 to 36.79 kg/m^2 for obese female. For the lean male, they were 52 to 74.5kg and 17.9 to 25 kg/m^2, and 42 to 55 kg and 17 to 22.9 kg/m^2 for lean female. All subjects were young and healthy (except obesity) ranging in age from 22 to 30 years for lean group and from 22 to 32 for obese group.

Table 3.1: Characteristics of lean subjects

Subject	Gender	Height (cm)	Weight (Kg)	Age (years)	BMI (Kg/m^2)
L1	M	170.5	52	27	17.9
L2	M	173	74.5	23	24.9
L3	M	167	59	23	21.2
L4	F	156	45	25	18.5
L5	M	166.5	68	23	24.5
L6	M	172	74	22	25
L7	F	157	42	27	17
L8	F	162	54	30	20.6
L9	M	173	71	24	23.7
L10	F	155	55	24	22.9

Table 3.2: Characteristics of obese subjects

Subject	Gender	Height (cm)	Weight (Kg)	Age (years)	BMI (Kg/m^2)
O1	M	160	89	22	34.76
O2	M	168	95	22	33.66
O3	M	172	110	24	37.18
O4	F	162	83	24	31.62
O5	M	172	106	23	35.83
O6	M	162	89	28	33.91
O7	F	152	85	30	36.79
O8	F	153	75	32	32.04
O9	M	171	94	25	32.15
O10	F	148	75	23	34.24

3.3 Instrumentation

3.3.1 Stair design

A four-step wooden stair was constructed by the use of three non-connected wooden sections, as shown in **Figure 3.1**. The number of the steps was chosen to be sufficient to perform a full gait cycle (Andiriachi et al., 1980). The first section is composed of the third and the fourth step which was extended to a one-meter platform on which the subject could turn around and prepare to descend. A portion of the second wooden section was cut out so that a force plate (Kistler, model 9281CA) can be placed and provide the second stair step. To do that, a special metal stand was designed to hold the force plate on top of it, as shown in **Figure 3.2**. To make sure that the force plate was fixed, four holes were drilled on top of the stand and the force plate were screwed on as shown in **Figure 3.2**. Additionally, to provide support for the third section, two small wooden boxes were installed on the top of the second section just under the third step as shown in **Figure 3.1**. A second force plate (Kistler, model 9281CA) was embedded in the laboratory floor just in front of the stairs as shown in **Figure 3.3**.

The dimensions of the wooden sections and the metal stand were chosen so that each step was 25.5 centimeters deep, one meter wide, and 21 centimeters high. The slope of the staircase was 38 degrees. This staircase dimension is the standard dimension for an outdoor staircase (Andiriachi et al., 1980). Outdoor-staircase dimensions specify a greater step height and slope than do indoor staircase dimensions and are supposed to produce higher physiological demands (Riener et al., 2002).

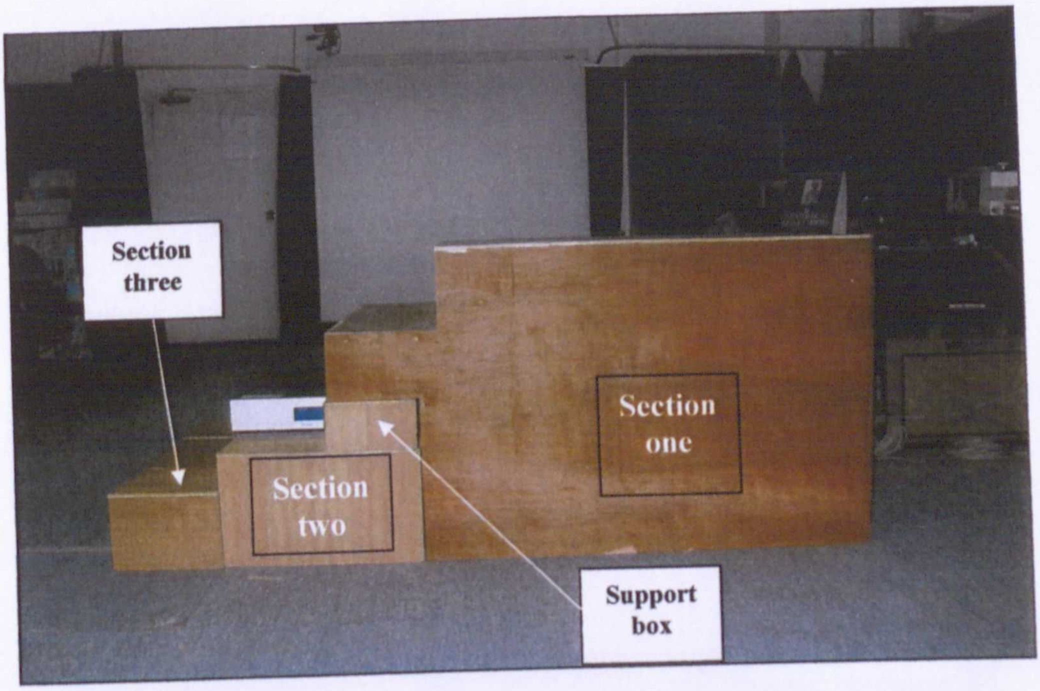


Figure 3.1: Wooden staircase sections.

Figure 3.2: Second step setup.

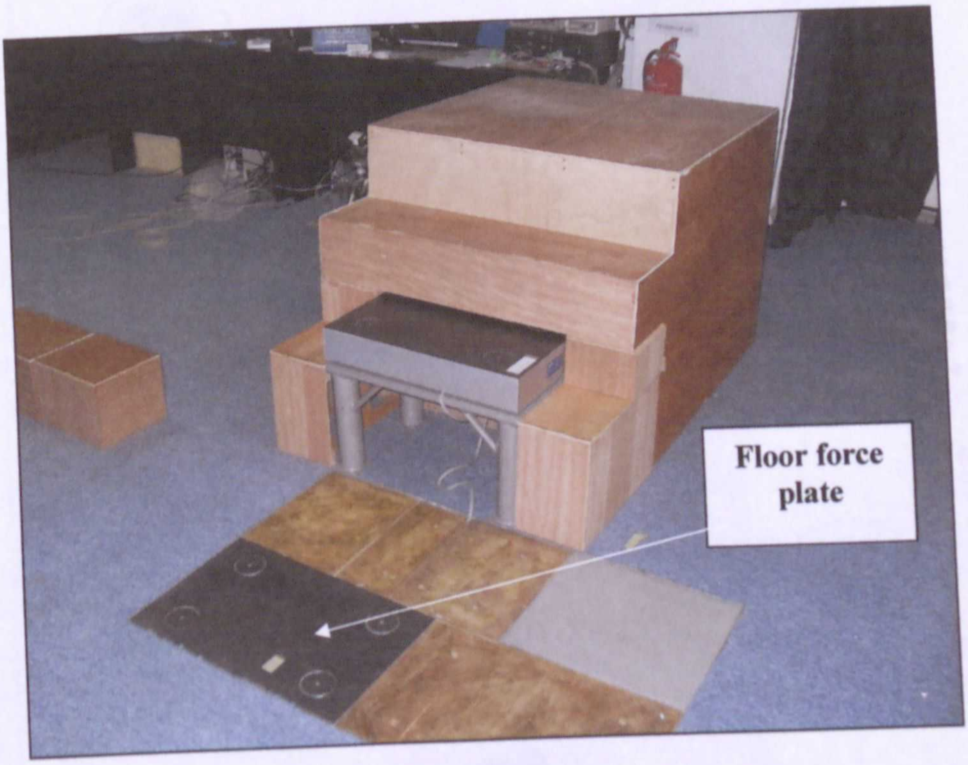


Figure 3.3: Floor force plate.

3.3.2 Vicon motion analysis system

The Motion Analysis Laboratory at the Biomedical Engineering Department, University of Malaya, provides many hardware and software services which facilitated the research done in the field of human motion analysis. The VICON MX MOTION ANALYSIS SYSTEM was used to conduct all the current experiments. **Figure 3.3** shows the system configuration.

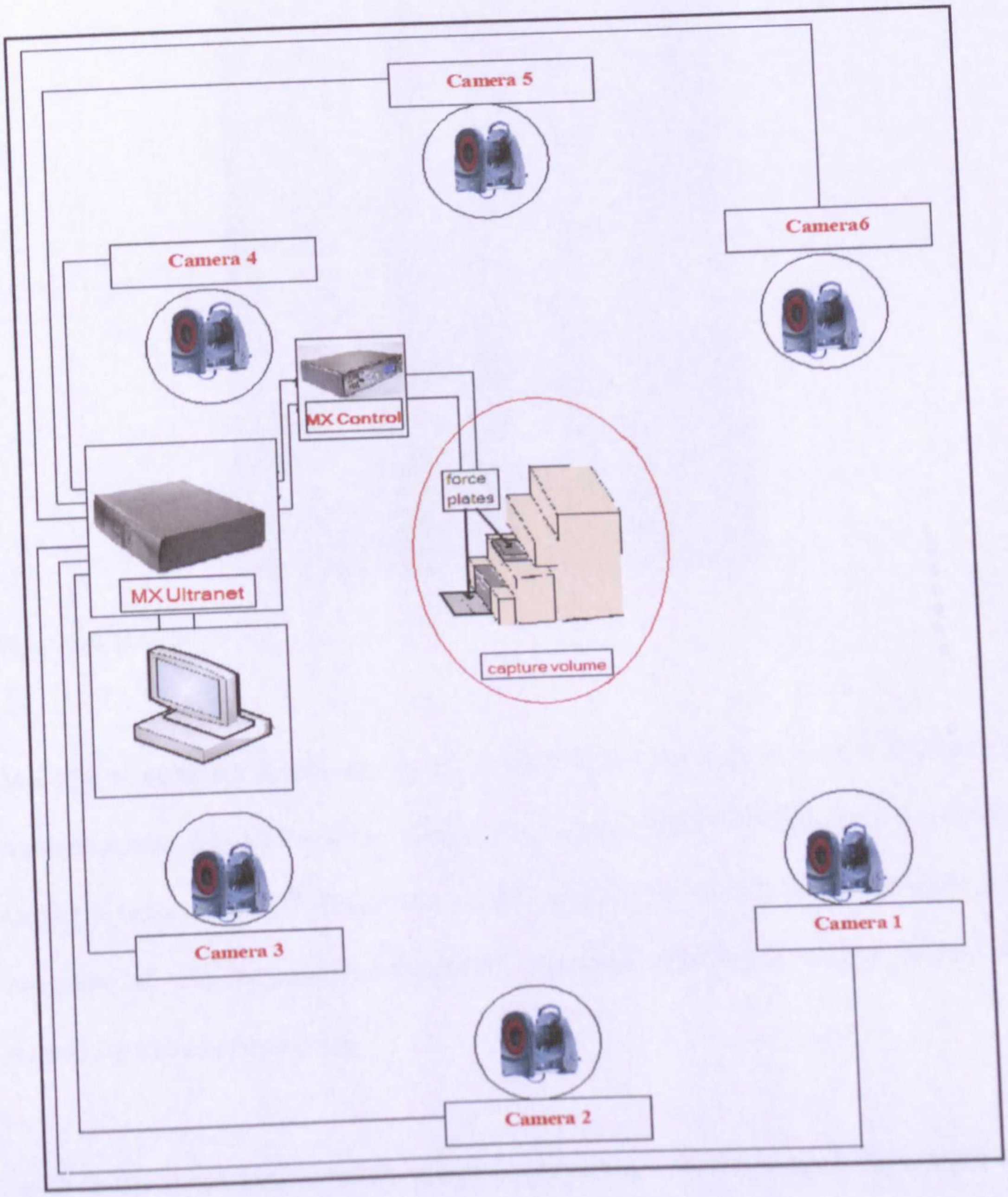


Figure 3.4: System configuration.

The Hardware components include: **6-MX cameras**, **MX ultranet**, **MX control**, and the **host pc**. The following is a brief description for each of these components:

MX cameras: six MX-F20 cameras were fixed to the top of the laboratory walls and arranged in the manner shown in **Figure 3.4** above. Each camera unit consists of distinct video camera, a strobe head unit, lens, optical filter, and cables as shown in **Figure 3.5**.

Figure 3.5: MX-F20 camera.

MX-F20 cameras are height-quality devices which provide high speed and low-latency motion capture. MX-F20 has a resolution of up to 2 megapixels (1600 vertical and 1280 vertical) and a maximum frame rate of 370 at maximum resolution. Each camera is programmed with firmware to control its operation, enabling it to perform its own onboard grayscale processing.

MX Cameras evaluate an entire image in grayscale, rather than applying a black and white threshold. This provides more information and increases motion measurement accuracy over an equivalent resolution black and white camera. The MX Cameras perform the majority of data processing. They generate grayscale blobs for reflections from objects in the capture volume and then use centroid-fitting algorithms to determine which of these objects are likely to be markers.

MX ultranet: The MX ultranet supplies power, synchronization and communication for the six cameras and the MX control with the HOST PC.

MX control: The MX control provides the interface between the vicon system and the two kistler force plate .Its connected to MX ultranet in the same way as MX cameras.

Host pc: Vicon softwares were installed on this pc which contains an Ethernet port to enable communication between the software's and MX ultranet.

Two of the provided vicon software's were used: VICON nexus (version 1.3) and VICON polygon (3.1). The primary motion capture platform available in the Motion Analysis Laboratory is Vicon Nexus shown in **Figure 3.6**. It is a motion capture platform designed specifically for Life Sciences applications such as gait analysis, rehabilitation, biomechanics research, posture, balance, motor control, ergonomics, and many more. It is also used in sports and animal science. Nexus's versatility and user friendly interface makes it one of the most sought after tool by the Clinical and research laboratories, sports performance centers, universities and other institutions to track and measure motion in real time. Other optical, digital, and analog capture devices are all integrated in this easy to use platform.

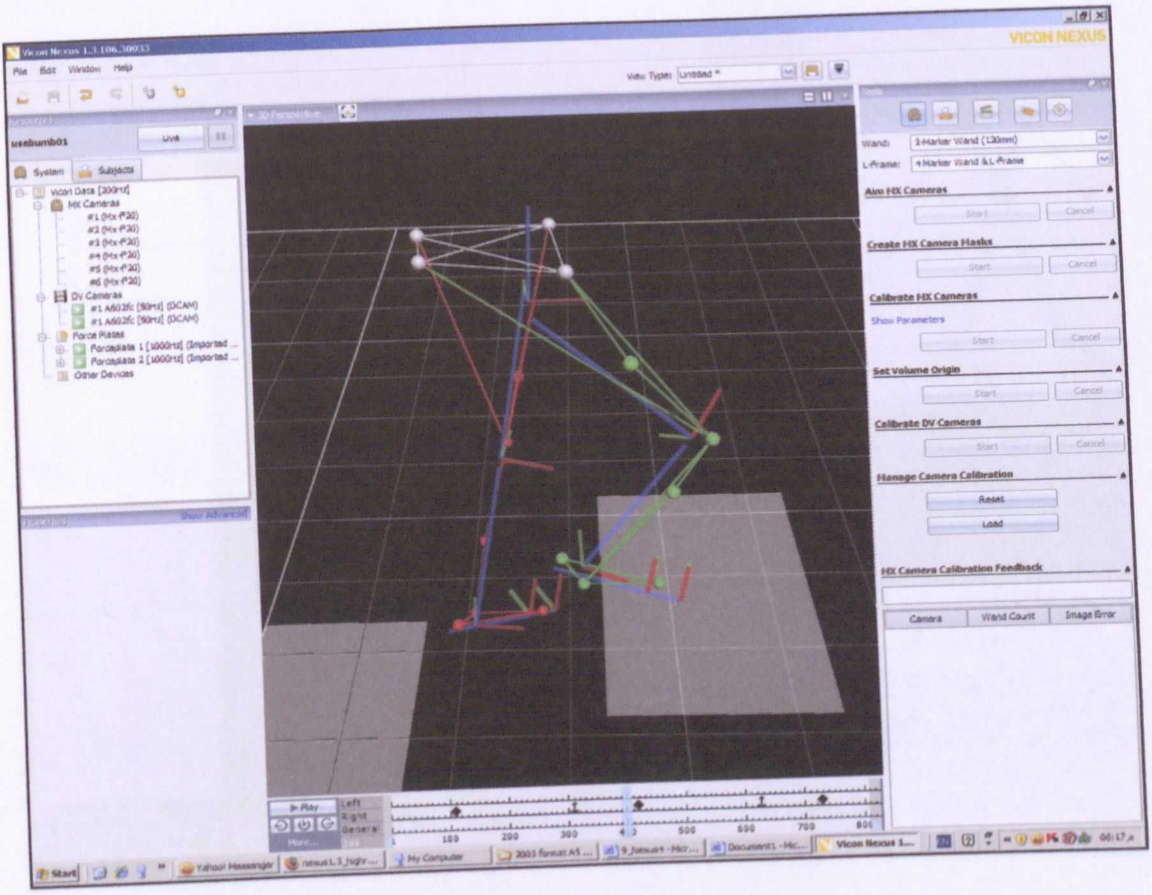


Figure 3.6: Vicon nexus 1.3 front page.

Polygon is a software tool (see **Figure 3.7**) that enables the user to create, edit, and export Polygon Reports or to create and show Polygon Presentations. It is mainly intended as a visualization and report editing tool for gait laboratories, enabling them to quickly and easily to create a gait report, analyze the patient, and to do research. However, Polygon is intentionally designed as a generic tool which can be used for a variety of biomechanical purposes, such as sports, ergonomics and motor control research, and rehabilitation studies. Polygon integrates with Vicon nexus software. The motion captured data processed through vicon nexus can be read and analyzed using Polygon.

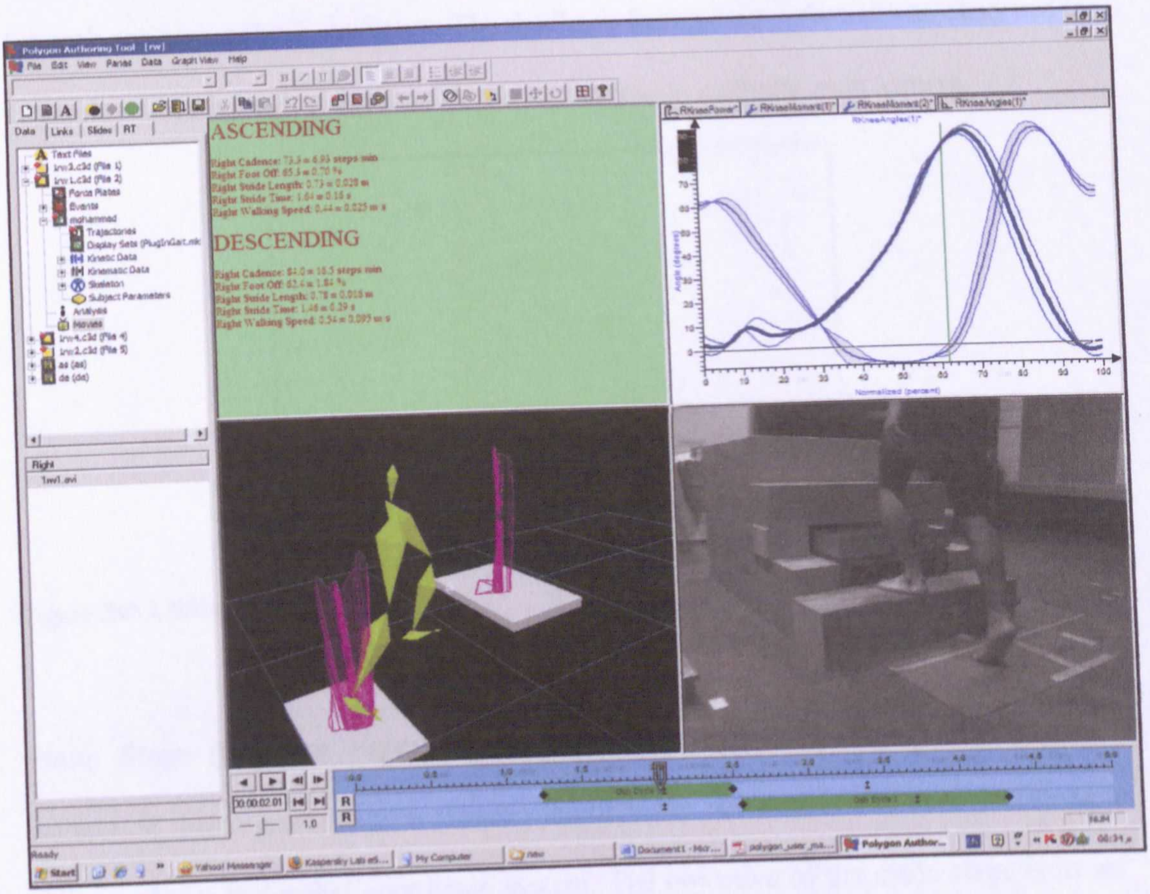


Figure 3.7: Vicon Polygon 3.1 report.

3.4 System Preparation

Before the subjects arrived at the laboratory, the system was prepared for the experiments. System preparation consists of two calibration stages: **Dynamic Stage (Camera Calibration)** and **Static Stage (Capture Volume Calibration).** The following is a description of each stage.

Dynamic Stage (Camera Calibration): During the dynamic stage of system calibration, the Vicon nexus software calculates the physical position and orientation of each Vicon camera in the capture volume based on the movement of a calibration wand. The objective of the dynamic stage is to describe the capture volume to the MX system. The calibration wand shown in **Figure 3.8** was waved throughout the empty capture volume until a good number of wand frames were spread evenly across the field of view for each camera as shown in figure. The feedback from nexus software was observed to determine when enough wand data has been acquired to calibrate each camera.

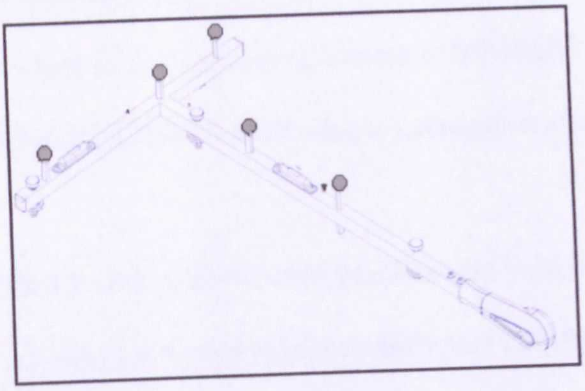


Figure 3.8: Calibration wand.

Static Stage (Capture Volume Calibration): During the static stage of system calibration, the Vicon nexus software measures the position of the static calibration object and sets the global coordinate system. The objective of the static stage is to set the global coordinates system so that subjects are displayed the right way up. The calibration object was placed flat on the corner of the floor force plate (see **Figure 3.9**) to identify the coordinates of the global origin (0, 0, 0), which represents the center of the capture volume, and the global axes (X, Y, Z), which represent the horizontal and vertical axes of the capture volume.

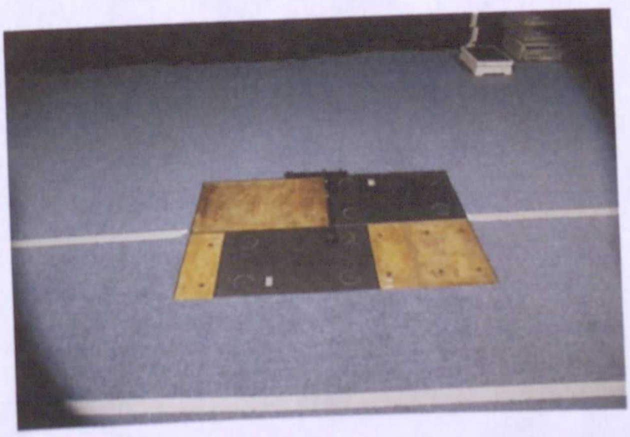


Figure 3.9: Placement of the calibration object on the corner of the floor force plate.

3.5 Subject Preparation

After successfully calibrating the cameras, the subjects were prepared for the experiments. Subject's preparation consists of two steps: MARKER PLACEMENT and SUBJECT STATIC CLIBRATION. The following is a description of each step.

MARKER PLACEMENT: All subjects were barefoot and wore tight shorts for male and tight shorts and a T-shirt for female to allow attachment of reflective markers on the skin of the lower limbs as shown in **Figure 3.10**. Sixteen reflective markers (14 mm spheres) were placed on the second metatarsal head (TOE), lateral malleolus (ANK), posterior calcaneus (HEE) at the same level as the second metatarsal marker, lateral surface of tibia (TIB), lateral aspects of the knee joint (KNE), lateral surface of the thigh hand swing (THI), and over both anterior and posterior superior iliac spines (ASI & PSI).

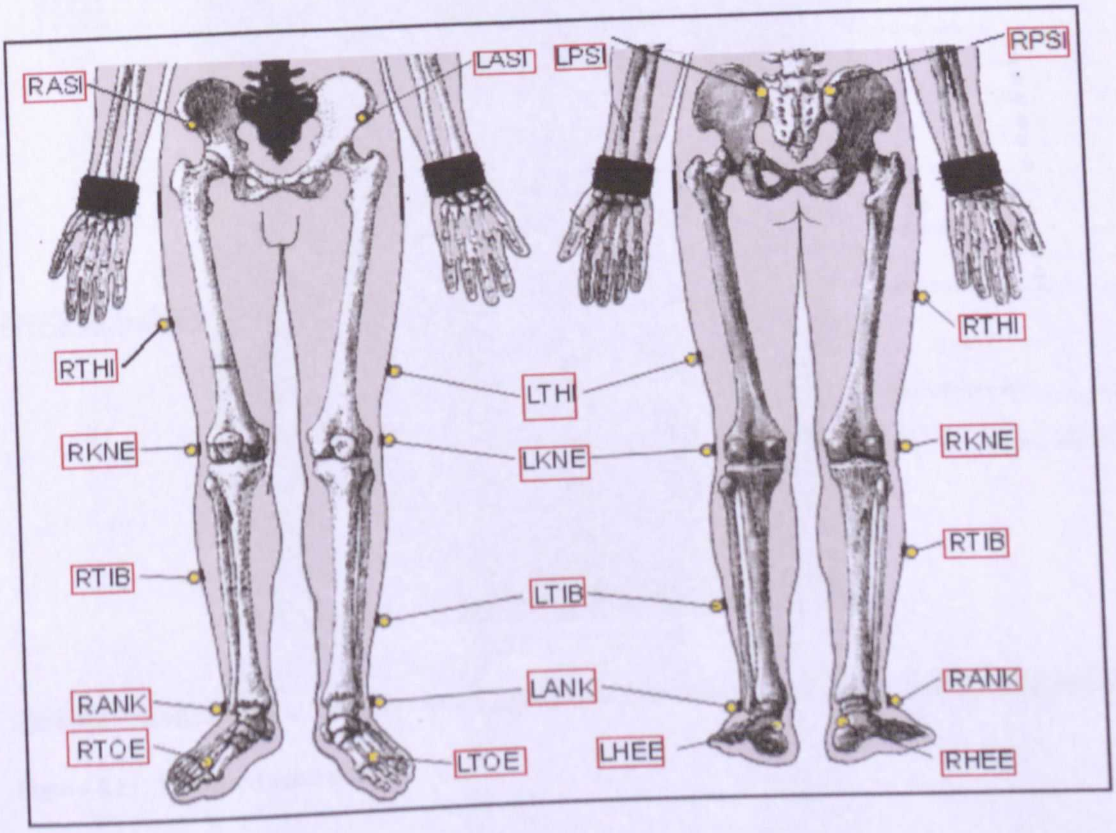


Figure 3.10: Marker positions.

To enable calculation of hip, knee, and ankle joint angles and external joint moments, anthropometric measures were obtained including bilateral leg length, knee width, ankle width, height, and body mass.

SUBJECT STATIC CLIBRATION: Subjects were asked to stand in the middle of the capture volume in the basic neutral pose, and raise the arms out straight to the sides with palms facing down in a position in the shape of a T, ensuring that the markers on the subject were visible to all the cameras. A static trial of 1-2 second was captured. Then the captured trial was processed in the nexus software to define the plug-in gait link segment model for each subject as shown in **Figure 3.11**.

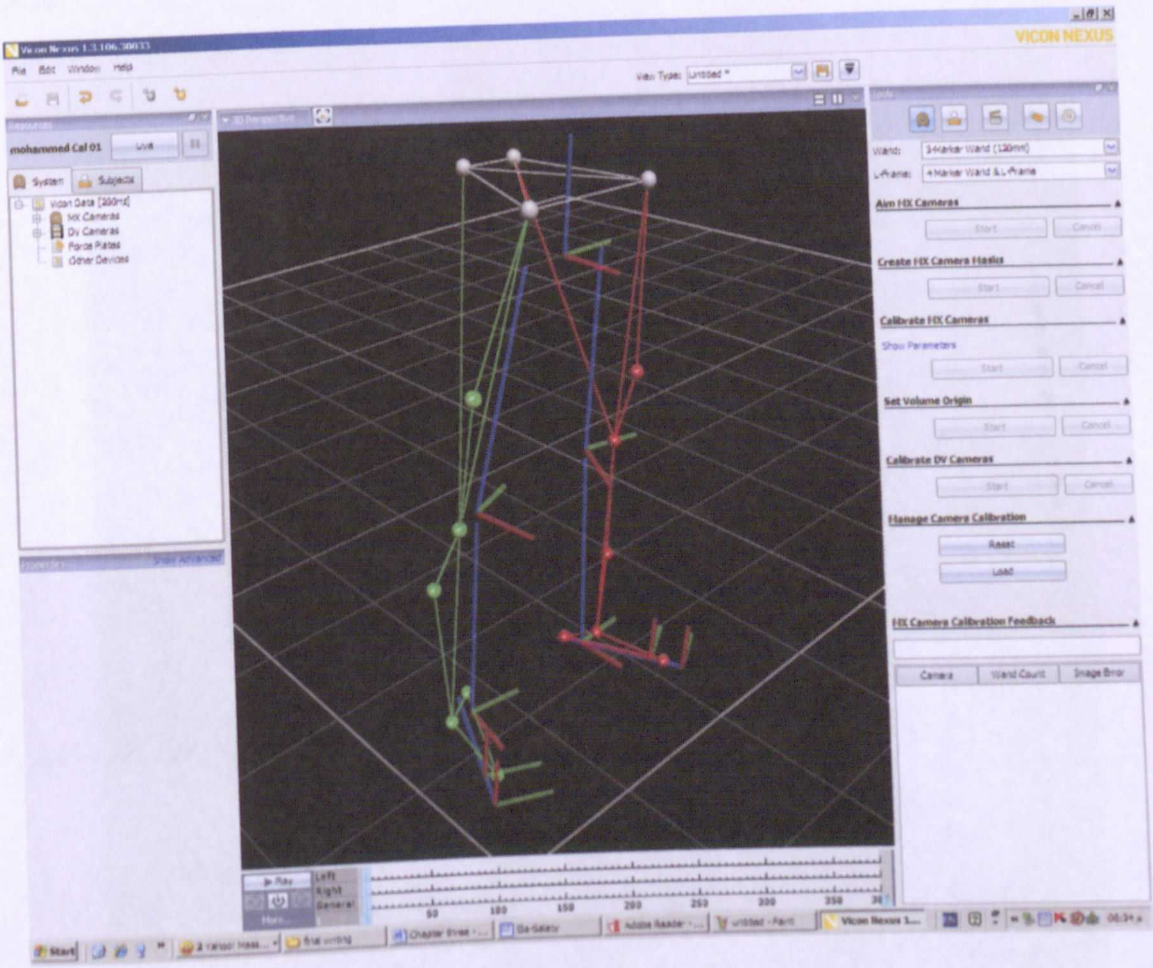


Figure 3.11: Processed static trial.

3.6 Exercise Procedures

Five stair climbing styles were included in this study. However, these movements can be divided into FORWARD STEPPING and LATERAL STEPPING, according to the relative orientation of the subject body with respect to the stairs. The following is a brief description of each stepping condition.

3.6.1 Forward stepping

Subjects were asked to perform four different styles of movements including: REGULAR STAIR WALKING (RSW), HANDS BEHIND HEAD (HBH), HOLDING DUMBBELLS (HDB), and CROSS STEP FORWARD (CSF), as shown in **Figure 3.12**.

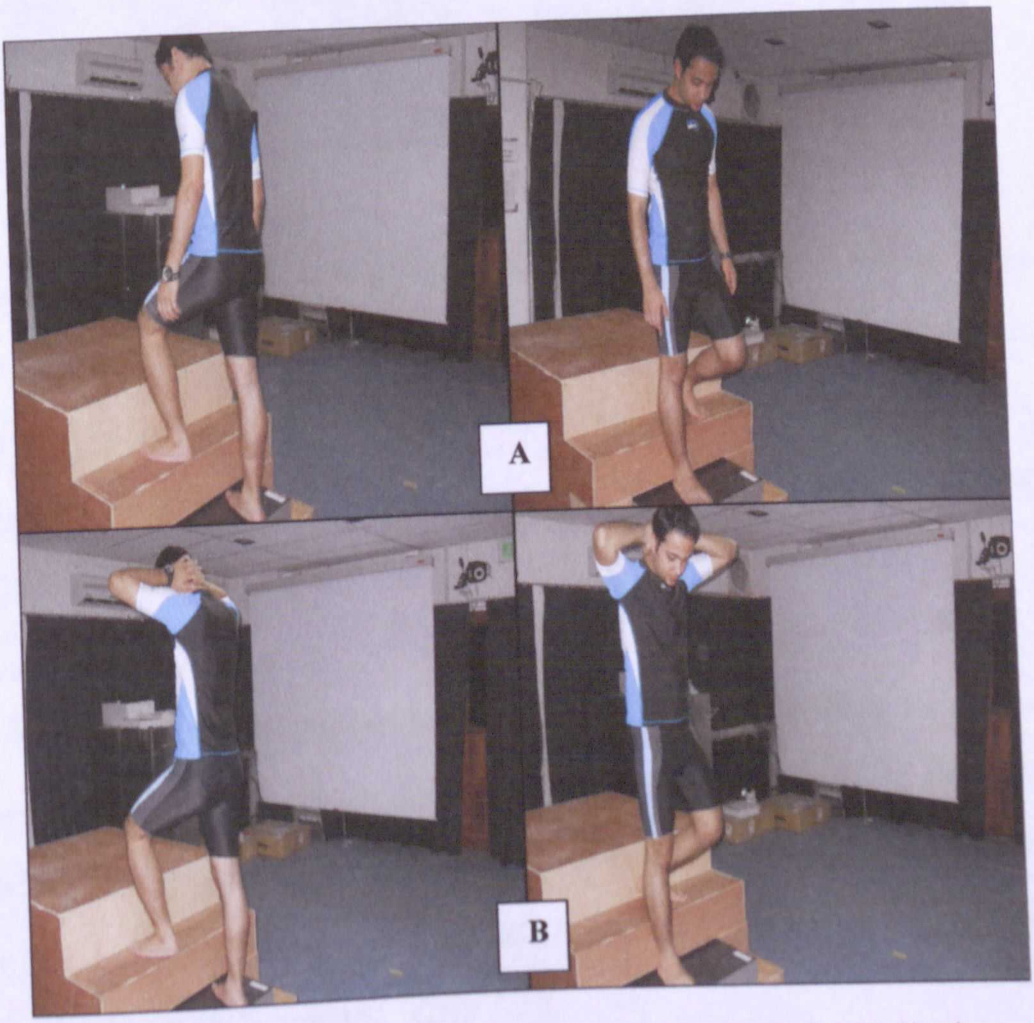
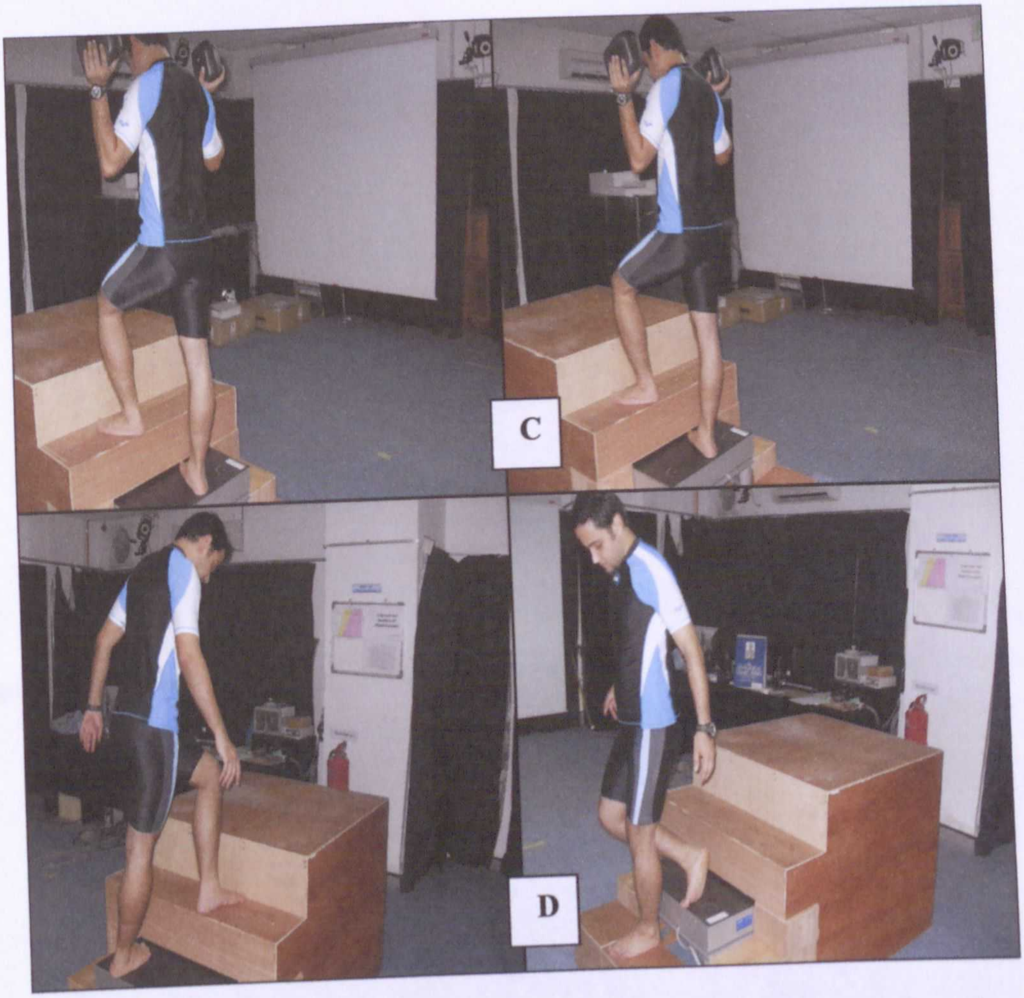


Figure 3.12: Forward stepping movements A) Regular stair walking. B) Hands behind head.



Contd. Figure 3.12: Forward stepping movements C) Holding dumbbells. D) Cross step forward.

For ascending, a subject was asked to stand in front of the floor force plate facing up the stairs as shown in **Figure 3.13(A)**. On the count of 3, he started moving with his right leg by stepping onto the floor force plate (see **Figure 3.13(B)**), then his right leg stepped on to the first step, and kept moving step-over-step until he reached the top platform with the right leg. Then he turned around, to be ready for descending.

For descending, the subject was asked to stand on the top platform facing the stairs as shown in **Figure 3.14(A)**. On the count of 3, he started moving with his left leg by stepping on the third step (see **Figure 3.14(B)**),)), then his right leg stepped on to the third step, and kept moving step-over-step until he reached the floor by stepping into the floor force plate with the right leg.

Figure 3.13: Forward stepping during ascending A) start position. B) Start moving with right leg (✦).

Figure 3.14: Forward stepping during descending A) start position. B) Start moving with left leg (✦).

3.6.2 Lateral stepping

This involves climbing the stair in a step-over-step manner, moving sideways. However, for lateral stepping, unlike forward stepping, each limb performed different function. Therefore, this movement was divided into: LATERAL STEPPING LEADING (LSL), where the leg in question (right leg) is the one responsible for forward progression (see **Figure 3.15(A)**), and LATERAL STEPPING TRAILING (LST), where the leg in question (right leg) is the trailing leg (see **Figure 3.15(B)**).

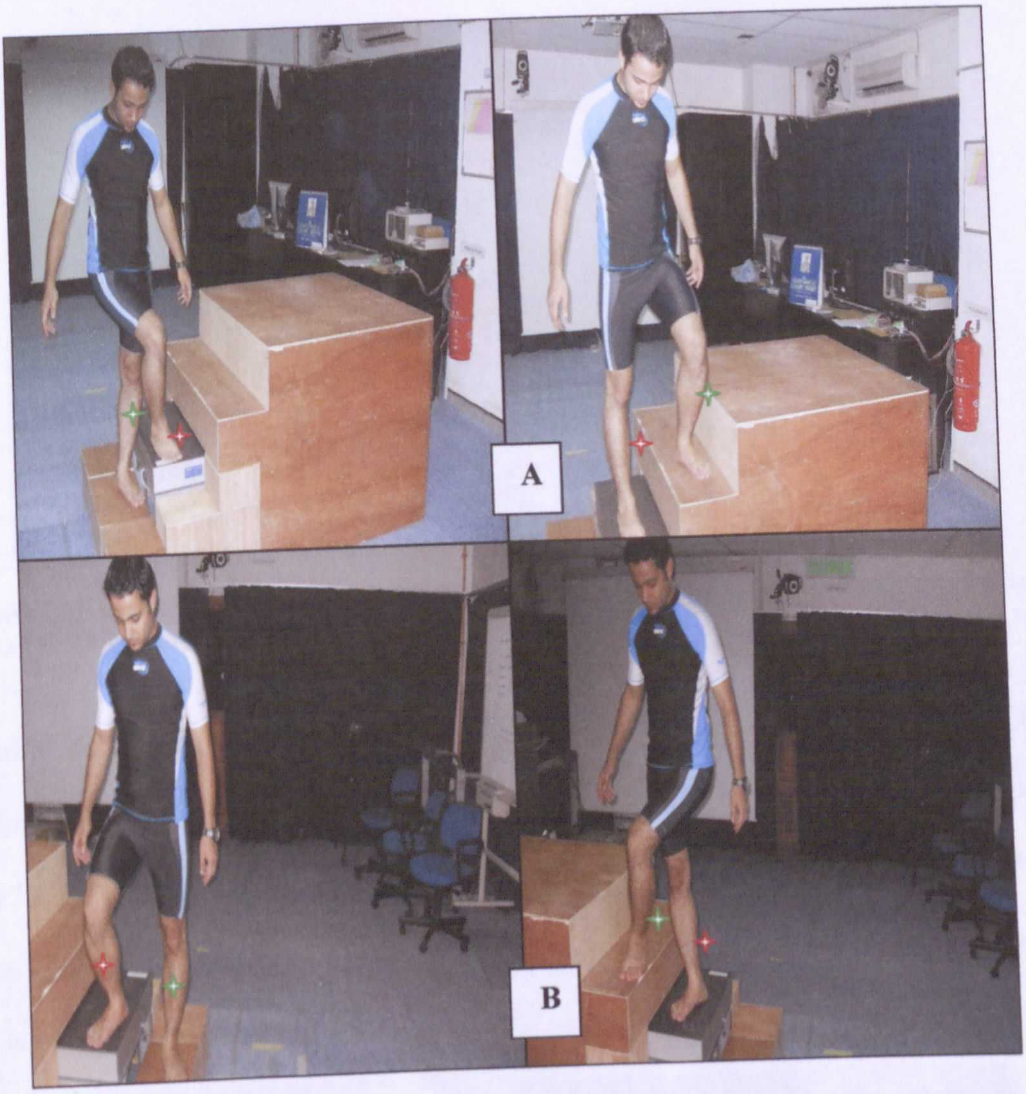


Figure 3.15: Lateral stepping movement A) Lateral stepping leading B) Lateral stepping trailing. ( ) for right leg and ( ) for left.

For LSL during ascending, a subject was asked to stand beside the floor force plate with his left leg closer to the stairs (the staircase on his LHS) as shown in **Figure 3.16(A)**. On the count of 3, he started moving with their right leg by stepping his right leg onto the floor force plate (see **figure 3.16(B)**), then his left leg stepped on to the first step, and kept moving until he reached the top platform with the right leg. Then he turned around to be ready for descending.

Figure 3.16: Lateral stepping leading during ascending. A) Start position. B) Start moving with right leg (✦). (✦) for left leg.

During descending, the subject was asked to stand on the top platform facing the sideways with his left leg closer to the edge of the top platform as shown in **Figure 3.17(A)**. On the count of 3, he started moving with his left leg by stepping onto the third step (see **Figure 3.17(B)**), then his right leg stepped on to the second step, and kept moving until he reached the floor by stepping on the floor force plate with the right leg.

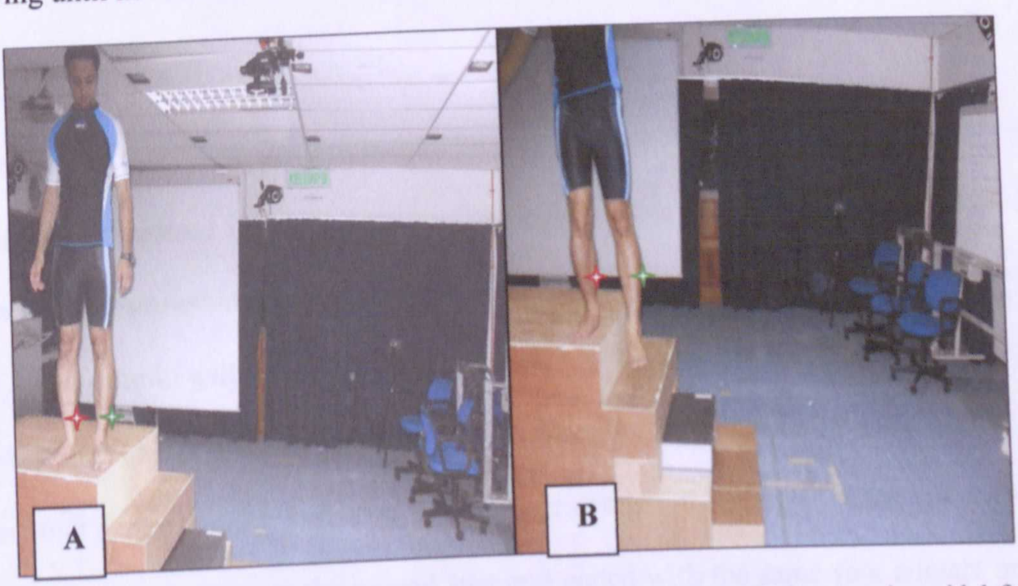


Figure 3.17: Lateral stepping leading during descending. A) Start position. B) Start moving with left leg c (✦). (✦) for left leg.

For lateral stepping trailing, the same instructions were given to the subject. The only difference was the starting posture. During ascending, a subject was asked to stand beside the floor force plate with his right leg closer to the stairs (the staircase on his RHS) as shown in **Figure 3.18(A)**. During descending, the subject was asked to stand in the top platform facing sideways with his right leg closer to the edge of the top platform as shown in **Figure 3.18(B)**.

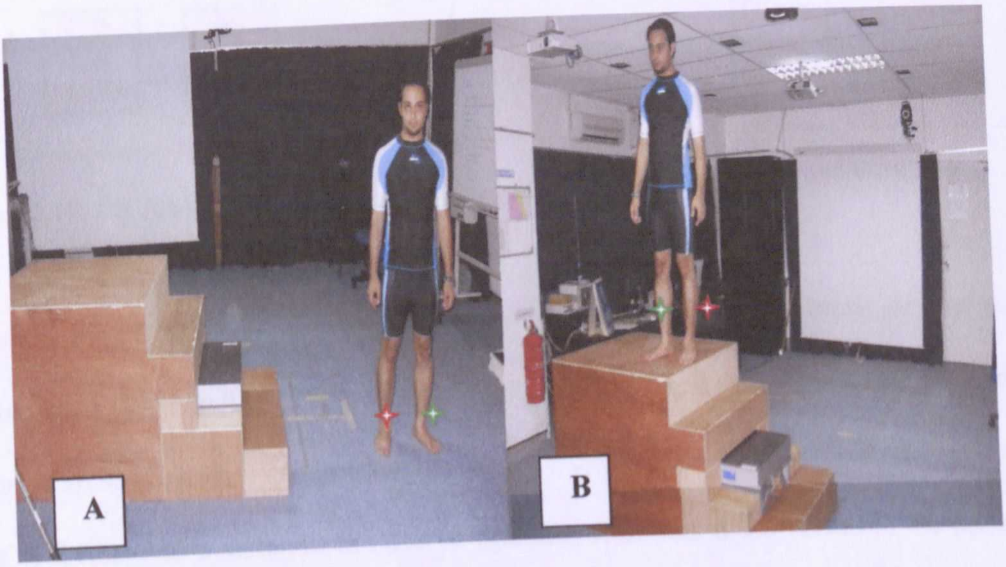


Figure 3.18 Lateral stepping trailing starting position. A) Ascending. B) Descending. left leg (✧). (✧) for Right leg.

3.7 Motion Analysis

Five trials of ascending and descending for each movement were captured. The captured data were processed in vicon nexus software including: marker trajectory gap filling, filtering and smoothing of the trajectory, detecting gait cycle parameters, and applying the vicon plug-in gait link segment model and get the results. The Stride cycle during stair ascent was defined as first right foot contact on the second step and ended at the same foot contact on the forth step. During stair descent, the selected stride cycle started with right foot contact on the second step and ended with the same foot contact on the floor (see **Figure 3.19**). The moments and powers were normalized to subject body weight and the moments were expressed as external moments.

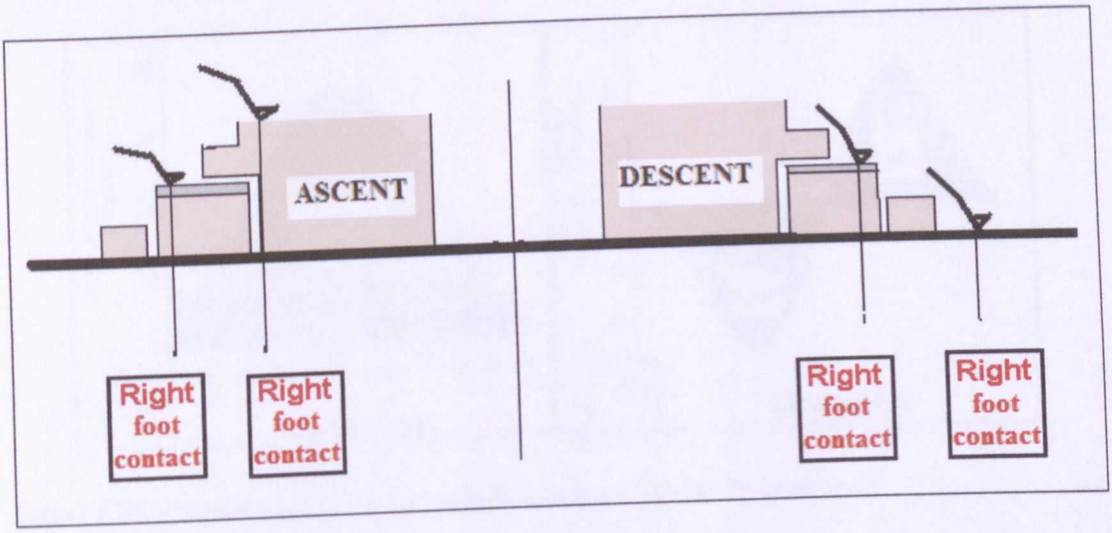


Figure 3.19: The Stride cycle during stair ascent and descent.

Vicon Polygon software was used to find the average of the five trials of ascending phase and of descending phase of each movement for each subject individually and to express all stride events as a percentage of stride cycle. The averaged data were saved in ASCII format and transferred to excel to find the mean maximum values of the included key variables, which were: cadence, cycle duration, stance phase, velocity, Hip/Knee/ankle angles, Hip/Knee/ankle sagittal and frontal plane moments, and powers, during ascent and descent. Additionally, angular impulses and total joints work were calculated using MATLAB and included in the analysis. Angular impulse was defined as the area under a moment curve (i.e. integration) and flexion, dorsiflexion or adduction angular impulses represent the areas under the positive phases of the moment curve as shown in **Figure 3.20**. Total joint work was defined as the area under the absolute power curves (i.e. integration) as shown in **Figure 3.20**.

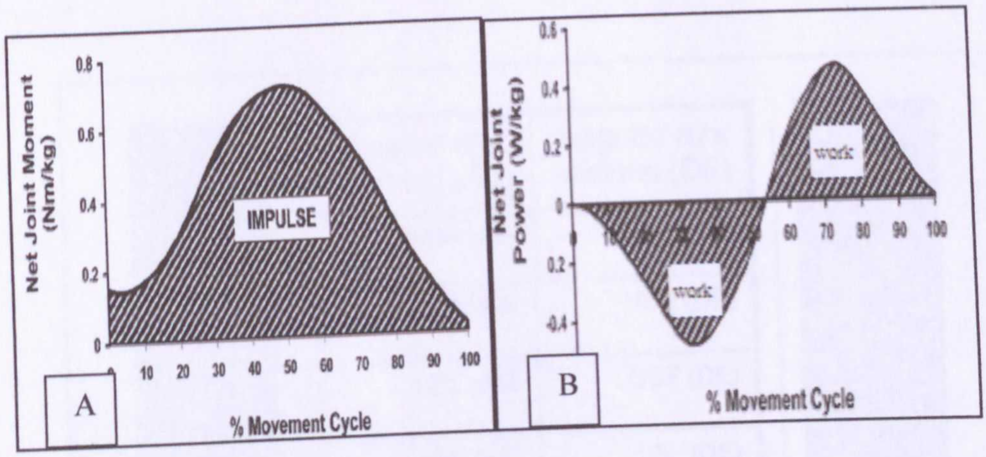


Figure 3.20: Representation of the definition of A) angular impulse. B) Total work.

Finally, all results were saved in excel format and transferred to SPSS 16 for statistical analysis and an ensemble average curves for the angles, moments, and powers for each group were produced using Polygon software.

3.8 Statistical Analysis

SPSS 16 was used to do all statistical analysis. Paired t test was used to compare ascending and descending phase for each exercise, compare between regular stair walking and each exercise during ascending, and compare between regular stair walking and each exercise during descending (**Figure 3.21**). Independent t test was used to compare between lean and obese groups at each phase of each exercise (**Figure 3.22**).

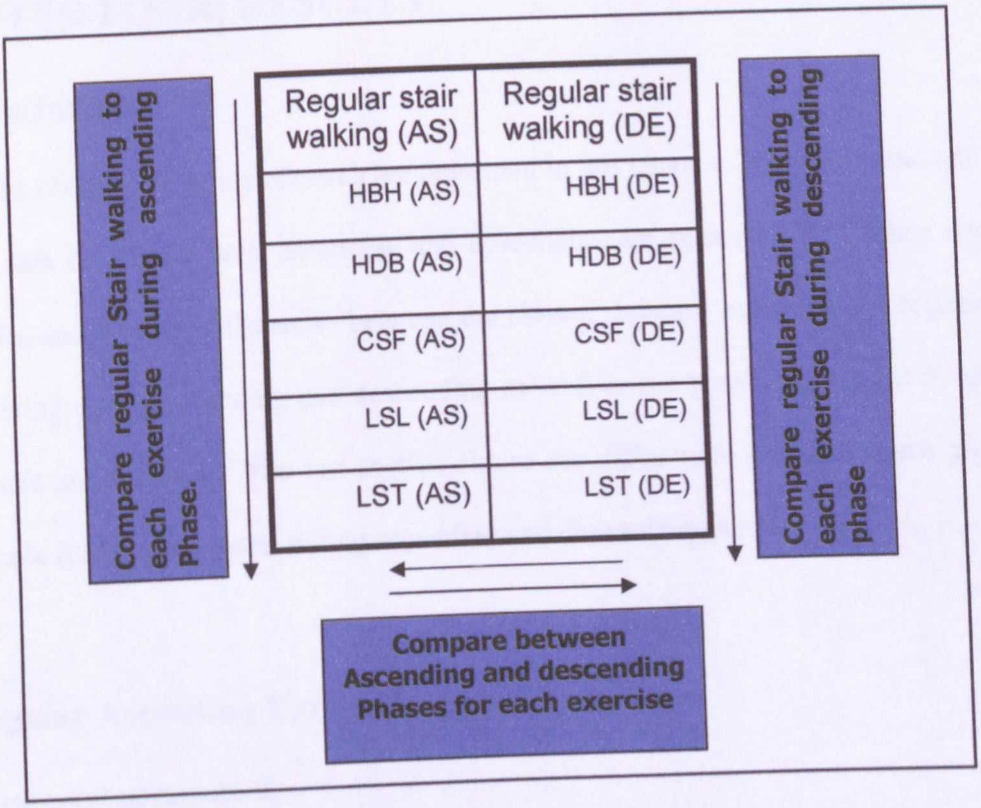


Figure 3.21: Comparison between exercises.

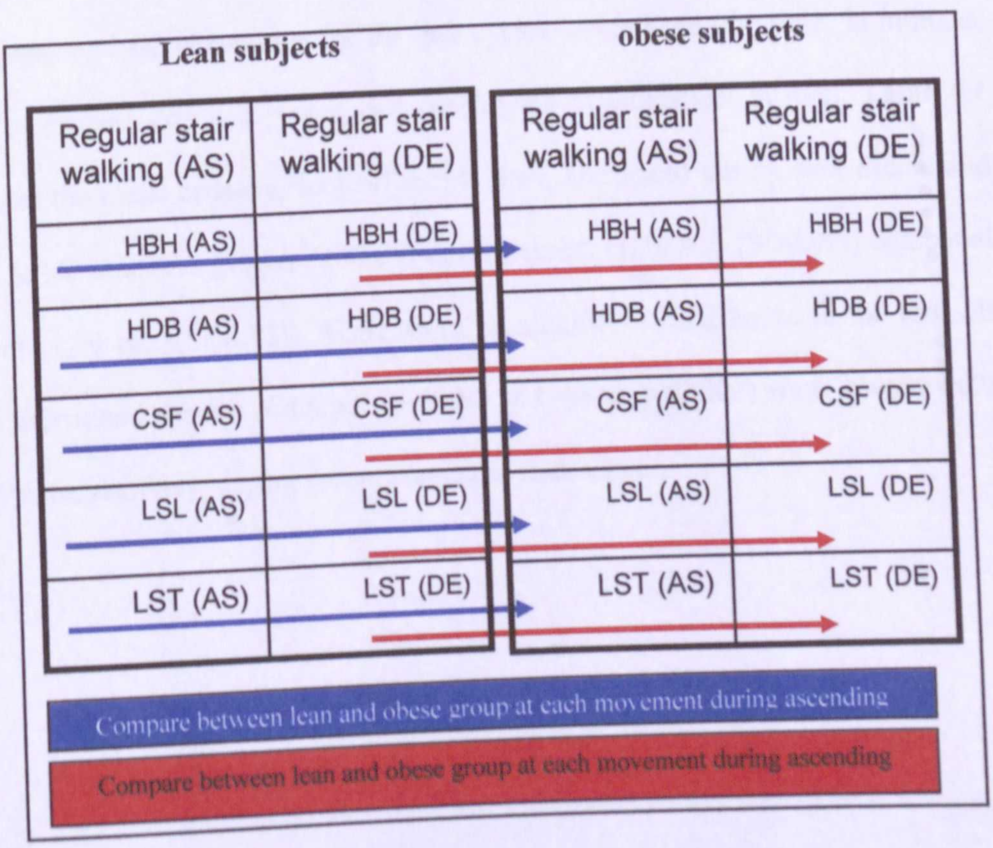


Figure 3.22: Comparison between groups.

CHAPTER FOUR: RESULTS

4.1 Introduction

The results obtained from the research are presented in this chapter. The kinematics and kinetics data for regular stair ascending and descending are presented first. Then the kinematics and kinetics differences between the chosen staircase exercises and regular stair walking during ascending and descending as well as the phase differences of all movements are presented. The last section shows the differences between obese and slim people for all movements during ascending and descending phases.

4.2 Regular Ascending Versus Descending

4.2.1 Temporal parameters

The four temporal parameters involved in the analysis are the cadence (steps/minute), foot off (stance phase percentage for the gait cycle), stride time (the time, in minuets, required to execute one gait cycle), and speed (rate of movement in m/s). **Table 4.1** summarizes the mean cadence, foot off, stride time, and speed during stair ascent and descent. Stride time was greater ($P<0.01$) during ascent (1.50 sec. (SD0.09)) compared to descent (1.39 sec. (SD0.11)). There were no significant differences in the foot off between ascent and descent. Cadence ($p<0.01$) and speed ($p<0.001$) were lower by 8% and 18.5%, respectively, during ascent compared to descent.

Table 4.1: Mean (SD) of time parameters during regular stair ascent and descent (n = 10).

	Mean(SD)	Significance
Cadence (steps/min.)		
ASCENT	80.7(4.8)	**DE>AS (8%)**
DESCENT	87.2(6.8)	
Foot off (%)		
ASCENT	62.4(1.7)	Not sig.
DESCENT	63.6(2.8)	
Stride time (s)		
ASCENT	1.50(.09)	**AS>DE (7.9%)**
DESCENT	1.39(.11)	
Speed (m/s)		
ASCENT	.49(.037)	**DE>AS (18.4%)**
DESCENT	.58(.050)	

4.2.2 Angles

The mean sagittal plane movements of the hip, knee, and ankle joints during stair ascent and descent are illustrated in **Figure 4.1**. During stair ascent in stance phase (from 0% to 62.4% of stride cycle) the hip and knee joints moved forwards into extension and the ankle joint into plantarflexion, while, during stair descent in stance phase (from 0% to 63.6 % of stride cycle), the hip and knee joints moved into flexion and the ankle joint into dorsiflexion. During ascent and descent phases, the maximum hip flexion and knee flexion occurred during the swing phase.

Table 4.2 and the corresponding Bar chart (**Figure 4.2**) summarize the mean maximum angles observed at the hip, knee, and ankle joints during stair ascent and descent. Subjects required greater flexion at the hip ($P < 0.001$) during ascending. There were no significant difference in knee flexion angle between ascending and descending. Subjects required greater ankle dorsiflexion angle ($P<0.001$) and plantar-flexion angle ($P<0.001$) during descent compared to during ascent.

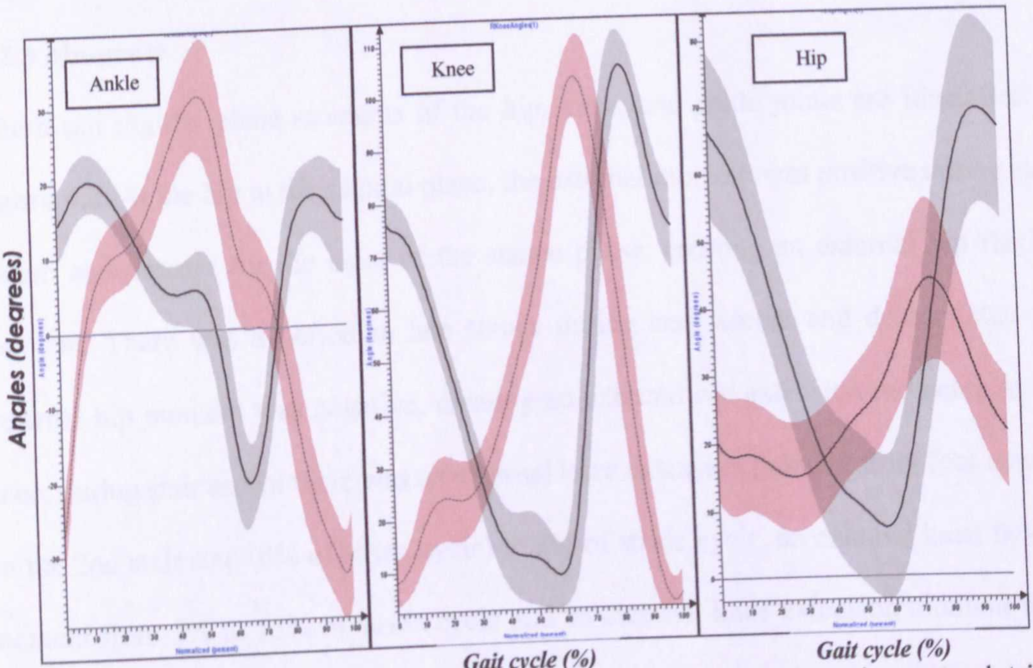


Figure 4.1: Mean sagittal plane angles of the hip, knee, and ankle joints during stair ascent and stair descent (n = 10). The continued and dashed lines represent the mean during stair ascent and descent, respectively. The grey and light red shades represent the SD during stair ascent and descent, respectively.

Table 4.2: Mean (SD) of maximum hip, knee and ankle angles during regular stair ascent and descent (n = 10).

	Mean(SD)	Significance
HIP flex. (degrees)		
ASCENT	71.97(12.47)	**AS>DE (62.4%)**
DESCENT	44.32(12.44)	
KNEE flex. (degrees)		
ASCENT	107.22(5.95)	Not sig.
DESCENT	104.83(7.72)	
ANKLE dorsi-flex. (degrees)		
ASCENT	20.69(3.05)	**DE>AS (55.8%)**
DESCENT	32.24(7.13)	
ANKLE plantar-flex. (degrees)		
ASCENT	22.88(4.75)	**DE>AS (46.9%)**
DESCENT	33.60(5.49)	

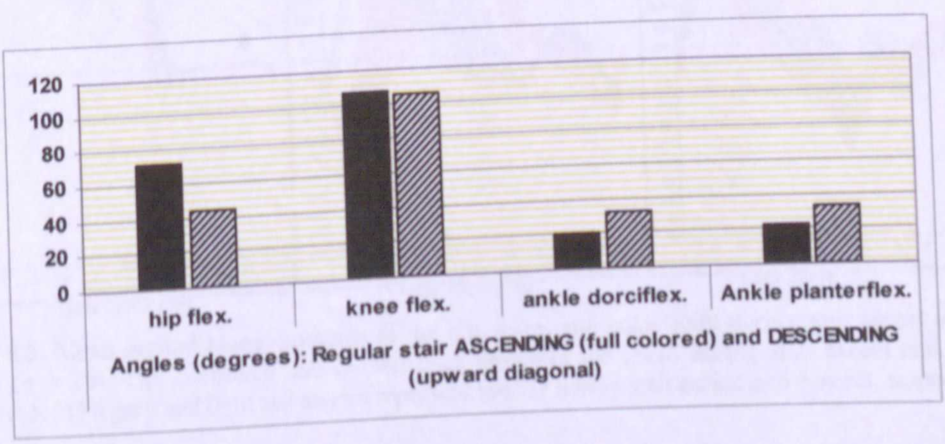


Figure 4.2: Bar chart representation of the mean maximum hip, knee, and ankle angles during regular stair ascent and descent.

4.2.3 Moments

The mean sagittal plane moments of the hip, knee, and ankle joints are illustrated in **figure 4.3**. At the hip in the sagittal plane, the external moment was positive during stair ascent and descent for the most of the stance phase, creating an external hip flexion moment. There was a period in late stance during stair ascent and descent that the external hip moment was negative, creating an external hip extension moment. At the knee, during stair ascent there was an external knee extension moment from foot contact on the 2nd stair step (0% of stride cycle) to 3% of stride cycle, an external knee flexion moment from 3% to 55% of stride cycle and an external knee extension moment from 55% to 62.4% (toe-off) of stride cycle. During stair descent there was an external knee extension moment from foot contact on the 2nd stair step (0% of stride cycle) to 14% of stride cycle, and an external knee flexion moment from 14% of stride cycle to 63.6% (toe-off) of stride cycle. The external ankle moment was positive in stance phase during stair ascent and descent, creating an external dorsiflexion moment.

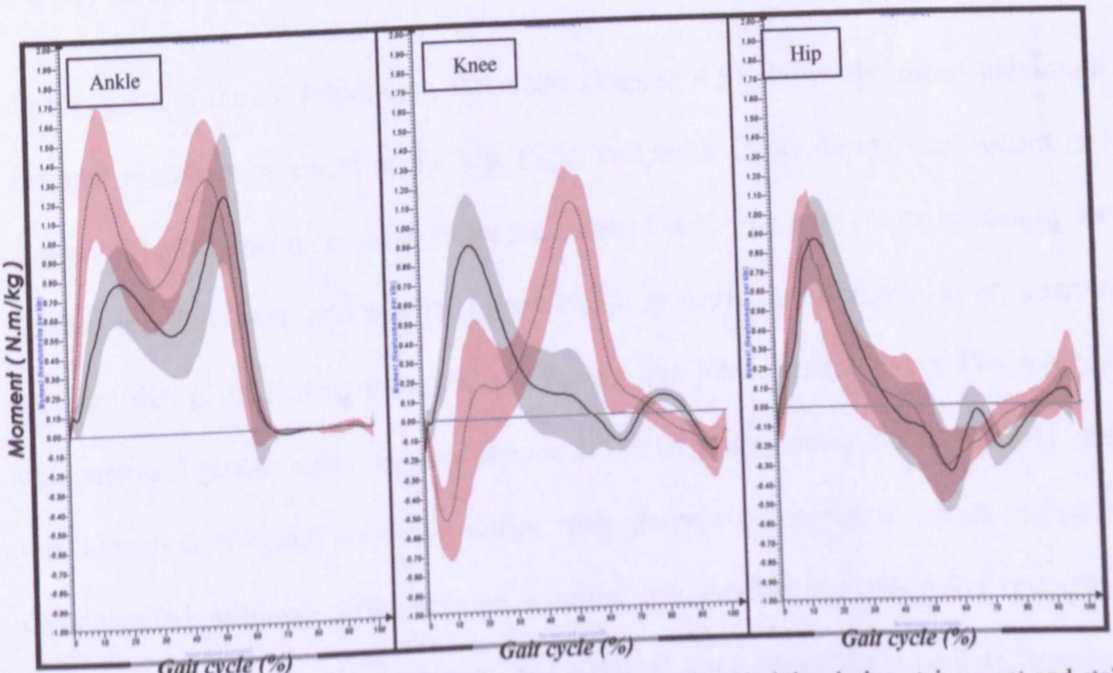


Figure 4.3: Mean sagittal plane moments of the hip, knee, and ankle joint during stair ascent and stair descent (n = 10). The continued and dashed lines represent the mean during stair ascent and descent respectively. The grey and light red shades represent the SD during stair ascent and descent, respectively.

The mean frontal plane moments of the hip and the knee joints during ascent and descent are illustrated in **figure 4.4**. The external hip and knee moments were positive in stance phase during stair ascent and descent, creating an external adduction moment.

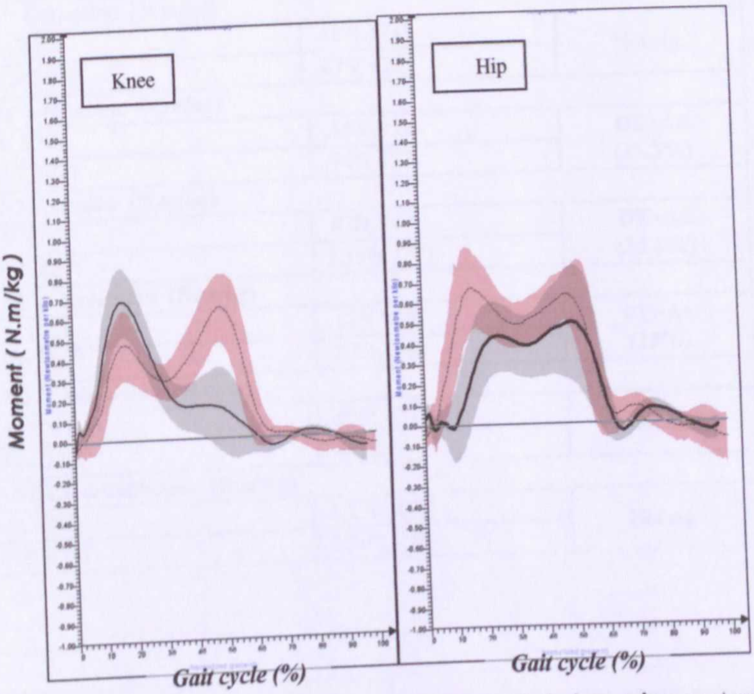


Figure 4.4: Mean frontal plane moments of the hip and knee joint during stair ascent and stair descent (n = 10). The continued and dashed lines represent the mean during stair ascent and descent respectively. The grey and light red shades represent the SD during stair ascent and descent, respectively.

Table 4.3 and the corresponding Bar chart (**Figure 4.5**) shows the mean maximum external moments observed at the hip, knee, and ankle joints during stair ascent and descent. The external moment includes the moment about the joint center created by the ground reaction force and inertial forces which is equal and opposite to an internal moment that is created by muscles, soft tissues and joint contact forces The subjects demonstrated greater external knee flexion (P <0.01), knee extension (P <0.001), and hip adduction (P<0.05) moments during stair descent compared to ascent. Subjects demonstrated minimal differences in external hip flexion and extension moments, external ankle dorsiflexion moments, and external knee adduction moments, between stair ascent and descent.

Table 4.3: Mean (SD) of maximum external hip, knee and ankle moments during regular stair ascent and descent (n = 10).

	Mean(SD)	Significance
HIP flexion (N.m/kg)		
ASCENT	.893(.199)	Not sig.
DESCENT	.918(.195)	
HIP Extension (N.m/kg)		
ASCENT	.407(.134)	Not sig.
DESCENT	.375(.129)	
HIP adduction (N.m/kg)		
ASCENT	.552(.233)	**DE>AS (35.3%)**
DESCENT	.747(.177)	
KNEE flexion (N.m/kg)		
ASCENT	.878(.240)	**DE>AS (32.6%)**
DESCENT	1.164(.135)	
KNEE Extension (N.m/kg)		
ASCENT	.173(.048)	**DE>AS (23%)**
DESCENT	.571(.155)	
KNEE adduction (N.m/kg)		
ASCENT	.695(.151)	Not sig.
DESCENT	.673(.151)	
ANKLE dorsiflexion (N.m/kg)		
ASCENT	1.279(.193)	Not sig.
DESCENT	1.509(.218)	

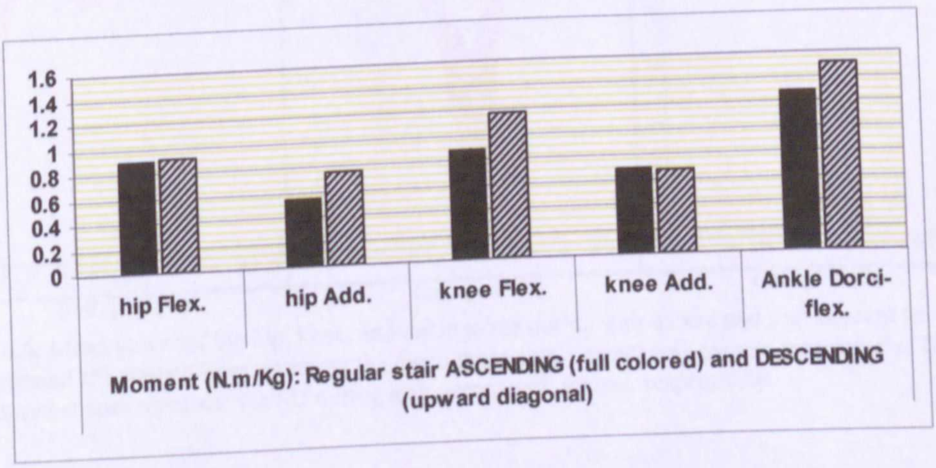


Figure 4.5: Bar chart representation of the mean maximum hip, knee, and ankle moments during regular stair ascent and descent.

4.2.4 Powers

During ascent, all the joints produced energy (positive power) during most of the stride phases (**Figure 4.6**).The knee and hip joint powers reached their maximum values at the beginning of the stance phase (at 18% for the knee and 15% for hip of the cycle time). In the hip, a second lower peak was observed during the swing phase. The ankle joint exhibited maximum power production at the end of the stance phase (5% cycle time), not only during ascent but also descent. During descent, the joint powers were predominantly negative, i.e., energy was absorbed. Only the hip joint showed a remarkable phase of energy production, with a peak of power at 57% cycle time. The maximum (negative value) of the knee joint power occurred at 53% cycle time. The ankle joint absorbed energy during descent at the beginning of the stance phase (6% cycle time).

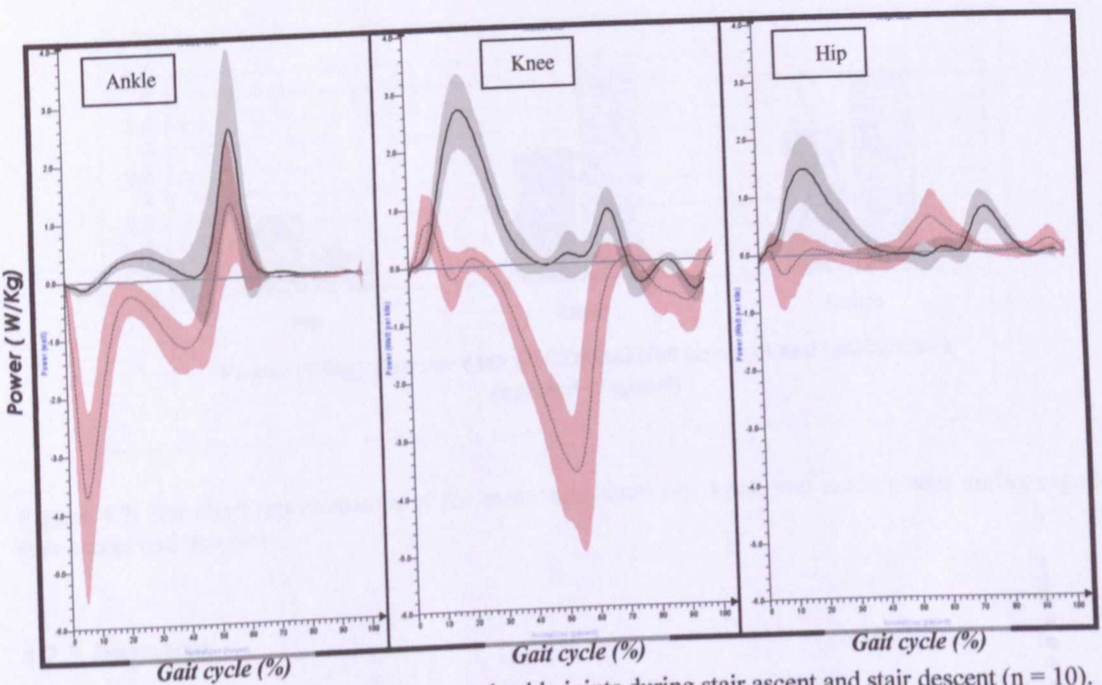


Figure 4.6: Mean power of the hip, knee, and ankle joints during stair ascent and stair descent (n = 10). The continued and dashed lines represent the mean during stair ascent and descent respectively. The grey and light red shades represent the SD during stair ascent and descent, respectively.

Table 4.4 and the corresponding Bar chart (**Figure 4.7**) shows the mean maximum absolute powers observed at the hip, knee, and ankle joints during stair ascent and descent. Higher power at the hip (P<0.001) and lower power at the knee (P<0.01) were required during ascending compared to descending. No significant differences were found and the maximum power values at the ankle joint between stair ascent and descent.

Table 4.4: Mean (SD) of maximum external hip, knee and ankle power during regular stair ascent and descent (n = 10).

	Mean(SD)	significance
HIP power (W/Kg)		
ASCENT	1.56(.47)	**AS>DE (90.2%)**
DESCENT	.82(.32)	
KNEE power (W/Kg)		
ASCENT	2.64(.62)	**DE>AS (62%)**
DESCENT	4.28(1.06)	
ANKLE power (W/Kg)		
ASCENT	2.87(.87)	Not sig.
DESCENT	4.01(1.71)	

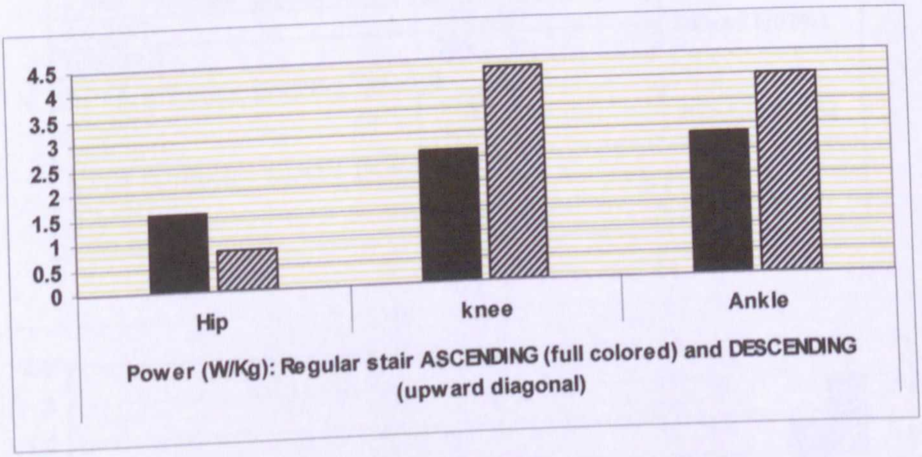


Figure 4.7: Bar chart representation of the mean maximum hip, knee, and ankle power during regular stair ascent and descent.

4.2.5 Impulses

Table 4.5 and the corresponding Bar chart (**Figure 4.8**) shows the mean maximum impulses observed at the hip, knee, and ankle joints during stair ascent and descent. No significant differences were found in hip flexion and extension impulse between stair ascent and descent. Subjects demonstrated greater knee flexion ($P < 0.05$), knee extension ($P < 0.01$), ankle dorsiflexion ($P < 0.01$), knee adduction ($P < 0.05$), and hip adduction ($P < 0.05$) impulses during stair descent compared to ascent.

Table 4.5: Mean (SD) of maximum external hip, knee, and ankle impulses during regular stair ascent and descent (n = 10).

	Mean(SD)	Significance
HIP flexion impulse (N.m.s/kg)		
ASCENT	.624(.277)	Not sig.
DESCENT	.624(.342)	
HIP Extension impulse (N.m.s/kg)		
ASCENT	.300(.148)	Not sig.
DESCENT	.281(.100)	
HIP adduction impulse (N.m.s/kg)		
ASCENT	.751(.495)	**DE>AS (38.3%)**
DESCENT	1.039(.342)	
KNEE flexion impulse (N.m.s/kg)		
ASCENT	.742(.247)	**DE>AS (22.2%)**
DESCENT	.907(.191)	
KNEE Extension impulse (N.m.s/kg)		
ASCENT	.138(.055)	**DE>AS (107%)**
DESCENT	.286(.134)	
KNEE adduction impulse (N.m.s/kg)		
ASCENT	.626(.363)	**DE>AS (26.4%)**
DESCENT	.791(.291)	
KNEE dorsiflexion impulse (N.m.s/kg)		
ASCENT	1.383(.470)	**DE>AS (45%)**
DESCENT	2.006(.547)	

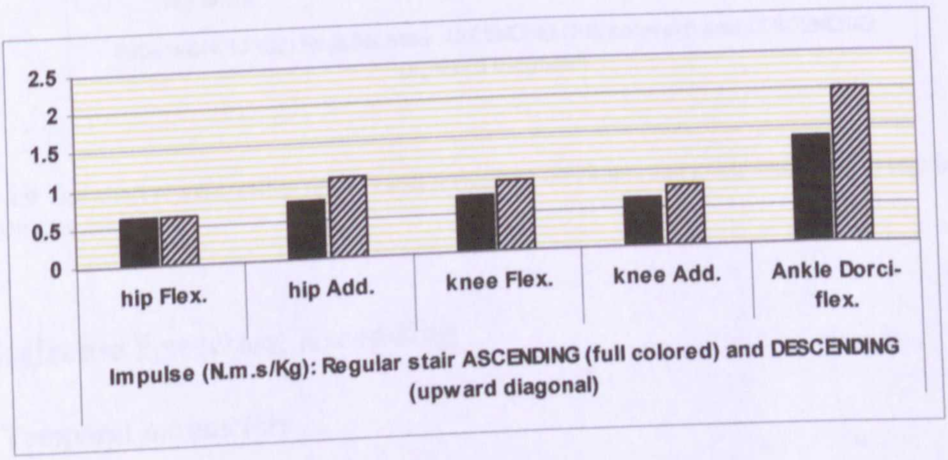


Figure 4.8: Bar chart representation of the mean maximum hip, knee, and ankle impulse during regular stair ascent and descent.

4.2.6 Total work

Table 4.4 and the corresponding bar chart (**Figure 4.9**) shows the mean maximum total work observed at the hip, knee, and ankle joints during stair ascent and descent. Higher work at the hip ($P<0.001$) but lower work at the knee ($P<0.01$) and the ankle ($P<0.001$) were required during ascending compared to descending.

Table 4.6: Mean (SD) of maximum external hip, knee and ankle work during regular stair ascent and descent (n = 10).

	Mean(SD)	Significance
HIP work (J/Kg)		
ASCENT	1.434(.693)	**AS>DE (97.8%)**
DESCENT	.725(.388)	
KNEE work (J/Kg)		
ASCENT	2.324(.604)	**DE>AS (44.5%)**
DESCENT	3.359(1.004)	
ANKLE work (J/Kg)		
ASCENT	1.239(.500)	**DE>AS (106.3%)**
DESCENT	2.556(.887)	

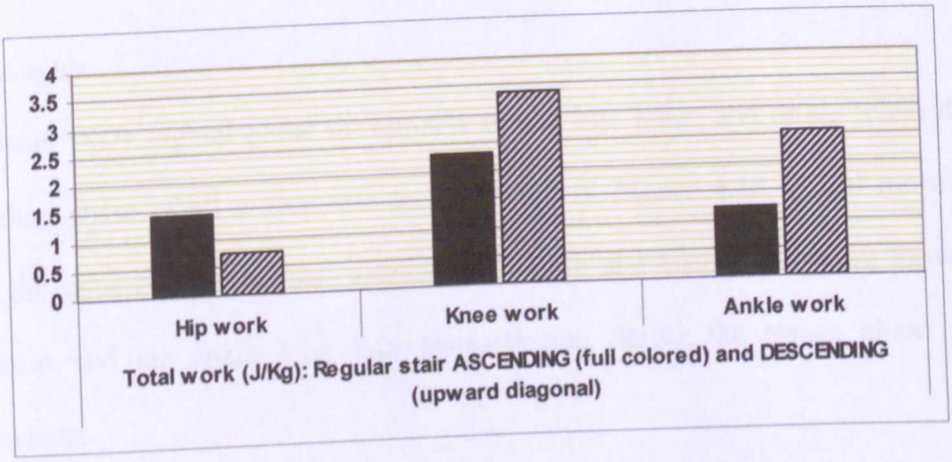


Figure 4.9: Bar chart representation of the mean maximum hip, knee, and ankle work during regular stair ascent and descent.

4.3 Staircase Exercises: Ascending

4.3.1 Temporal parameters

Table 4.7 summarizes the mean cadence, foot off, stride time, and speed during the ascending phase of all movements. CSF shows lower cadence (P<0.01) and velocity (P<.05) compared to regular ascending .LSL shows lower velocity (P<.05) compared to regular ascending. No significant differences were found for HBH, HDB, and LST in cadence and velocity compared to RSW .Only LST shows lower foot off(P<.001) compared to regular ascending .

Table 4.7: Mean (SD) of time parameters during stair ascending exercises (n = 10).

	RSW	HBH	HDB	CSF	LSL	LST
Cadence (steps/min.)	**80.7(4.8)**	80.88(4.8) **Not sig.**	86.58(7.3) **Not sig.**	73.04(7.4) L **(9.5%)**	75.85(11.1) **Not sig.**	79.21(5.4) **Not sig.**
Foot off (%)	**62.4(1.7)**	62.26(1.4) **Not sig.**	62.61(1.5) **Not sig.**	61.9(2.2) **Not sig.**	64.2(3.7) **Not sig.**	59.66(1.7) L **(4.4%)**
Stride time (s)	**1.50(.09)**	1.49(.086) **Not sig.**	1.4(.114) **Not sig.**	1.67(.51) H (11.3%)	1.63(.294) H (8.7%)	1.53(.102) **Not sig.**
Speed (m/s)	**.49(.037)**	.48(.024) **Not sig.**	.51(.049) **Not sig.**	.44(.054) L **(10.2%)**	.44(.064) L **(10.2%)**	.52(.036) **Not sig.**

4.3.2 Angles

The mean (SD) sagittal plane movements of the hip, knee, and ankle joints during ascending phase of all movements are illustrated in **Figure 4.10**. All of movements show the same trend as regular ascending. The hip and knee joints move forward in extension and the ankle joint into plantarflexion during the stance phase of all movements.

Table 4.8 and the corresponding bar chart (**Figure 4.11**) summarizes the mean maximum angles observed at the hip, knee, and ankle joints during ascending phase of all movements. Subjects required lower flexion at the hip for HDB ($P<0.05$) and LST ($P<0.01$) and lower knee flexion for HBH ($P<0.01$) and LSL ($P<0.001$) compared to regular ascending. No significant difference in for hip flexion angle for HBH, CSF, and LSL, and in the knee flexion angle for HDB and CSF compared to regular ascending. Subjects required greater knee flexion angle for LST ($P<0.001$), greater ankle dorsiflexion angle for LSL ($P<0.001$) and LST ($P<0.05$), and greater ankle plantarflexion angle for HDB ($P<0.01$) compared to regular ascending.

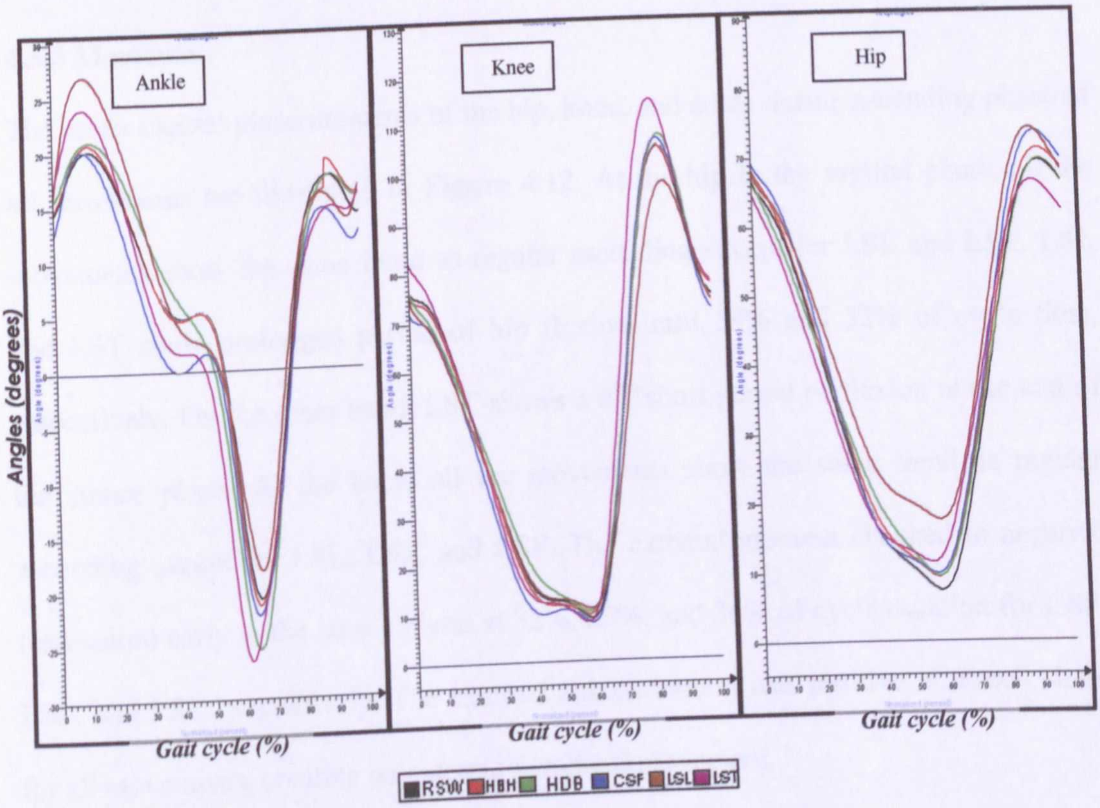


Figure 4.10: Mean angle power of the hip, knee, and ankle joint during stair ascent phase of all exercises (n = 10).

Table 4.8: Mean (SD) of maximum hip, knee and ankle angles during stair ascending exercises (n = 10).

	RSW	HBH	HDB	CSF	LSL	LST
Hip flex. (degrees)	**71.97(12.47)**	71.36(12.7) **Not sig.**	69.69(11.5) **L (3.2%)**	74.33(11.3) **Not sig.**	74.66(11.2) **Not sig.**	66.87(11.8) **L (7.1%)**
Knee flex. (degrees)	**107.22(5.95)**	105.39(5.83) **L (1.7%)**	108.05(6.76) **Not sig.**	107.59(8.82) **Not sig.**	99.14 (8.9) **L (7.5%)**	115.54(6.9) **H (7.8%)**
Ankle dorsiflex. (degrees)	**20.69(3.05)**	20.93(3.25) **Not sig.**	21.19(2.54) **Not sig.**	20.67(3.98) **Not sig.**	27.78(4.40) **H (34.2%)**	24.25(4.69) **H (17.2%)**
Ankle Plantarflex. (degrees)	**22.88(4.75)**	22.17(5.32) **Not sig.**	26.39(6.71) **H (15.3%)**	23.5(7.56) **Not sig.**	23.69(7.05) **Not sig.**	21.62(9.77) **Not sig.**

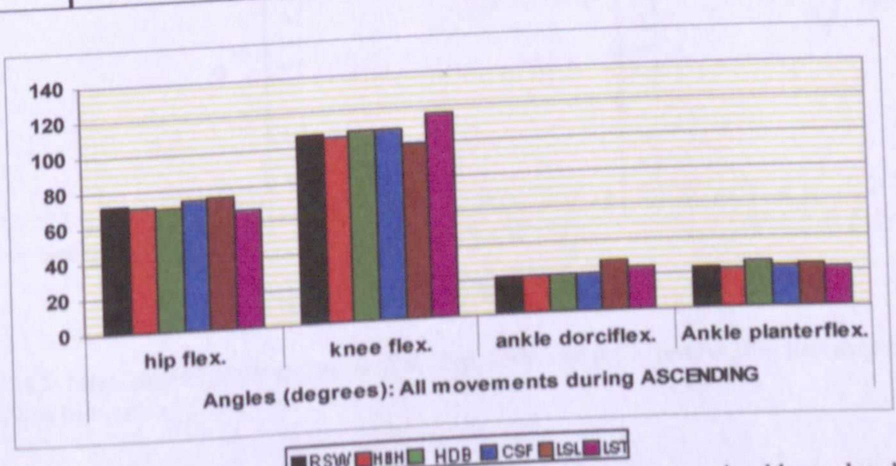


Figure 4.11: Bar chart representation of the mean maximum hip, knee, and ankle angles during stair ascending exercises.

4.3.3 Moments

The mean sagittal plane moments of the hip, knee, and ankle during ascending phase of all movements are illustrated in **Figure 4.12**. At the hip in the sagittal plane, all the movements show the same trend as regular ascending except for LSL and LST. LSL and LST show prolonged period of hip flexion until 59% and 52% of cycle time, respectively. On the other hand, LST shows a 2nd short period of flexion at the end of the stance phase. At the knee, all the movements show the same trend as regular ascending except for LSL, LST, and CSF. The external moment changed to negative (extension) early in the stance phase at 32%, 50%, and 36% of cycle duration for CSF, LSL, and LST, respectively. The external ankle moment was positive in stance phase for all movements, creating an external dorsiflexion moment.

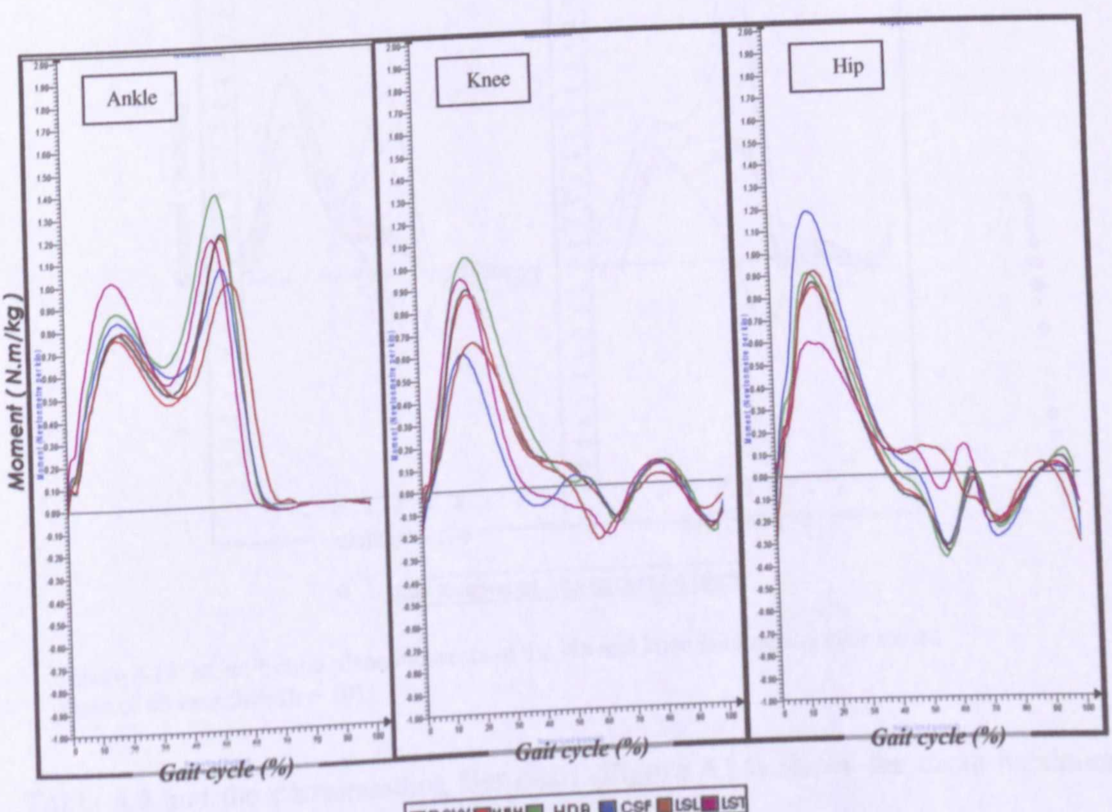


Figure 4.12: Mean sagittal plane moments of the hip, knee, and ankle joint during stair ascent phase of all exercises (n = 10).

The frontal plane moments of the hip, knee, and ankle joints during the ascending phase of all movements are illustrated in **figure 4.13**. The external hip and knee moments were positive in stance phase during all movements, creating an external adduction moment, except for LSL. At the hip for LSL, external hip moment were positive from the beginning of the movement until 47% of cycle duration it turns to negative, creating an external abduction moment. At the knee for LSL, external hip moment were positive from the beginning of the movement until 45% of cycle duration it turns to negative, creating an external abduction moment.

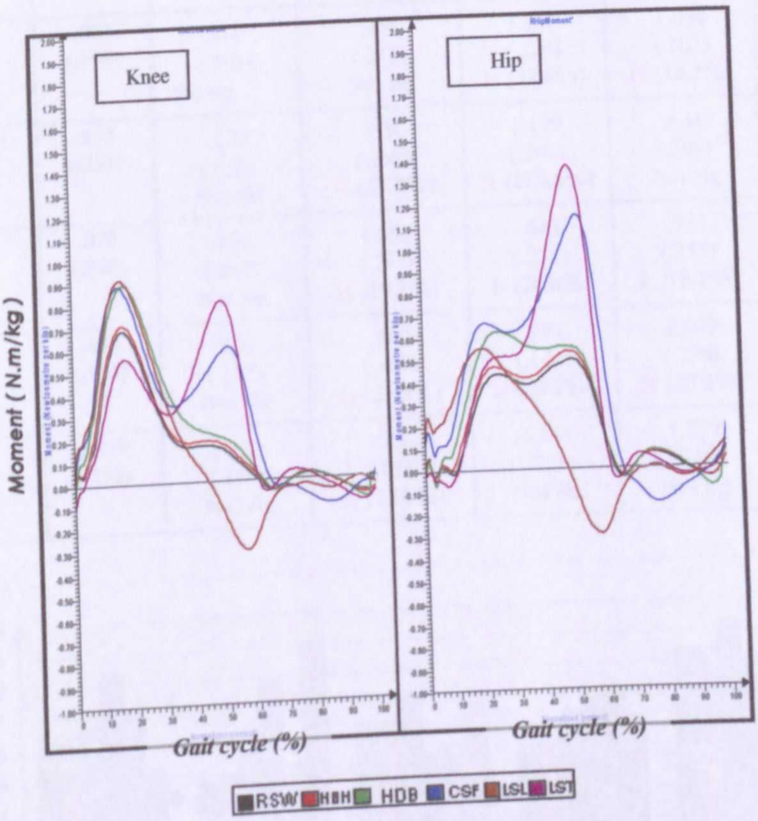


Figure 4.13: Mean frontal plane moments of the hip and knee joint during stair ascent phase of all exercises (n = 10).

Table 4.9 and the corresponding Bar chart (**Figure 4.14**) shows the mean maximum external moments observed at the hip, knee, and ankle joints during ascending phase of all movements. At the hip joint, subjects demonstrated greater external hip flexion moments for CSF (P <0.01) and LSL (P <0.05), and greater hip adduction moments for HDB (P<0.01), CSF (P<0.001) and LST (P<0.001) compared to regular stair ascending.

At the knee, subjects demonstrated greater knee flexion moments for HDB (P<0.001) and lower knee flexion moments for CSF (P<0.001) and LSL (P<0.001) compared to regular stair ascending. In the frontal plane, subjects show greater knee adduction moment for HDB (P<0.001), CSF (P<0.001), LSL (P<0.001), and LST (P<0.05) compared to regular stair ascending. At the ankle joint, only HDB shows greater dorsiflexion moment (P<0.05) compared to regular stair ascending.

Table 4.9: Mean (SD) of maximum external hip, knee and ankle moments during stair ascending exercises (n = 10).

	RSW	HBH	HDB	CSF	LSL	LST
Hip flexion (N.m/kg)	**.893 (.199)**	.880 (.191) **Not sig**	.945 (.213) **Not sig**	1.272 (.282) **H (42.4%)**	1.038 (.202) **H (16.2%)**	.642 (.262) **L (28.1%)**
Hip adduction (N.m/kg)	**.552 (.233)**	.604 (.256) **Not sig**	.724 (.259) **H (31.2%)**	1.179 (.287) **H (113.6%)**	.641 (.209) **Not sig**	1.423 (.173) **H (157.8)**
Knee flexion (N.m/kg)	**.878 (.240)**	.884 (.263) **Not sig**	1.052 (.297) **H (19.2%)**	.643 (.271) **L (26.8%)**	.719 (.255) **L (18.1%)**	.965 (.273) **Not sig**
Knee Adduction (N.m/kg)	**.695 (.151)**	.720 (.131) **Not sig**	.907 (.165) **H (30.5%)**	.975 (.144) **H (40.2%)**	1.009 (.206) **H (45.2%)**	.849 (.120) **H (22.2%)**
Ankle dorsiflexion (N.m/kg)	**1.279 (.193)**	1.277 (.194) **Not sig**	1.452 (.173) **H (13.5%)**	1.243 (.291) **Not sig**	1.357 (.249) **Not sig**	1.278 (.220) **Not sig**

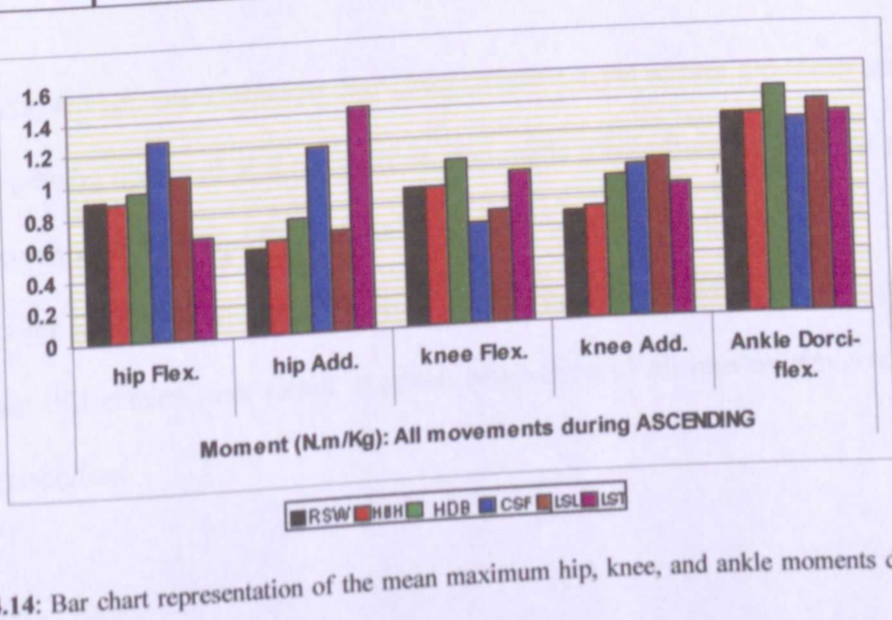


Figure 4.14: Bar chart representation of the mean maximum hip, knee, and ankle moments during stair ascending exercises.

4.3.4 Powers

The Mean powers at the hip, knee, and ankle joints during ascending phase of all movements are illustrated in **Figure 4.15**. All the movements show the same power production trend as regular ascending at the hip, knee, and ankle.

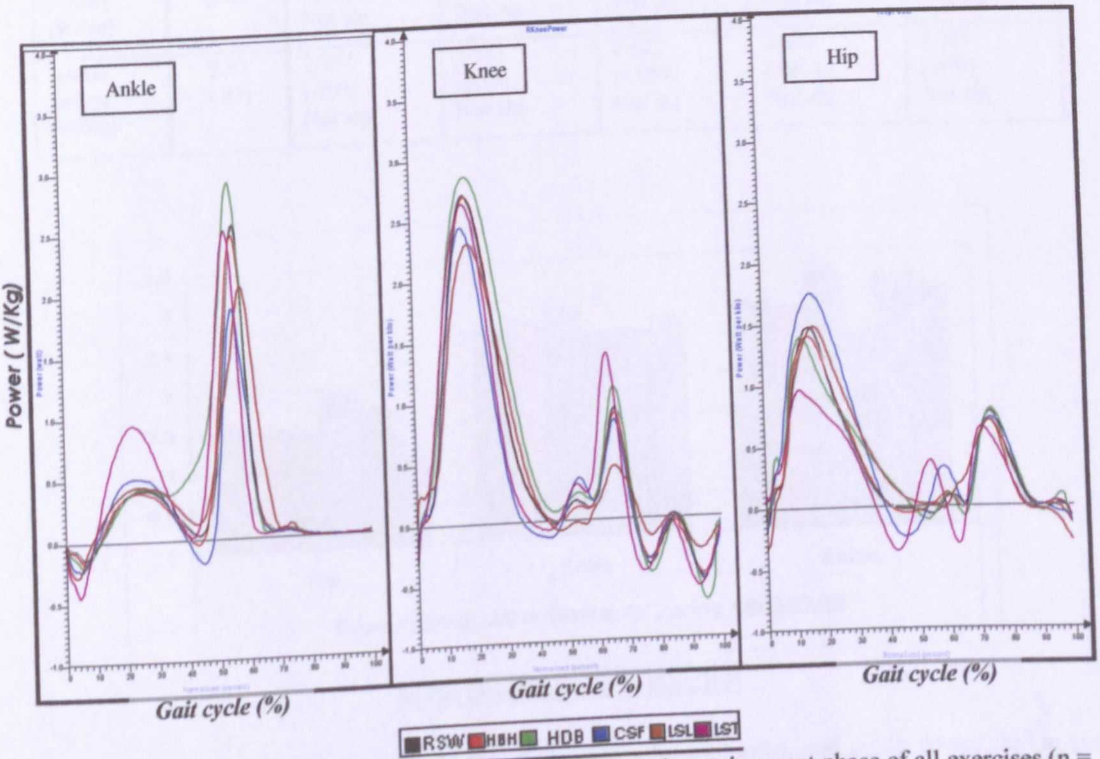


Figure 4.15: Mean power of the hip, knee, and ankle joint during stair ascent phase of all exercises (n = 10).

Table 4.10 and the corresponding Bar chart (**Figure 4.16**) shows the mean maximum absolute powers observed at the hip, knee, and ankle joints during ascending phase of all movements. At the hip, CSF produces greater power ($P<0.05$) and LST produces lower power ($P<0.05$) compared to regular ascending. At the knee and ankle joints, no significant differences were found in power production of all movements compared to regular ascending.

Table 4.10: Mean (SD) of maximum external hip, knee and ankle power during stair ascending exercises (n = 10).

	RSW	HBH	HDB	CSF	LSL	LST
Hip power (W/Kg)	**1.56 (.47)**	1.512 (.450) **Not sig**	1.456 (.403) **Not sig**	1.957 (.560) **H (25.4%)**	1.720 (.731) **Not sig**	1.153 (.566) **L (26.1%)**
Knee Power (W/Kg)	**2.64 (.62)**	2.719 (.607) **Not sig**	2.878 (.779) **Not sig**	2.548 (.714) **Not sig**	2.579 (.637) **Not sig**	2.728 (.665) **Not sig**
Ankle power (W/Kg)	**2.87 (.87)**	2.794 (.767) **Not sig**	3.273 (.619) **Not sig**	2.432 (1.058) **Not sig**	3.186 (.863) **Not sig**	3.028 (.970) **Not sig**

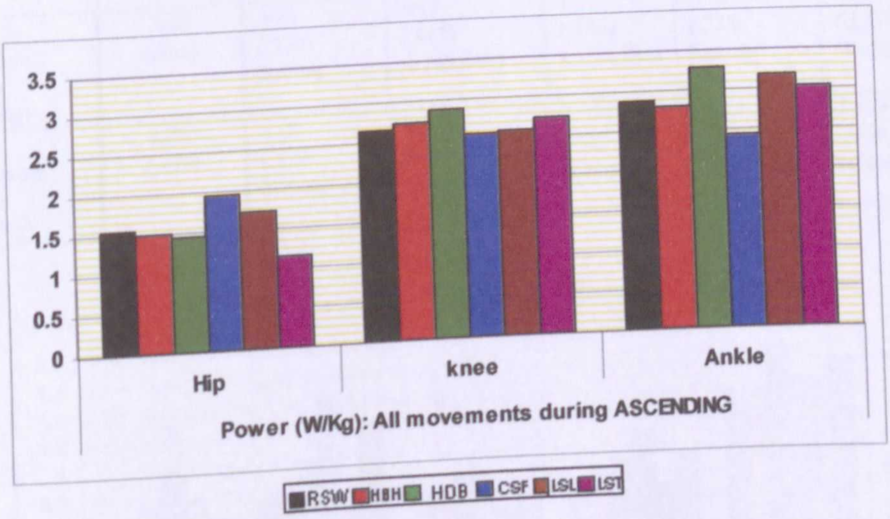


Figure 4.16: Bar chart representation of the mean maximum hip, knee, and ankle power during stair ascending exercises.

4.3.5 Impulses

Table 4.11 and the corresponding bar chart (**Figure 4.17**) shows the mean maximum impulses observed at the hip, knee, and ankle joints during ascending phase of all movements. At the hip, the subjects demonstrated greater hip flexion impulse for HDB (P < 0.03), CSF (P <0.01), and LSL (P <0.05), greater adduction impulse HDB (P <0.01), CSF (P <0.001), and LST (P <0.001). At the knee, the subjects demonstrated greater knee flexion impulse for HDB (P <0.01), lower knee flexion impulse for CSF (P <0.01), and greater knee adduction impulse for HDB (P <0.001), CSF (P <0.001), and LST (P <0.01), compared to regular ascending. At the ankle, only HDB produced significantly higher dorsiflexion impulse (P<0.01) compared to regular ascending.

Table 4.11: Mean (SD) of maximum external hip, knee and ankle impulse during stair ascending exercises (n = 10).

	RSW	HBH	HDB	CSF	LSL	LST
Hip flexion Impulse (N.m.s/kg)	.624 (.277)	.643 (.297) Not sig	.764 (.408) H (22.4%)	.953 (.303) H (52.7%)	.786 (.198) H (26%)	.627 (.395) Not sig
Hip adduction Impulse (N.m.s/kg)	.751 (.495)	.820 (.545) Not sig	1.004 (.639) H (33.7%)	1.454 (.648) H (93.6%)	.616 (.256) Not sig	1.259 (.428) H (67.6%)
Knee flexion impulse (N.m.s/kg)	.742 (.247)	.687 (.230) Not sig	.894 (.243) H (20.5%)	.459 (.277) L (38%)	.579 (.216) Not sig	.637 (.164) Not sig
Knee Adduction impulse (N.m.s/kg)	.626 (.363)	.675 (.362) Not sig	.913 (.477) H (45.8%)	1.11 (.384) H (77.3%)	.718 (.228) Not sig	.928 (.333) H (48.2%)
Ankle dorsiflexion Impulse (N.m.s/kg)	1.383 (.470)	1.38 (.479) Not sig	1.697 (.522) H (22.7%)	1.471 (.542) Not sig	1.443 (.517) Not sig	1.588 (.464) Not sig

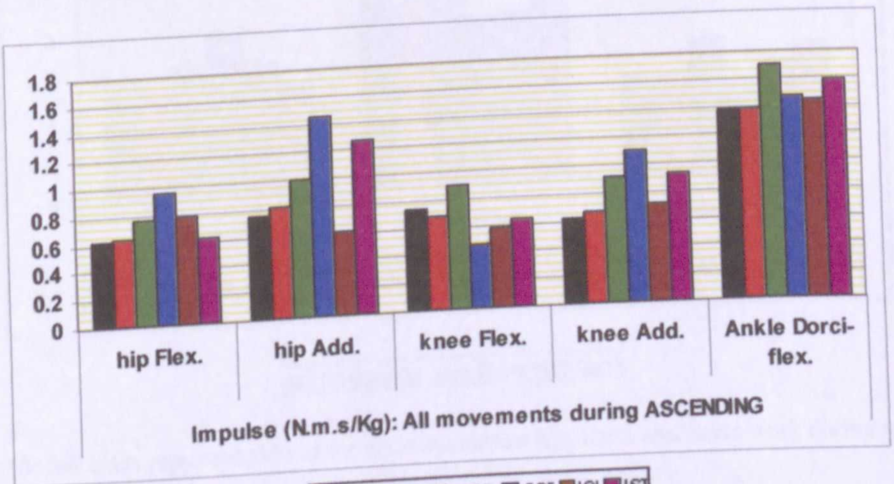


Figure 4.17: Bar chart representation of the mean maximum hip, knee, and ankle impulse during stair ascending exercises.

4.3.6 Total work

Table 4.12 and the corresponding Bar chart (**Figure 4.18**) shows the mean total work observed at the hip, knee, and ankle joints during ascending phase of all movements. At the hip, CSF generates higher work (P <0.01) compared to regular ascending. At the knee, HDB generated higher work (P <0.01), while CSF (P <0.05) and LSL (P <0.05) generated lower work, compared to regular ascending. At the ankle, HDB (P<0.05) and

LST (P<0.01) generated higher work, and CSF less the work (P<0.05), compared to regular ascending.

Table 4.12: Mean (SD) of maximum external hip, knee and ankle work during stair ascending exercises (n = 10).

	RSW	HBH	HDB	CSF	LSL	LST
Hip work (J/Kg)	**1.434 (.693)**	1.478(.659) **Not sig**	1.589(.768) **Not sig**	1.994(.856) **H (39.1%)**	1.616(.702) **Not sig**	1.323(.717) **Not sig**
Knee Work (J/Kg)	**2.324 (.604)**	2.266(.611) **Not sig**	2.882(.793) **H (24%)**	2.014(.635) **L (13.3%)**	2.058(.630) **L (11.4%)**	2.437(.501) **Not sig**
Ankle work (J/Kg)	**1.239 (.500)**	1.237(.466) **Not sig**	1.659(.645) **H (33.9%)**	1.112(.497) **L (10.3%)**	1.407(.617) **Not sig**	1.586(.479) H (28%)

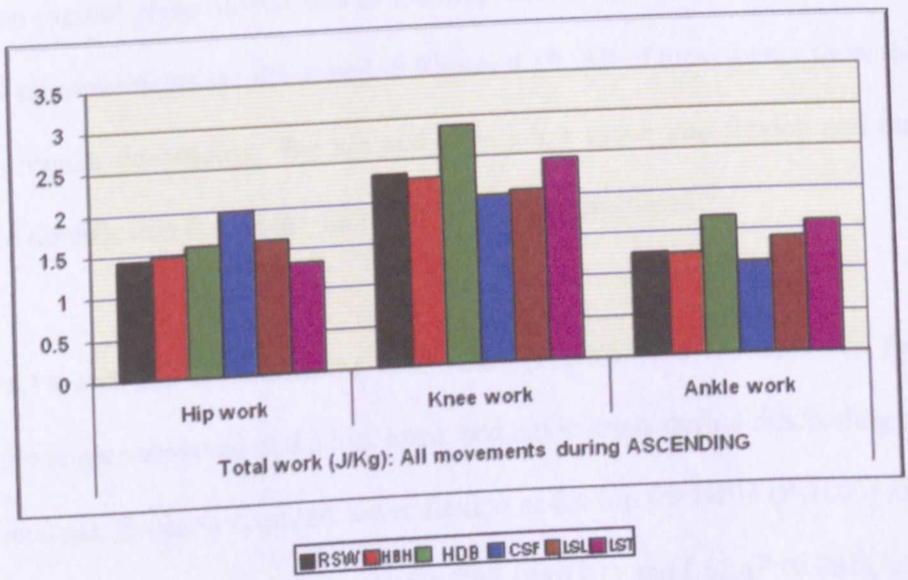


Figure 4.18: Bar chart representation of the mean maximum hip, knee, and ankle work during stair ascending exercises.

4. Staircase Exercises: Descending

4.4.1 Temporal parameters

Table 4.13 summarizes the mean cadence, foot off, stride time, and speed during the descending phase of all movements. CSF shows lower cadence (P<0.01) and velocity (P<0.01) compared to regular descending .No significant differences were found for HBH, HDB, LSL, and LST in cadence and velocity compared to RSW .Only HDB shows higher foot off(P<0.05) compared to regular descending.

Table 4.13: Mean (SD) of time parameters during stair descending exercises (n = 10).

	RSW	HBH	HDB	CSF	LSL	LST
Cadence (steps/min)	**87.2(6.8)**	87.59(5.2) **Not sig**	92.31(8.6) **Not sig**	72.39(8.1) L **(17%)**	82.48(11.9) **Not sig**	82.71(10.8) **Not sig**
Foot off (%)	**63.6(2.8)**	64.11(3.1) **Not sig**	64.98(2.8) H **(2.2%)**	62.57(2.6) **Not sig**	64.39(2.7) **Not sig**	63.48(2.7) **Not sig**
Stride time (s)	**1.39(.11)**	1.38(.083) **Not sig**	1.32(.111) **Not sig**	1.69(.198) H **(22.3%)**	1.50(.256) **Not sig**	1.48(.176) **Not sig**
Speed (m/s)	**.58(.050)**	.59(.044) Not sig	.62(.075) **Not sig**	.48(.058) L **(17.2%)**	.53(.07) **Not sig**	.55(.052) **Not sig**

4.4.2 Angles

The mean sagittal plane movements of the hip, knee, and ankle joint during descending phase of all movements are illustrated in **Figure 4.19**. All of movements show the same trend as regular descending. The hip and knee joints move into flexion and the ankle joint into dorsiflexion during the stance phase of all movements.

Table 4.14 and the corresponding Bar chart (**Figure 4.20**) summarizes the mean maximum angles observed at the hip, knee, and ankle joints during descending phase of all movements. Subjects required lower flexion at the hip for HBH ($P<0.05$) and HDB ($P<0.05$), and higher hip flexion angle for CSF ($P<0.01$) and LSL ($P<0.001$), compared to regular descending. No significant difference in the hip flexion angle for LST, as well as in the knee flexion angle for HBH, HDB, and LSL, compared to regular descending. Subjects required greater knee flexion angle for CSF ($P<0.01$) and LST ($P<0.05$), lower ankle dorsiflexion angle for CSF ($P<0.01$) and LST ($P<0.05$), and lower ankle plantarflexion angle for LST ($P<0.01$), compared to regular descending.

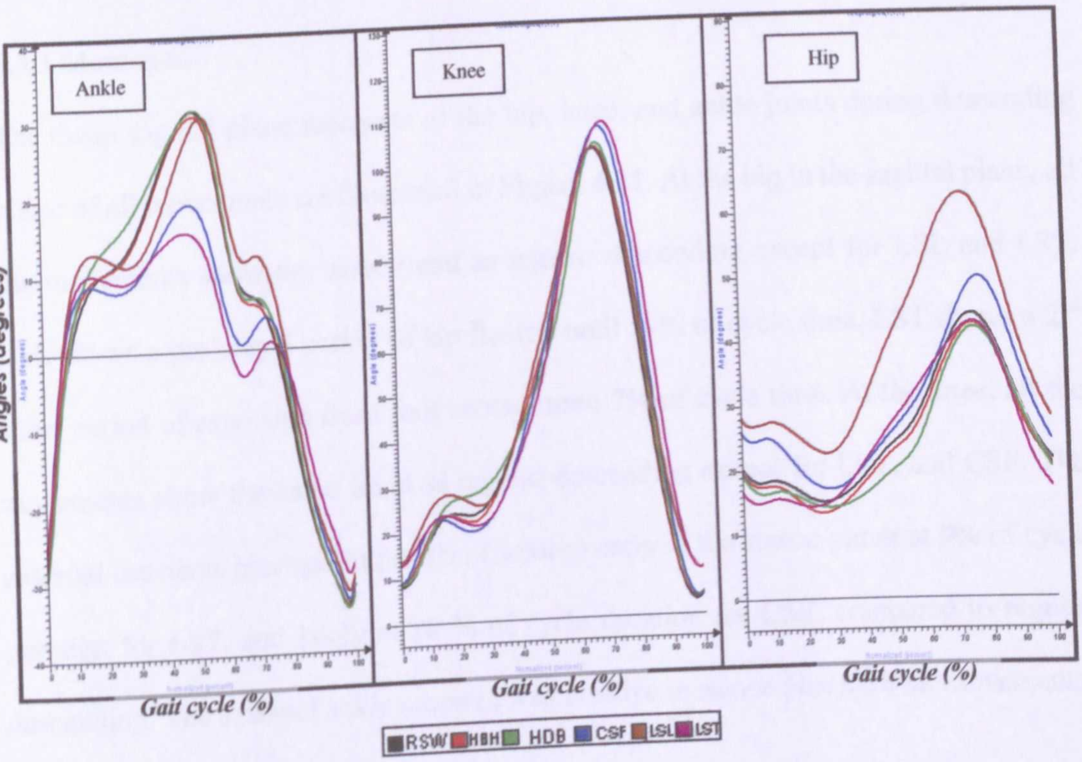


Figure 4.19: Mean sagittal plane angles of the hip, knee, and ankle joint during stair descent phase of all exercises (n = 10).

Table 4.14: Mean (SD) of maximum hip, knee and ankle angles during stair descending exercises (n = 10).

	RSW	HBH	HDB	CSF	LSL	LST
Hip flex. (degrees)	**44.32 (12.44)**	42.74 (11.7) **L (3.6%)**	42.53 (11.7) **L (4%)**	50.09 (12.0) **H (13%)**	63.1 (10.3) **H (42.4%)**	43.51 (12.4) **Not sig**
Knee flex. (degrees)	**104.83 (7.72)**	105.08 (6.58) **Not sig**	106.48 (5.74) **Not sig**	110.21 (6.21) **H (12%)**	104.13 (7.03) **Not sig**	110.21 (7.8) **H (12%)**
Ankle dorsi-flex. (degrees)	**32.24 (7.13)**	32.15 (6.94) **Not sig**	32.28 (5.86) **Not sig**	21.63 (5.49) **L (33%)**	30.55 (6.57) **Not sig**	22.68 (7.43) **L (29.7%)**
Ankle plantar-flex. (degrees)	**33.60 (5.49)**	33.97 (4.06) **Not sig**	34.26 (5.40) **Not sig**	33.08 (4.97) **Not sig**	32.04 (6.20) **Not sig**	30.36 (7.56) **L (9.6%)**

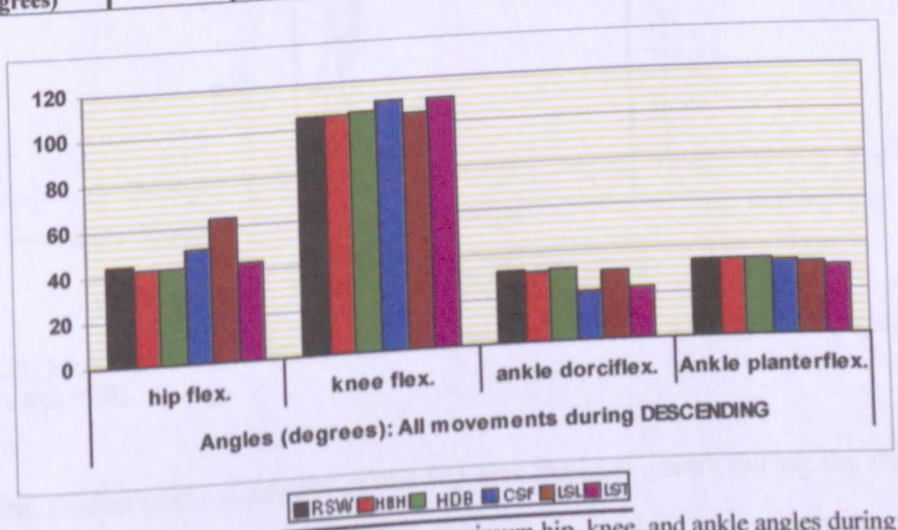


Figure 4.20: Bar chart representation of the mean maximum hip, knee, and ankle angles during stair descending exercises.

4.4.3 Moments

The mean sagittal plane moments of the hip, knee, and ankle joints during descending phase of all movements are illustrated in **Figure 4.21**. At the hip in the sagittal plane, all the movements show the same trend as regular descending except for LSL and LST. LSL shows a prolonged period of hip flexion until 59% of cycle time. LST shows a 2nd short period of extension from foot contact until 7% of cycle time. At the knee, all the movements show the same trend as regular descending except for LST, and CSF. The external moments changed to positive (flexion) early in the stance phase at 9% of cycle duration for LST, and lately at 28 % of cycle duration for CSF, compared to regular descending. The external ankle moment was positive in stance phase for all movements, creating an external dorsiflexion moment.

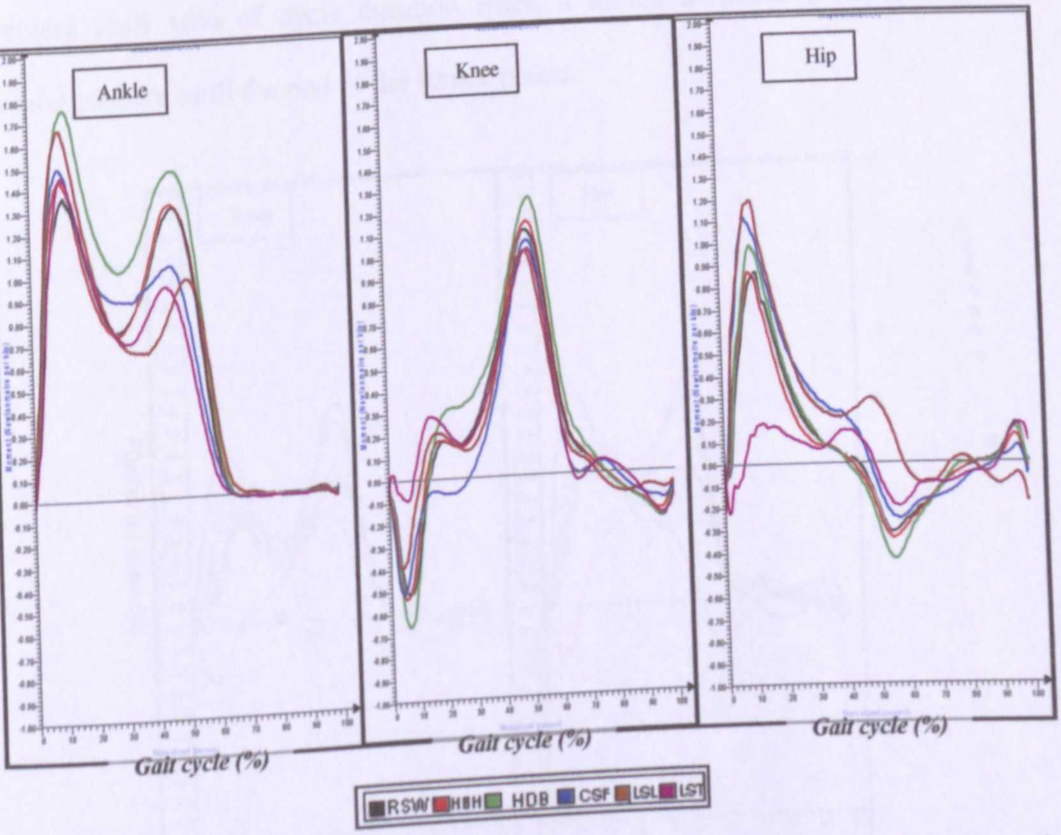


Figure 4.21: Mean sagittal plane moments of the hip, knee, and ankle joint during stair descent phase of all exercises (n = 10).

The mean frontal plane moments of the hip and the knee joints during the descending phase of all movements are illustrated in **figure 4.22**. The external hip moments were positive in stance phase during all movements, creating an external adduction moment, except for LSL and LST. For LSL, the external hip moment were positive from the beginning of the movement until 52% of cycle duration it turned to negative, creating an external abduction moment. For LST, the external hip moment was negative (abduction), from the beginning of the movement until 12% of cycle duration when it turned to positive (adduction) and remained positive until the end of stance phase. At the knee as well, the external moments were positive in stance phase during all movements, creating an external adduction moment except for LSL and LST. For LSL, the external knee moment was positive from the beginning of the movement until 59% of cycle duration when it turned negative, creating an external abduction moment. For LST, the external hip moment was negative (abduction), from the beginning of the movement until 16% of cycle duration when it turned to positive (adduction) and remained positive until the end of the stance phase.

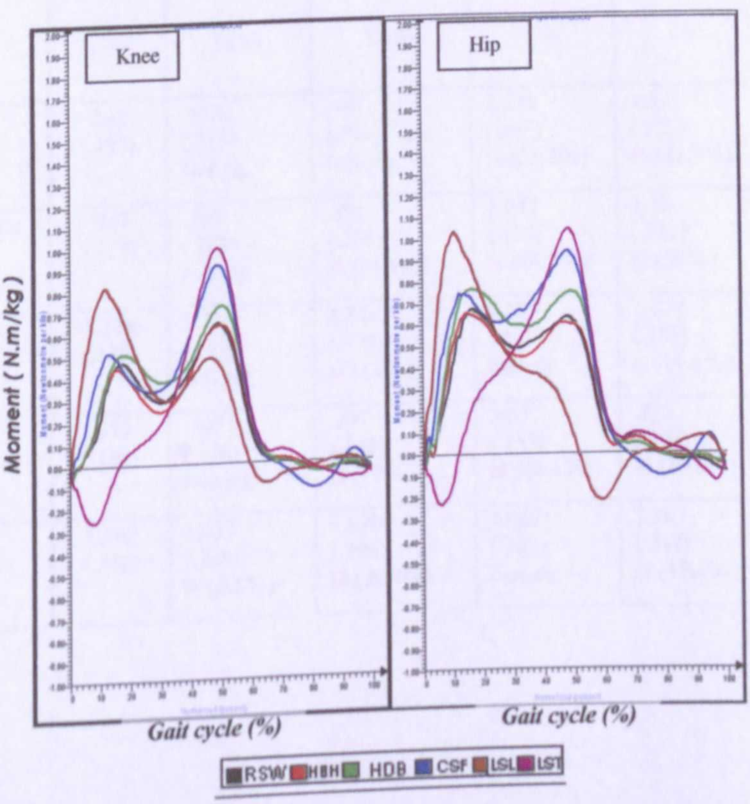


Figure 4.22: Mean frontal plane moments of the hip and knee joint during stair descent phase of all exercises (n = 10).

Table 4.15 and the corresponding Bar chart (**Figure 4.23**) shows the mean maximum external moments observed at the hip, knee, and ankle joints during descending phase of all movements. At the hip joint, subjects demonstrated greater external hip flexion moments for CSF (P <0.05) and LSL (P <0.01), lower hip flexion moments for LST (P<0.001), and greater hip adduction moments for HDB (P<0.05), CSF (P<0.01), LSL (P<0.01) and LST (P<0.001), compared to regular stair descending. At the knee, Subjects' demonstrated greater knee flexion moments for HDB (P<0.05) and lower knee flexion moments for LSL (P<0.01) and LST (P<0.05), compared to regular stair descending. In the frontal plane, subjects show greater knee adduction moment for HDB (P<0.01), CSF (P<0.001), LSL (P<0.01), and LST (P<0.001), compared to regular stair ascending. The ankle dorsiflexion moment was higher for HBH (P<0.05), HDB (P<0.001), and LSL (P<0.05) compared to regular stair descending.

Table 4.15: Mean (SD) of maximum external hip, knee and ankle moments during stair descending exercises (n = 10).

	RSW	HBH	HDB	CSF	LSL	LST
Hip flexion (N.m/kg)	**.918 (.195)**	.9380 (.313) **Not sig**	.961 (.270) **Not sig**	1.228 (.292) **H (33.8%)**	1.31 (.328) **H (42.7%)**	.342 (.134) **L (62.7%)**
Hip adduction (N.m/kg)	**.747 (.177)**	.766 (.228) **Not sig**	.895 (.216) **H (91.8%)**	1.047 (.155) **H (40.2%)**	1.12 (.222) **H (50%)**	1.077 (.079) **H (44.2%)**
Knee flexion (N.m/kg)	**1.164 (.135)**	1.206 (.119) **Not sig**	1.304 (.176) **H (12%)**	1.108 (.138) **Not sig**	1.029 (.149) **L (11.6%)**	1.046 (.150) **L (10.1%)**
Knee Adduction (N.m/kg)	**.673 (.151)**	.707 (.170) **Not sig**	.787 (.148) **H (17%)**	.965 (.153) **H (43.4%)**	.872 (.197) **H (29.6%)**	1.021 (.171) **H (51.7%)**
Ankle dorsiflexion (N.m/kg)	**1.509 (.218)**	1.637 (.268) **H (8.5%)**	1.820 (.296) **H (20.6%)**	1.622 (.262) **Not sig**	1.767 (.247) **H (17.1%)**	1.52 (.257) **Not sig**

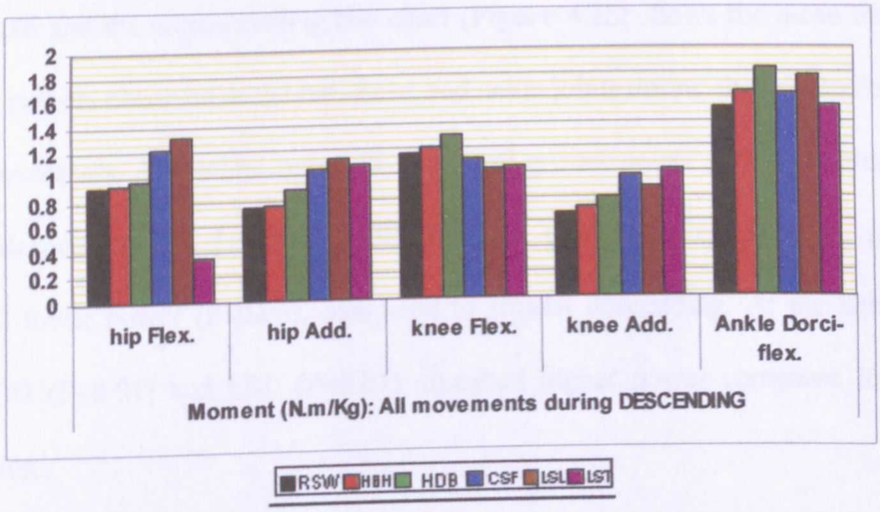


Figure 4.23: Bar chart representation of the mean maximum hip, knee, and ankle moments during stair descending exercises.

4.4.4 Powers

The mean powers at the hip, knee, and ankle joints during descending phase of all movements are illustrated in **Figure 4.24**. All the movements showed the same power production trend as regular ascending at the hip, knee, and ankle. However, LSL did not show the phase of energy production at the hip in the late stance.

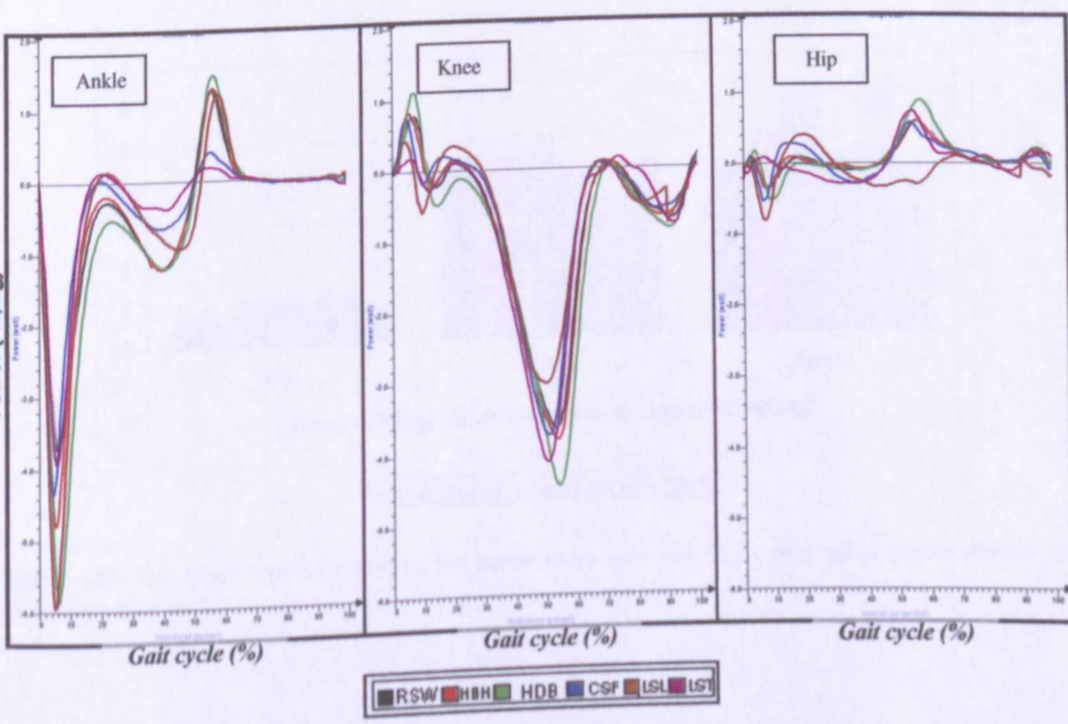


Figure 4.24: Mean power of the hip, knee, and ankle joint during stair descent phase of all exercises (n = 10).

Table 4.16 and the corresponding Bar chart (**Figure 4.25**) shows the mean maximum absolute powers observed at the hip, knee, and ankle joints during the descending phase of all movements. At the hip, only LSL produced greater power ($P<0.05$) compared to regular descending. At the knee, HDB absorbed greater power ($P<0.01$), and LSL absorbed lower power ($P<0.05$), compared to regular descending. At the ankle joint, both HDB ($P<0.01$) and LSL ($P<0.01$) absorbed higher power compared to regular descending.

Table 4.16: Mean (SD) of maximum external hip, knee and ankle power during stair descending exercises (n = 10).

	RSW	HBH	HDB	CSF	LSL	LST
Hip power (W/Kg)	**.82 (.32)**	.757 (.267) **Not sig**	1.054 (.378) **Not sig**	1.063 (.590) **Not sig**	1.20 (.512) **H (46.3%)**	.872 (.223) **Not sig**
Knee Power (W/Kg)	**4.28 (1.06)**	4.590 (.945) **Not sig**	5.044 (.652) **H (17.9%)**	3.892 (.650) **Not sig**	3.423 (.678) **L (20%)**	4.313 (.639) **Not sig**
Ankle power (W/Kg)	**4.01 (1.71)**	4.982 (2.637) **Not sig**	5.954 (2.32) **H (48.5%)**	4.525 (2.091) **Not sig**	6.366 (1.805) **H (58.8%)**	4.143 (1.764) **Not sig**

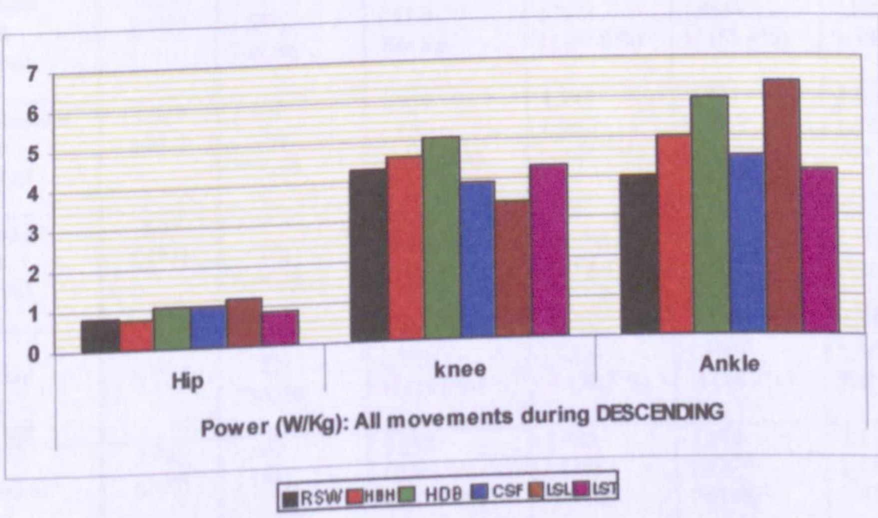


Figure 4.25: Bar chart representation of the mean maximum hip, knee, and ankle power during stair descending exercises.

4.4.5 Impulses

Table 4.17 and the corresponding Bar chart (**Figure 4.26**) shows the mean maximum impulses observed at the hip, knee, and ankle joints during the descending phase of all movements. At the hip, the subjects demonstrated greater hip flexion impulse for CSF ($P < 0.01$) and LSL ($P < 0.01$), and greater adduction impulse HDB ($P < 0.01$) and CSF ($P < 0.01$), compared to regular descending. At the knee, subjects demonstrated a greater knee flexion impulse for HDB ($P < 0.001$), a lower knee flexion impulse for CSF ($P < 0.05$), and a greater knee adduction impulse for HDB ($P < 0.001$), CSF ($P < 0.001$), and LSL ($P < 0.05$), compared to regular descending. At the ankle, HDB produce significantly higher dorsiflexion impulse ($P<0.001$), and lower dorsiflexion impulse for LST ($P<0.05$), compared to regular descending.

Table 4.17: Mean (SD) of maximum external hip, knee and ankle impulse during stair descending exercises (n = 10).

	RSW	HBH	HDB	CSF	LSL	LST
Hip flexion Impulse (N.m.s/kg)	**.624 (.342)**	.586 (.357) **Not sig**	.739 (.532) **Not sig**	.860 (.370) **H (37.8%)**	.970 (.461) **H (55.4%)**	.269 (.188) **L (56.9%)**
Hip adduction Impulse (N.m.s/kg)	**1.039 (.342)**	1.030 (.354) **Not sig**	1.259 (.370) **H (21.2%)**	1.395 (.306) **H (34.3%)**	1.023 (.366) **Not sig**	1.035 (.238) **Not sig**
Knee flexion impulse (N.m.s/kg)	**.907 (.191)**	.923 (.172) **Not sig**	1.123 (.262) **H (23.8%)**	.740 (.1579) **L (18.4%)**	.829 (.248) **Not sig**	.892 (.313) **Not sig**
Knee Adduction impulse (N.m.s/kg)	**.791 (.291)**	.781 (.327) **Not sig**	.932 (.315) **H (17.8%)**	1.032 (.256) **H (30.5%)**	.939 (.380) **H (18.7%)**	.755 (.188) **Not sig**
Ankle dorsiflexion Impulse (N.m.s/kg)	**2.006 (.547)**	2.061 (.554) **Not sig**	2.557 (.776) **H (27.5%)**	1.980 (.528) **Not sig**	1.976 (.479) **Not sig**	1.734 (.437) **L (13.6%)**

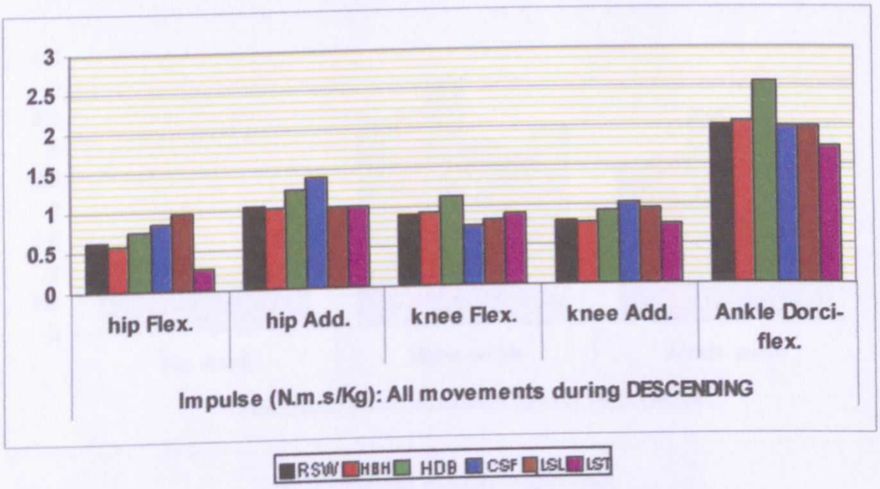


Figure 4.26: Bar chart representation of the mean maximum hip, knee, and ankle impulse during stair descending exercises.

4.4.6 Total work

Table 4.18 and the corresponding Bar chart (**Figure 4.27**) shows the mean total work observed at the hip, knee and ankle joint during descending phase of all movements. At the hip, LSL generates higher work ($P < 0.05$) compared to regular descending. At the knee, HDB generates higher work ($P < 0.01$), and CSF ($P < 0.05$) and LSL ($P < 0.01$) generates lower work, compared to regular descending. At the ankle, HDB ($P < 0.001$) generates higher work, and CSF ($P < 0.01$) and LST ($P < 0.01$) generate lower work, compared to regular descending.

Table 4.18: Mean (SD) of maximum external hip, knee and ankle work during stair descending exercises (n = 10).

	RSW	HBH	HDB	CSF	LSL	LST
Hip Work (J/Kg)	.725 (.388)	.670(.295) **Not sig**	.854(.286) **Not sig**	.876(.387) **Not sig**	.974(.467) **H (34.3%)**	.745(.224) **Not sig**
Knee Work (J/Kg)	3.359 (1.004)	3.504(.941) **Not sig**	4.021(.920) **H (19.7%)**	2.937(.613) **L (12.6%)**	2.756(.822) **L (18%)**	3.227(.725) **Not sig**
Ankle work (J/Kg)	2.556 (.887)	2.695(.885) **Not sig**	3.439(1.250) **H (34.5%)**	1.781(.780) **L (30.3%)**	2.729(1.044) **Not sig**	1.557(.378) **L (39.1%)**

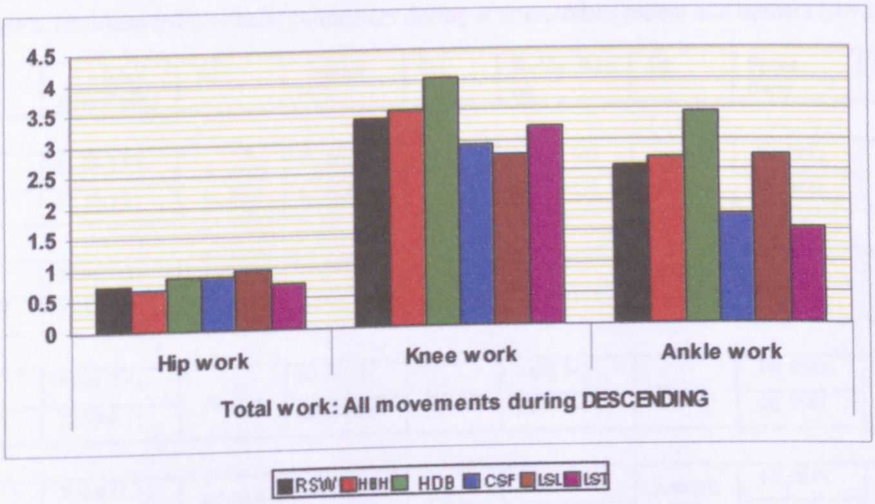


Figure 4.27: Bar chart representation of the mean maximum hip, knee, and ankle work during stair descending exercises.

4.5 Staircase Exercises: Ascending versus descending movements

4.5.1 Temporal parameters

Table 4.19 summarizes the mean cadence, foot off, stride time, and speed during ascent and descent phases of all movements. Stride time was greater during ascent compared to descent for HBH ($p<0.05$), HDB ($p<0.05$), and LSL ($p<0.01$). Both HDB ($p<0.05$) and LST ($p<0.01$) shows significantly higher foot off during ascent compared to descent. The speed of descending was higher compared to descending for all movements [HBH ($p<0.001$), HDB ($p<0.01$), CSF ($p<0.01$), LSL ($p<0.001$), LST ($p<0.05$)]. The cadence was greater during descent for HBH ($P<0.05$), HDB ($P<0.05$), and LSL ($P<0.001$), compared to ascent.

Table 4.19: Mean (SD) of time parameters during stair exercises ascent and descent (n =10).

	Cadence (steps/min.)	Sig.	Foot off (%)	Sig.	Stride time (s)	Sig.	Speed (m/s)	Sig.
HBH								
ASCENT	80.88(4.8)	**DE>AS (8.3%)**	62.26(1.4)	Not sig	1.49(.086)	**AS>DE (7.4%)**	.48(.024)	**DE>AS (22.9%)**
DESCENT	87.59(5.2)		64.11(3.1)		1.38(.083)		.59(.044)	
HDB								
ASCENT	86.58(7.3)	**DE>AS (6.6%)**	62.61(1.5)	**DE>AS (3.8%)**	1.4(.114)	**AS>DE (6.1%)**	.51(.049)	**DE>AS (21.6%)**
DESCENT	92.31(8.6)		64.98(2.8)		1.32(.111)		.62(.075)	
CSF								
ASCENT	73.04(7.4)	Not sig	61.9(2.2)	Not sig	1.67(.51)	Not sig	.44(.054)	**DE>AS (9.1%)**
DESCENT	72.39(8.1)		62.57(2.6)		1.69(.198)		.48(.058)	
LSL								
ASCENT	75.85(11.1)	**DE>AS (8.7%)**	64.2(3.7)	Not sig	1.63(.294)	**AS>DE (8%)**	.44(.064)	**DE>AS (20.5%)**
DESCENT	82.48(11.9)		64.39(2.7)		1.50(.256)		.53(.07)	
LST								
ASCENT	79.21(5.4)	Not sig	59.66(1.7)	**DE>AS (6.4%)**	1.53(.102)	Not sig	.52(.036)	**DE>AS (5.8%)**
DESCENT	82.71(10.8)		63.48(2.7)		1.48(.176)		.55(.052)	

4.5.2 Angles

Table 4.20 and the corresponding Bar chart (**Figure 4.28**) summarize the mean maximum angles observed at the hip, knee, and ankle joints during stair ascent and descent phases of all movements. Subjects required a greater flexion at the hip during ascending for all movements [HBH ($p<0.001$), HDB ($p<0.001$), CSF ($p<0.001$), LSL ($p<0.001$), LST ($p<0.001$)] compared to descending. There were no significant differences in knee flexion angle between ascending and descending phases of all movements. At the ankle joint, subjects required a greater ankle dorsiflexion angle during descending for HBH ($p<0.001$), HDB ($p<0.001$), and LSL ($p<0.05$) compared to ascending. All the movements showed a greater ankle plantarflexion angle during descending [HBH ($p<0.001$), HDB ($p<0.001$), CSF ($p<0.001$), LSL ($p<0.01$), LST ($p<0.05$)] compared to ascending.

Table 4.20: Mean (SD) of maximum hip, knee and ankle angles during stair exercises ascent and descent (n = 10).

	Hip Flex. (degrees)	Sig.	Knee Flex. (degrees)	Sig.	Ankle dorsi-flex. (degrees)	Sig.	Ankle plantar-flex. (degrees)	Sig.
HBH								
ASCENT	71.36(12.7)	**AS>DE** (67%)	105.39(5.83)	Not sig	20.93(3.25)	**DE>AS** (50.4%)	2.217(5.32)	**DE>AS** (53.2%)
DESCENT	42.74(11.7)		105.08(6.58)		31.47 (6.94)		33.97(4.06)	
HDB								
ASCENT	69.69(11.5)	**AS>DE** (63.9%)	108.05(6.76)	Not sig	21.19(2.54)	**DE>AS** (52.3%)	26.39(6.71)	**DE>AS** (29.8%)
DESCENT	42.53(11.7)		106.48(5.74)		32.28(5.86)		34.26(5.40)	
CSF								
ASCENT	74.33(11.3)	**AS>DE** (48.4%)	107.59(8.82)	Not sig	20.67(3.98)	Not sig	23.5(7.56)	**DE>AS** (40.8%)
DESCENT	50.09(12.0)		110.21(6.21)		21.63(5.49)		33.08(4.97)	
LSL								
ASCENT	74.66(11.2)	**AS>DE** (18.3%)	99.14 (8.9)	**DE>AS** (5%)	27.78(4.40)	**DE>AS** (10%)	23.69(7.05)	**DE>AS** (35.2%)
DESCENT	63.1(10.3)		104.13(7.03)		30.55(6.57)		32.04(6.20)	
LST								
ASCENT	66.87(11.8)	**AS>DE** (53.7%)	115.54(6.9)	Not sig	24.25(4.69)	Not sig	21.62(9.77)	**DE>AS** (40.4%)
DESCENT	43.51(12.4)		110.21(7.8)		22.68(7.43)		30.36(7.56)	

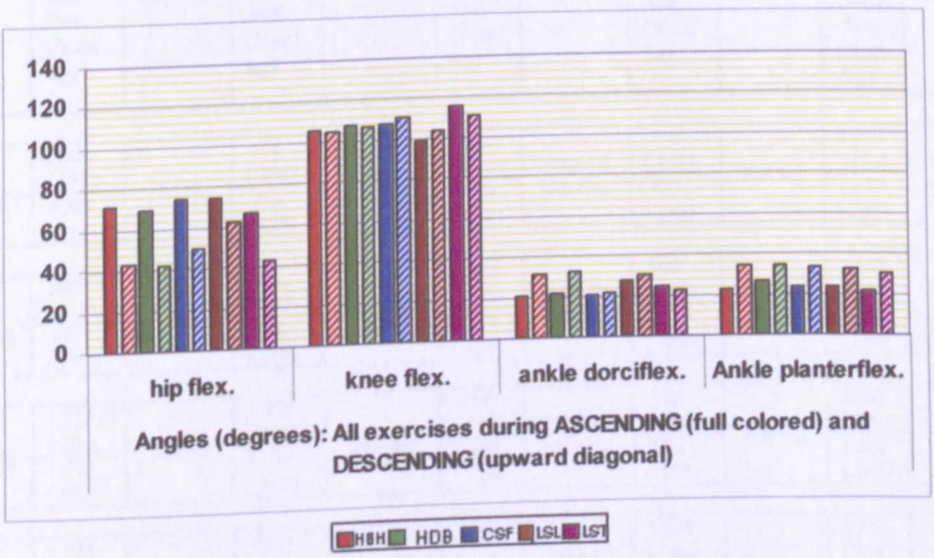


Figure 4.28: Bar chart representation of the mean maximum hip, knee, and ankle angles during stair exercises ascent and descent.

4.5.3 Moments

Table 4.21 and the corresponding Bar chart (**Figure 4.29**) shows the mean maximum external moments observed at the hip, knee, and ankle joints during stair ascent and descent phases of all movements. At the hip, subjects demonstrated a greater external hip flexion moment during descending for LSL ($P < 0.05$), and lower external hip flexion moment for LST ($P < 0.01$), compared to ascending phase. The external hip adduction moments were greater during descending for LSL ($P < 0.001$), and lower for LST ($P < 0.01$), compared to ascending phase. At the knee, all the movements required higher flexion moment during descending [HBH ($p<0.01$), HDB ($p<0.01$), CSF ($p<0.001$), LSL ($p<0.01$)] except LST, which showed no significant difference between ascending and descending. The external knee adduction moments were greater during descending for LST ($P < 0.05$), and lower for HDB ($P < 0.05$), compared to ascending phase. At the ankle, all the movements required higher dorsiflexion moment during descending [HBH ($p<0.05$), HDB ($p<0.05$), CSF ($p<0.01$), LSL ($p<0.01$)] except LST, which shows no significant difference between ascending and descending.

Table 4.21: Mean (SD) of maximum external hip, knee and ankle moments during stair exercises ascent and descent (n = 10).

	Hip Flex. (N.m/kg)	Sig.	**Hip Add. (N.m/kg)**	Sig.	**Knee Flex. (N.m/kg)**	Sig.	**Knee Add. (N.m/kg)**	Sig.	**Ankle Dorsi-flex. (N.m/kg)**	Sig.
HBH										
ASCENT	.880 (.191)	Not sig	.604 (.256)	Not sig	.884 (.263)	**DE>AS** (36.4%)	.720 (.131)	Not sig	1.277 (.194)	**DE>AS** (28.2%)
DESCENT	.9380 (.313)		.766 (.228)		1.206 (.119)		.707 (.170)		1.637 (.268)	
HDB										
ASCENT	.945 (.213)	Not sig	.724 (.259)	Not sig	1.052 (.297)	**DE>AS** (24%)	.907 (.165)	**AS>DE** (15.2%)	1.452 (.173)	**DE>AS** (25.3%)
DESCENT	.961 (.270)		.895 (.216)		1.304 (.176)		.787 (.148)		1.820 (.296)	
CSF										
ASCENT	1.272 (.282)	Not sig	1.179 (.287)	Not sig	.643 (.271)	**DE>AS** (72.3%)	.975 (.144)	Not sig	1.243 (.291)	**DE>AS** (38.5%)
DESCENT	1.228 (.292)		1.047 (.155)		1.108 (.138)		.965 (.153)		1.622 (.262)	
LSL										
ASCENT	1.038 (.202)	**DE>AS** (26.2%)	.641 (.209)	**DE>AS** (74.7%)	.719 (.255)	**DE>AS** (43.1%)	1.009 (.206)	Not sig	1.357 (.249)	**DE>AS** (30.2%)
DESCENT	1.31 (.328)		1.12 (.222)		1.029 (.149)		.872 (.197)		1.767 (.247)	
LST										
ASCENT	.642 (.262)	**AS>DE** (87.7%)	1.423 (.173)	**AS>DE** (32.1%)	.965 (.273)	Not sig	.849 (.120)	**DE>AS** (20.3%)	1.278 (.220)	Not sig
DESCENT	.342 (.134)		1.077 (.079)		1.046 (.150)		1.021 (.171)		1.52 (.257)	

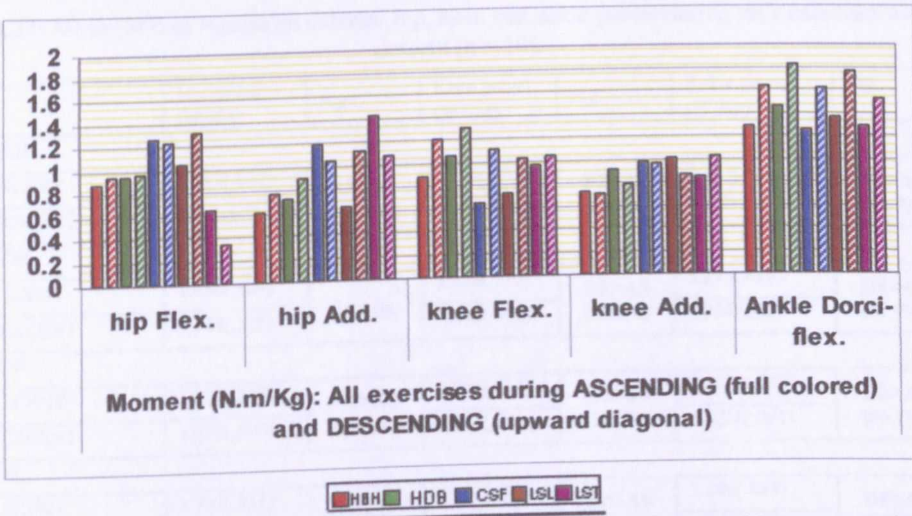


Figure 4.29: Bar chart representation of the mean maximum hip, knee, and ankle moments during stair exercises ascent and descent.

4.5.4 Powers

Table 4.22 and the corresponding Bar chart (**Figure 4.30**) shows the mean maximum absolute powers observed at the hip, knee, and ankle joints during stair ascent and descent phases of all movements. At the hip, both HBH ($P<0.001$) and CSF ($P<0.05$) required greater power during ascending compared to descending. At the knee, all the movements required higher power during descending [HBH ($p<0.01$), HDB ($p<0.01$), CSF ($p<0.001$), LSL ($p<0.01$), LST ($p<0.05$)] compared to ascending. At the ankle, all the movements required higher power during descending [HBH ($p<0.05$), HDB ($p<0.01$), CSF ($p<0.05$), LSL ($p<0.001$)] except LST, which shows no significant difference between ascending and descending.

Table 4.22: Mean (SD) of maximum external hip, knee and ankle power during stair exercises ascent and descent (n = 10).

	Hip power (W/Kg)	Sig.	Knee power (W/Kg)	Sig.	Ankle power (W/Kg)	Sig.
HBH						
ASCENT	1.512(.450)	**AS>DE (99.7%)**	2.719(.607)	**DE>AS (68.8%)**	2.794(.767)	**DE>AS (78.3%)**
DESCENT	.757(.267)		4.590(.945)		4.982(2.637)	
HDB						
ASCENT	1.456(.403)	Not sig	2.878(.779)	**DE>AS (75.3%)**	3.273(.619)	**DE>AS (81.9%)**
DESCENT	1.054(.378)		5.044(.652)		5.954(2.32)	
CSF						
ASCENT	1.957(.560)	**AS>DE (84.1%)**	2.548(.714)	**DE>AS (52.7%)**	2.432(1.058)	**DE>AS (86.1%)**
DESCENT	1.063(.590)		3.892(.650)		4.525(2.091)	
LSL						
ASCENT	1.720(.731)	Not sig	2.579(.637)	**DE>AS (32.7%)**	3.186(.863)	**DE>AS (99.8%)**
DESCENT	1.20(.512)		3.423(.678)		6.366(1.805)	
LST						
ASCENT	1.153(.566)	Not sig	2.728(.665)	**DE>AS (58.1%)**	3.028(.970)	Not sig
DESCENT	.872(.223)		4.313(.639)		4.143(1.764)	

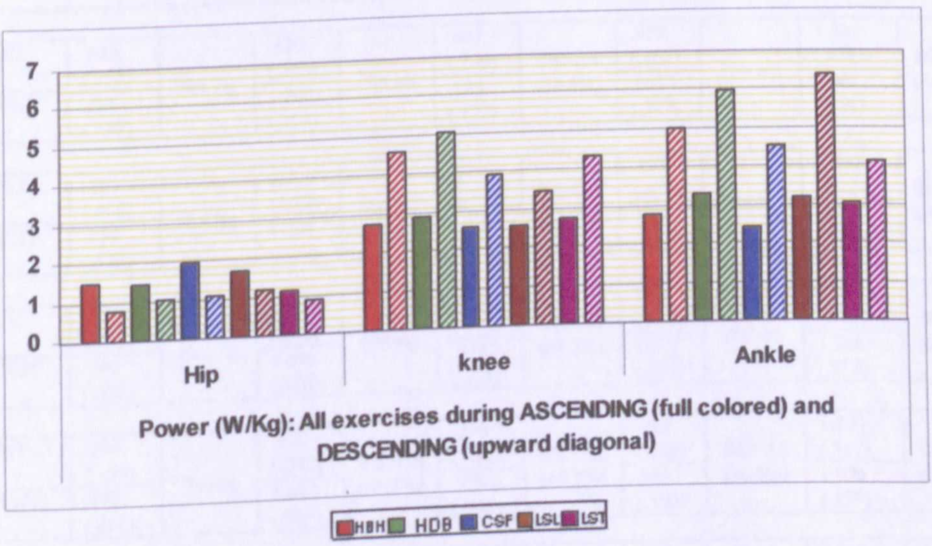


Figure 4.30: Bar chart representation of the mean maximum hip, knee, and ankle power during stair exercises ascent and descent.

4.5.5 Impulses

Table 4.23 and the corresponding Bar chart (**Figure 4.31**) shows the mean maximum impulses observed at the hip, knee, and ankle joints during stair ascent and descent phases of all movements. At the hip, subjects demonstrated a greater hip flexion impulse during ascending for LST (P <0.01), compared to descending phase. The hip adduction impulse was greater during descending for LSL (P <0.01) compared to ascending phase. At the knee, all the movements required higher flexion moment during descending [HBH ($p<0.05$), HDB ($p<0.05$), CSF ($p<0.01$), LSL ($p<0.01$), LST ($p<0.05$)]. The knee adduction impulse was greater during descending for LSL ($P<0.05$) compared to ascending phase. At the ankle, all the movements required higher dorsiflexion impulse during descending [HBH ($p<0.001$), HDB ($p<0.001$), CSF ($p<0.01$), LSL ($p<0.001$)] except LST, which shows no significant difference between ascending and descending.

Table 4.23: Mean (SD) of maximum external hip, knee and ankle impulse during stair exercises ascent and descent (n = 10).

	Hip Flex. **(N.m.s/kg)**	Sig.	Hip Add. **(N.m.s/kg)**	Sig.	Knee Flex. **(N.m.s/kg)**	Sig.	Knee Add. **(N.m.s/kg)**	Sig.	Ankle Dorsi-flex. **(N.m.s/kg)**	Sig.
HBH										
ASCENT	.643 (.297)	Not sig	.820 (.545)	Not sig	.687 (.230)	**DE>AS** (34.4%)	.675 (.362)	Not sig	1.38 (.479)	**DE>AS** (49.3%)
DESCENT	.586 (.357)		1.030 (.354)		.923 (.172)		.781 (.327)		2.061 (.554)	
HDB										
ASCENT	.764 (.408)	Not sig	1.004 (.639)	Not sig	.894 (.243)	**DE>AS** (25.6%)	.913 (.477)	Not sig	1.697 (.522)	**DE>AS** (50.7%)
DESCENT	.739 (.532)		1.259 (.370)		1.123 (.262)		.932 (.315)		2.557 (.776)	
CSF										
ASCENT	.953 (.303)	Not sig	1.454 (.648)	Not sig	.459 (.277)	**DE>AS** (61.2%)	1.11 (.384)	Not sig	1.471 (.542)	**DE>AS** (37.2%)
DESCENT	.860 (.370)		1.395 (.306)		.740 (.157)		1.032 (.256)		1.980 (.528)	
LSL										
ASCENT	.786 (.198)	Not sig	.616 (.256)	**DE>AS** (66.1%)	.579 (.216)	**DE>AS** (43.2%)	.718 (.228)	**DE>AS** (30.8%)	1.443 (.517)	**DE>AS** (36.9%)
DESCENT	.970 (.461)		1.023 (.366)		.829 (.248)		.939 (.380)		1.976 (.479)	
LST										
ASCENT	.627 (.395)	**AS>DE** (33.1%)	1.259 (.428)	Not sig	.637 (.164)	**DE>AS** (40%)	.928 (.333)	Not sig	1.588 (.464)	Not sig
DESCENT	.269 (.188)		1.035 (.238)		.892 (.313)		.755 (.188)		1.734 (.437)	

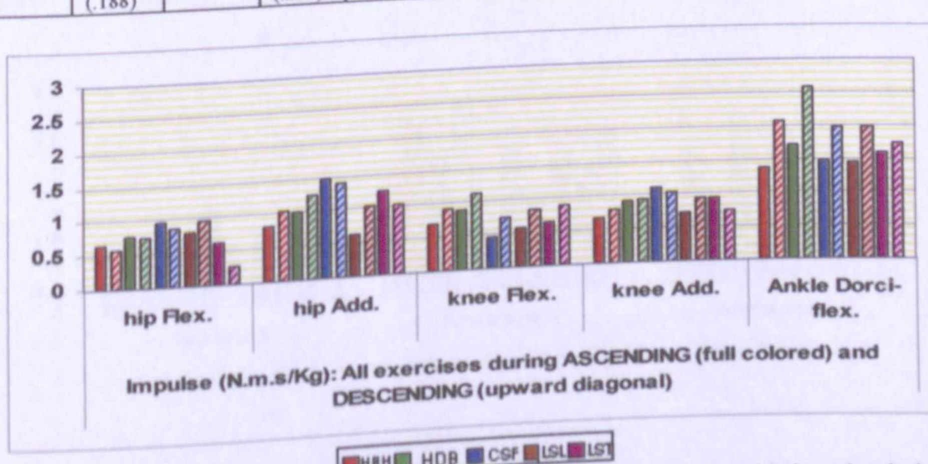


Figure 4.31: Bar chart representation of the mean maximum hip, knee, and ankle impulse during stair exercises ascent and descent.

4.5.6 Total work

Table 4.24 and the corresponding Bar chart (**Figure 4.32**) shows the mean maximum total work observed at the hip, knee, and ankle joints during stair ascent and descent phases of all movements. At the hip, all the movements required higher work during ascending [HBH ($p<0.001$), HDB ($p<0.01$), CSF ($p<0.001$), LSL ($p<0.01$), LST ($p<0.01$)] compared to descending. At the knee, all the movements required higher work during descending [HBH ($p<0.01$), HDB ($p<0.001$), CSF ($p<0.001$), LSL ($p<0.01$), LST ($p<0.01$)] compared to ascending. At the ankle, all the movements required higher work during descending [HBH ($p<0.001$), HDB ($p<0.001$), CSF ($p<0.05$), LSL ($p<0.001$)] except for LST, which showed no significant difference between ascending and descending.

Table 4.24: Mean (SD) of maximum external hip, knee and ankle work during stair exercises ascent and descent (n = 10).

	Hip work (J/Kg)	Sig.	Knee work (J/Kg)	Sig.	Ankle work (J/Kg)	Sig.
HBH						
ASCENT	1.478(.659)	**AS>DE** (120.6%)	2.266(.611)	**DE>AS** (54.6%)	1.237(.466)	**DE>AS** (117.9%)
DESCENT	.670(.295)		3.504(.941)		2.695(.885)	
HDB						
ASCENT	1.589(.768)	**AS>DE** (86.1%)	2.882(.793)	**DE>AS** (39.5%)	1.659(.645)	**DE>AS** (107.3%)
DESCENT	.854(.286)		4.021(.920)		3.439(1.250)	
CSF						
ASCENT	1.994(.856)	**AS>DE** (127.6%)	2.014(.635)	**DE>AS** (45.8%)	1.112(.497)	**DE>AS** (60.2%)
DESCENT	.876(.387)		2.937(.613)		1.781(.780)	
LSL						
ASCENT	1.616(.702)	**AS>DE** (66%)	2.058(.630)	**DE>AS** (33.9%)	1.407(.617)	**DE>AS** (94%)
DESCENT	.974(.467)		2.756(.822)		2.729(1.044)	
LST						
ASCENT	1.323(.717)	**AS>DE** (77.6%)	2.437(.501)	**DE>AS** (32.4%)	1.586(.479)	Not sig
DESCENT	.745(.224)		3.227(.725)		1.557(.378)	

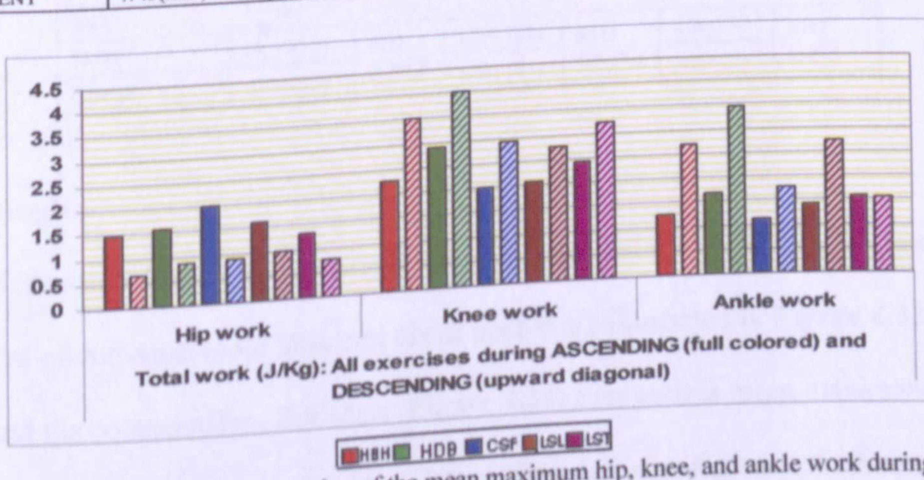


Figure 4.32: Bar chart representation of the mean maximum hip, knee, and ankle work during stair exercises ascent and descent

4.6 Slim Versus Obese people: Ascending

4.6.1 Temporal parameters

Table 4.25 summarizes the mean foot off, stride time, and speed during ascent phase of all movements for obese and slim people. Obese people require longer Stride time for RW ($p<.05$), HBH ($p<.05$), HDB ($p<.05$), CSF ($P<.05$), LSL ($p<.05$), and LST ($p<.001$) compared to slim people. Obese people show greater foot off for all movements [RW ($p<.05$), HBH ($p<.01$), HDB ($p<.05$), CSF ($P<.05$), LSL ($p<.05$), LST ($p<.001$)]. The speed was higher for slim people compared to obese people for all movements [RW ($p<.05$), HBH ($p<.01$), HDB ($p<.01$), CSF ($p<.05$), LSL ($p<.01$), LST ($p<.001$)].

Table 4.25: Mean (SD) of time parameters during stair ascending of all movements for slim (n = 10) and obese (n = 10) people.

	Foot off (%)	Sig.	Stride time (s)	Sig.	Speed (m/s)	Sig.
RW						
SLIM	62.4(1.7)	S<O (3%)	1.5(.089)	S<O (13.3%)	.49(.037)	S>O (16.7%)
OBESE	64.3(2.3)		1.70(.267)		.42(.063)	
HBH						
SLIM	62.26(1.4)	S<O (4.5%)	1.49(.086)	S<O (13.4%)	.48(.024)	S>O (14.3%)
OBESE	65.08(1.9)		1.69(.283)		.42(.069)	
HDB						
SLIM	62.61(1.5)	S<O (3.7%)	1.4(.114)	S<O (16.4%)	.51(.049)	S>O (21.4%)
OBESE	64.94(2.4)		1.63(.263)		.42(.062)	
CSF						
SLIM	61.9(2.2)	S<O (3.9%)	1.67(.51)	S<O (18%)	.44(.054)	S>O (15.8%)
OBESE	64.31(2.6)		1.93(.271)		.38(.049)	
LSL						
SLIM	64.2(3.7)	S<O (5.1%)	1.63(.294)	S<O (17.1%)	.44(.064)	S>O (18.9%)
OBESE	67.5(2.1)		1.91(.254)		.37(.051)	
LST						
SLIM	59.66(1.7)	S<O (6.3%)	1.53(.102)	S<O (18.3%)	.52(.036)	S>O (30%)
OBESE	63.39(2.2)		1.81(.161)		.40(.022)	

4.6.2 Angles

The Mean sagittal plane movements of the hip, knee, and ankle joints during ascending phase of all movements for slim and obese people are illustrated in **Figure 4.33**. **Table 4.26** and the corresponding Bar chart (**Figure 4.34**) summarizes mean maximum angles observed at the hip, knee, and ankle joints during stair ascent phase of all movements for slim and obese people. No significant differences were found between obese and slim people in the hip/knee flexion angle and in the ankle dorsiflexion and plantarflexion angles. However, obese people require lower knee flexion angle for LST (P<.01) compared to slim people.

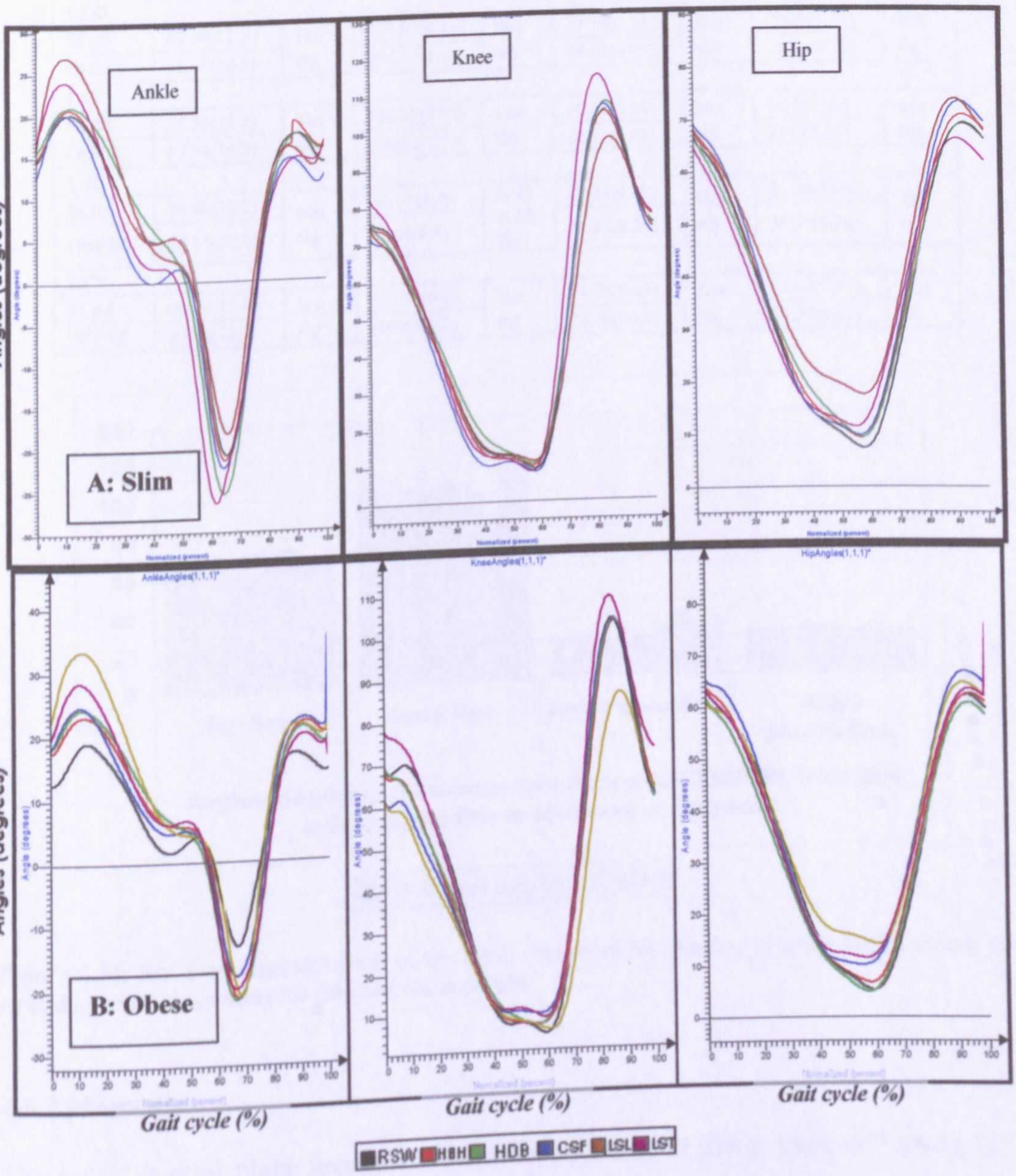


Figure 4.33: Mean angle power of the hip, knee, and ankle joint during stair ascent phase of all exercises A) Slim (n=10). B) Obese (n=10).

Table 4.26: Mean (SD) of maximum hip, knee and ankle angles during stair ascending of all movements for slim (n = 10) and obese (n = 10) people.

	Hip Flex. (degrees)	Sig.	Knee flex. (degrees)	Sig.	Ankle dorsi-flex. (degrees)	Sig.	Ankle plantar-flex. (degrees)	Sig.
RW								
SLIM	71.97(12.47)	Not sig	107.22(5.95)	Not sig	20.69(3.05)	Not sig	22.88(4.75)	Not sig
OBESE	63.80(11.13)		104.23(4.86)		22.53(6.37)		22.30(8.76)	
HBH								
SLIM	71.36(12.7)	Not sig	105.39(5.83)	Not sig	20.93(3.25)	Not sig	22.17(5.32)	Not sig
OBESE	63.03(13.3)		104.04(5.57)		23.51(7.23)		23.91(8.45)	
HDB								
SLIM	69.69(11.5)	Not sig	108.05(6.76)	Not sig	21.19(2.54)	Not sig	26.39(6.71)	Not sig
OBESE	61.45(10.6)		104.25(4.91)		24.53(6.65)		24.54(8.37)	
CSF								
SLIM	74.33(11.3)	Not sig	107.59(8.82)	Not sig	20.67(3.98)	Not sig	23.5(7.56)	Not sig
OBESE	67.54(10.3)		104.42(7.78)		25.12(7.01)		22.6(7.15)	
LSL								
SLIM	74.66(11.2)	Not sig	99.14 (8.9)	S>O (13.8 %)	27.78(4.40)	Not sig	23.69(7.05)	Not sig
OBESE	65.15(11.0)		87.08(9.5)		34.17(8.35)		24.71(7.28)	
LST								
SLIM	66.87(11.8)	Not sig	115.54(6.9)	Not sig	24.25(4.69)	Not sig	21.62(9.77)	Not sig
OBESE	63.86(12.2)		109.63(5.7)		28.76(6.15)		22.29(6.61)	

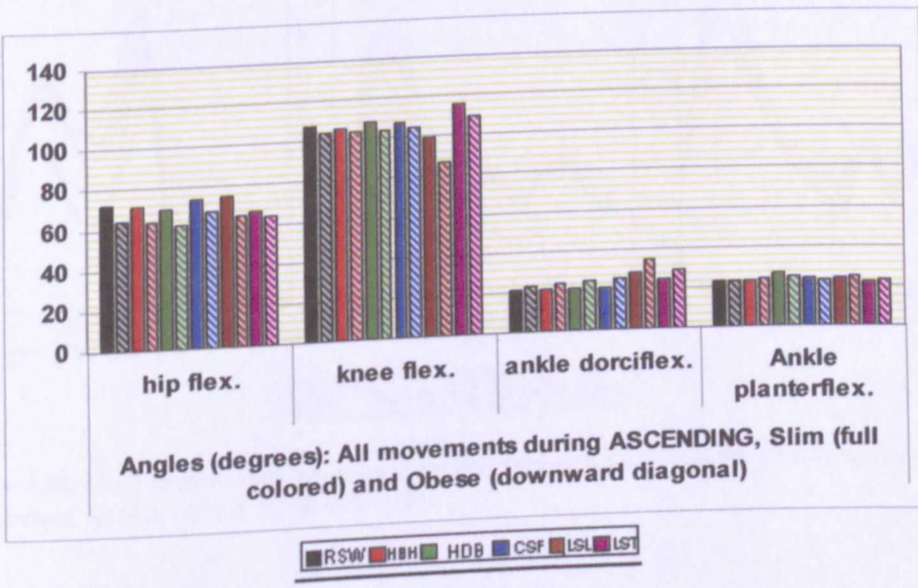


Figure 4.34: Bar chart representations of the mean maximum hip, knee, and ankle angles during stair ascending of all movements for slim and obese people.

4.6.3 Moments

The mean sagittal plane moments of the hip, knee, and ankle joint and mean (SD) frontal plane moments of the hip and the knee joint during ascending phase of all movements for obese and slim people are illustrated in **Figure 4.35** and **Figure 4.36**, respectively.

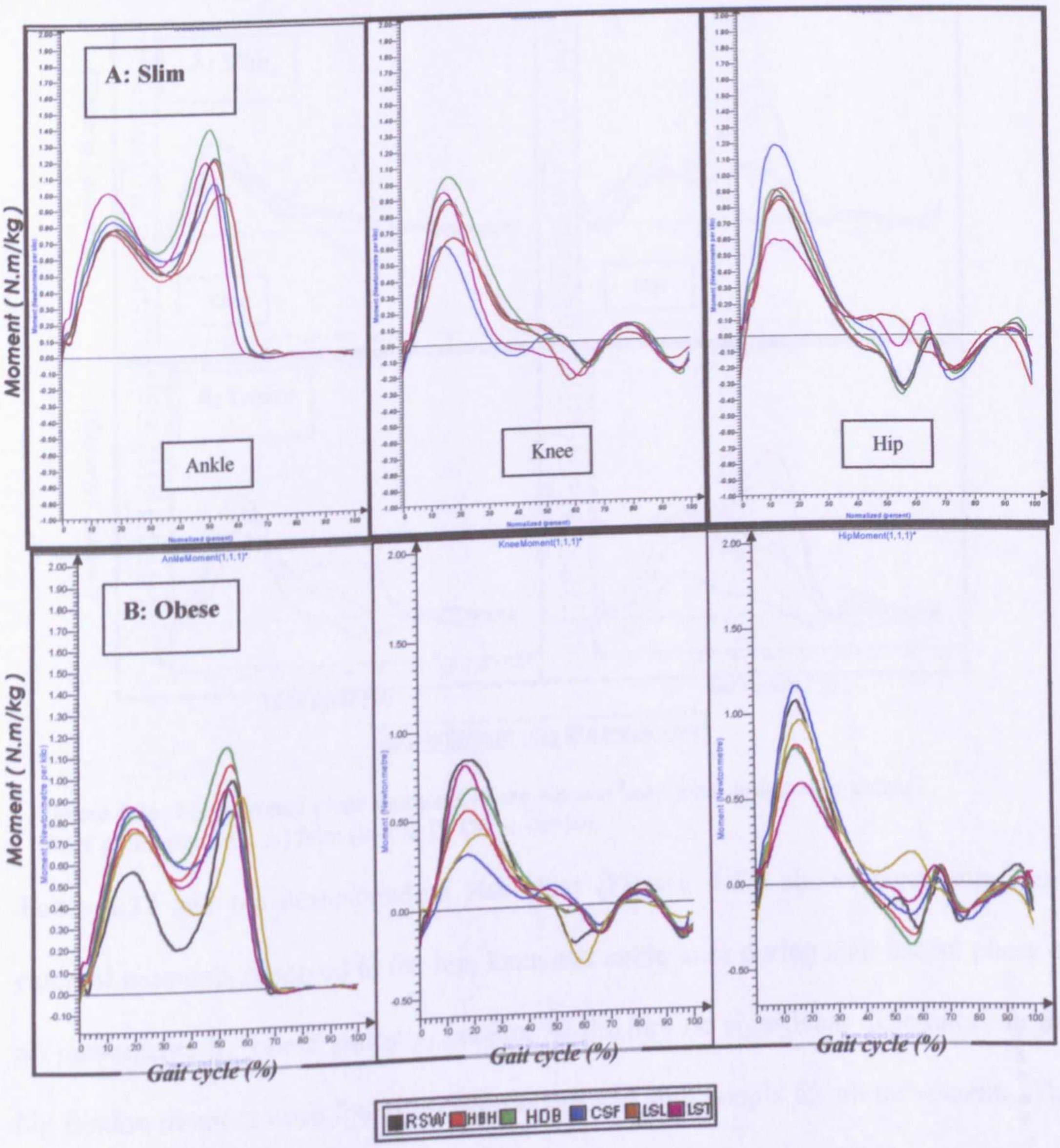


Figure 4.35: Mean sagittal plane moments of the hip, knee, and ankle joint during stair ascent phase of all exercises. A) Slim (n=10). B) Obese (n=10).

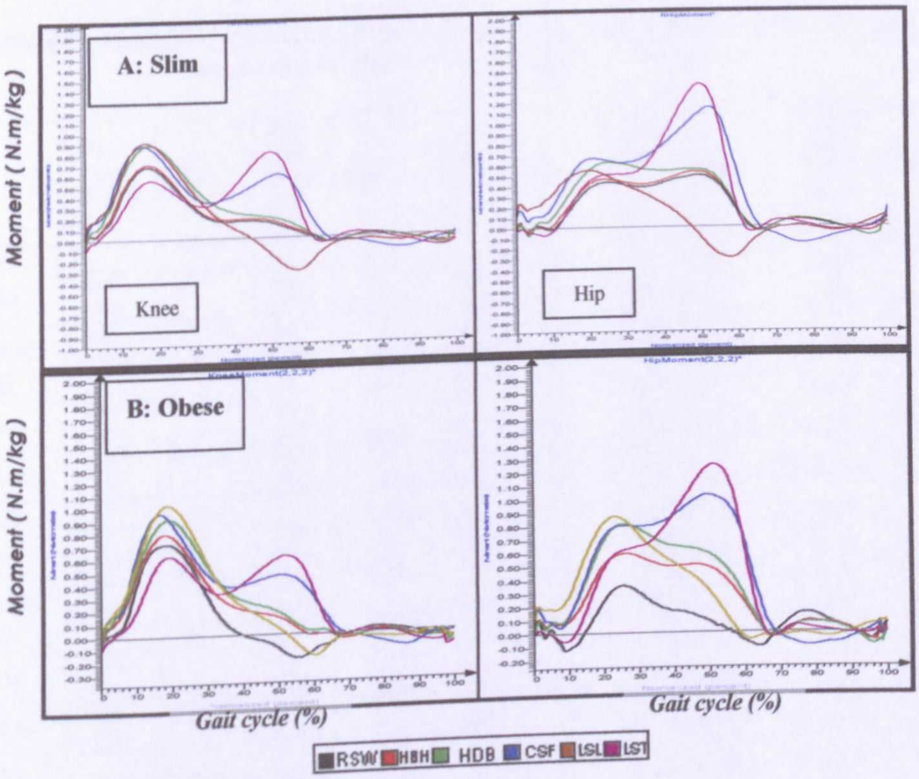


Figure 4.36: Mean frontal plane moments of the hip and knee joint during stair ascent phase of all exercises. A) Slim (n=10). B) Obese (n=10).

Table 4.27 and the corresponding Bar chart (**Figure 4.37**) shows mean maximum external moments observed at the hip, knee and ankle joint during stair ascent phase of all movements for obese and slim people. At the hip, no significant differences in the hip flexion moment were found between obese and slim people for all movements. The external hip adduction moments for LSL (P <.01) was greater for obese people compared to slim people. At the knee, obese people require lower flexion moment for RW (P<.05), HBH (p<.05), and HDB (p<.05) compared to slim people. The external knee adduction moments for LST were lower (p<.05) for obese people compared to slim people. At the ankle, slim people required higher dorsiflexion moment for HDB (p<.01), CSF (p<.05), LSL (p<.05), and LST (p<.01) compared to obese people.

Table 4.27: Mean (SD) of maximum external hip, knee and ankle moments during ascending of all movements for slim (n = 10) and obese (n = 10) people.

	Hip Flex. (N.m/kg)	**Sig.**	**Hip Add. (N.m/kg)**	**Sig.**	**Knee Flex. (N.m/kg)**	**Sig.**	**Knee Add. (N.m/kg)**	**Sig.**	**Ankle Dorsi-flex. (N.m/kg)**	**Sig.**
RW										
SLIM	.893 (.199)	Not sig	.552 (.233)	Not sig	.878 (.240)	S>O (53%)	.695 (.151)	Not sig	1.279 (.193)	Not sig
OBESE	.907 (.255)		.638 (.165)		.574 (.337)		.8147 (.152)		1.09 (.218)	
HBH										
SLIM	.880 (.191)	Not sig	.604 (.256)	Not sig	.884 (.263)	S>O (56.5%)	.720 (.131)	Not sig	1.277 (.194)	. Not sig
OBESE	.928 (.275)		.687 (.187)		.5653 (.362)		.831 (.175)		1.159 (.220)	
HDB										
SLIM	.945 (.213)	Not sig	.724 (.259)	Not sig	1.052 (.297)	S>O (50.7%)	.907 (.165)	Not sig	1.452 (.173)	S>O (18%)
OBESE	.896 (.264)		.877 (.113)		.698 (.355)		.936 (.176)		1.230 (.148)	
CSF										
SLIM	1.272 (.282)	Not sig	1.179 (.287)	Not sig	.643 (.271)	Not sig	.975 (.144)	Not sig	1.243 (.291)	S>O (23.1%)
OBESE	1.235 (.401)		1.151 (.160)		.399 (.253)		.985 (.198)		1.010 (.133)	
LSL										
SLIM	1.038 (.202)	Not sig	.641 (.209)	S<O (40.7%)	.719 (.255)	Not sig	1.009 (.206)	Not sig	1.357 (.249)	S>O (26.1%)
OBESE	1.016 (.383)		.902 (.172)		.486 (.326)		1.070 (.149)		1.076 (.212)	
LST										
SLIM	.642 (.262)	Not sig	1.423 (.173)	Not sig	.965 (.273)	. Not sig	.849 (.120)	. S>O (16.8%)	1.278 (.220)	S>O (28.8%)
OBESE	.571 (.229)		1.293 (.145)		.842 (.367)		.727 (.121)		.992 (.199)	

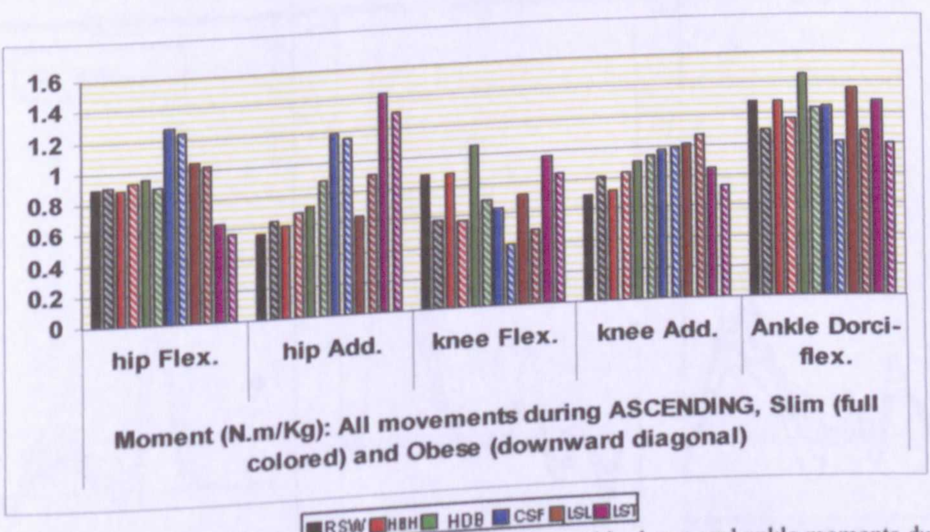


Figure 4.37: Bar chart representation of the mean maximum hip, knee, and ankle moments during ascending of all movements for slim and obese people.

4.6.4 Powers

The mean powers at the hip, knee, and ankle joints during ascending phase of all movements for obese and slim people are illustrated in **Figure 4.38**. **Table 4.28** and the corresponding Bar chart (**Figure 4.39**) shows mean maximum absolute powers observed at the hip, knee and ankle joint during stair ascent phase of all movements for obese and slim people. At the hip, obese people produce lower power for CSF (P<0.01) compared to slim people. At the knee, no significant differences between obese and slim people were found for all movements. At the ankle, slim people produce greater power for RW ($p<.05$), HDB ($p<.01$), LSL ($p<.05$), and LST ($p<.01$)], compared to obese people.

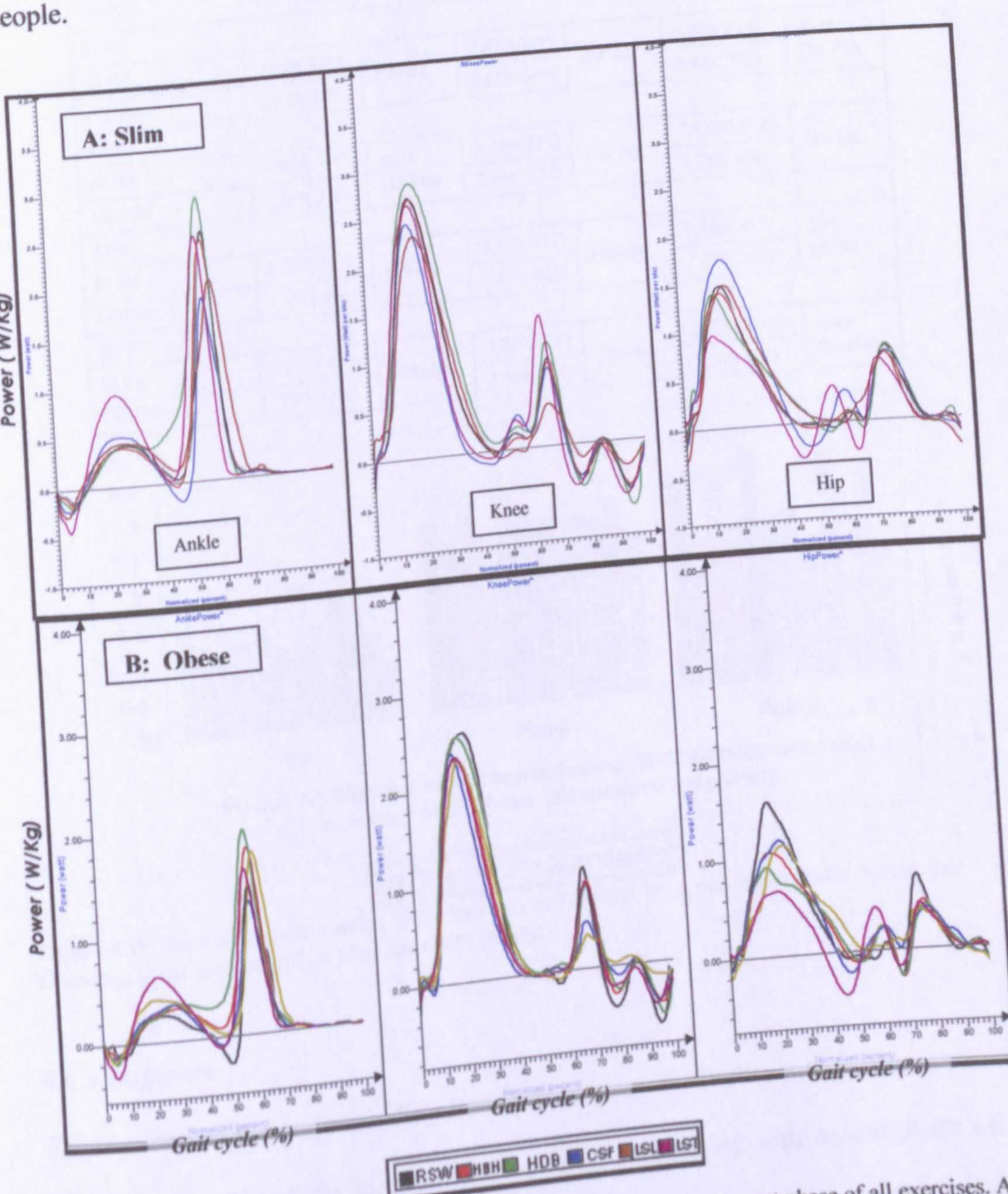


Figure 4.38: Mean power of the hip, knee, and ankle joints during stair ascent phase of all exercises. A) Slim (n=10). B) Obese (n=10).

Table 4.28: Mean (SD) of maximum external hip, knee and ankle power during stair ascending of all movements for slim (n = 10) and obese (n = 10) people.

	Hip power (W/Kg)	Sig.	Knee power (W/Kg)	Sig.	Ankle power (W/Kg)	Sig.
RW						
SLIM	1.56(.47)	Not sig	2.64(.62)	Not sig	2.87(.87)	S>O (43.5%)
OBESE	1.24(.44)		2.35(.60)		2.00(.56)	
HBH						
SLIM	1.512(.450)	Not sig	2.719(.607)	Not sig	2.794(.767)	Not sig
OBESE	1.271(.438)		2.397(.574)		2.244(.659)	
HDB						
SLIM	1.456(.403)	Not sig	2.878(.779)	Not sig	3.273(.619)	S>O (34.7%)
OBESE	1.123(.370)		2.613(.445)		2.430(.578)	
CSF						
SLIM	1.957(.560)	S>O (43.8%)	2.548(.714)	Not sig	2.432(1.058)	Not sig
OBESE	1.361(.310)		2.446(.527)		1.759(.850)	
LSL						
SLIM	1.720(.731)	Not sig	2.579(.637)	Not sig	3.186(.863)	S>O (40%)
OBESE	1.399(.496)		2.456(.423)		2.277(.843)	
LST						
SLIM	1.153(.566)	Not sig	2.728(.665)	Not sig	3.028(.970)	S>O (71.6%)
OBESE	.795(.270)		2.368(.718)		1.765(.628)	

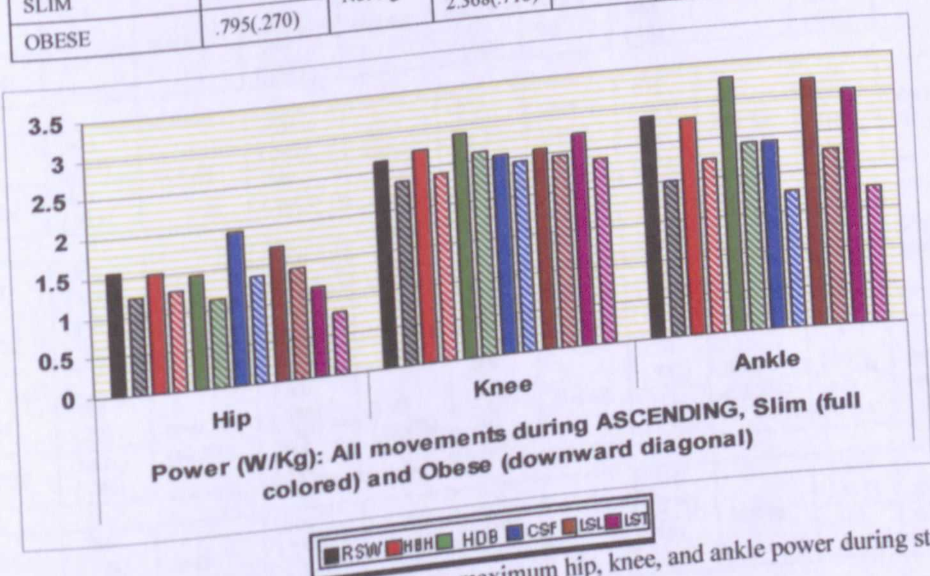


Figure 4.39: Bar chart representation of the mean maximum hip, knee, and ankle power during stair ascending of all movements for slim and obese people.

4.6.5 Impulses

Table 4.29 and the corresponding Bar chart (**Figure 4.40**) shows the mean maximum impulses observed at the hip, knee, and ankle joints during stair ascent phase of all movements for obese and slim people. At the hip, slim subjects demonstrated a greater hip flexion impulse for CSF (P <.05) and LSL (P <.05), compared to obese people. The hip adduction impulses were lower for the obese people for CSF (p.05<) and LST (P

<0.05) compared to slim peolpe. At the knee, obese people require lower flexion impulse for RW (P<.01), HBH (p<.01), HDB (p<.001), and LSL (P<.01), compared to slim people. The external knee adduction impulses of CSF (p<.01) and LST (p<.05) activities were lower for obese people compared to slim people. At the ankle, obese people required lower dorsiflexion impulse for all the movements [RW (p<.01), HBH (p<0.05), HDB (p<0.01), CSF (p<0.01), LSL (p<0.01), LST (p<.01)], compared to slim people.

Table 4.29 Mean (SD) of maximum external hip, knee and ankle impulse during stair ascending of all movements for slim (n = 10) and obese (n = 10) people.

	Hip Flex. (N.m.s/kg)	**Sig.**	**Hip Add. (N.m.s/kg)**	**Sig.**	**Knee Flex. (N.m.s/kg)**	**Sig.**	**Knee Add. (N.m.s/kg)**	**Sig.**	**Ankle Dorsi-flex. (N.m.s/kg)**	**Sig.**
RW										
SLIM	.624 (.277)	Not sig	.751 (.495)	Not sig	.742 (.247)	**S>O** (118.9 %)	.626 (.363)	Not sig	1.383 (.470)	**S>O (63.5%)**
OBESE	.416 (.166)		.546 (.189)		.339 (.196)		.461 (.143)		.846 (.222)	
HBH										
SLIM	.643 (.297)	Not sig	.820 (.545)	Not sig	.687 (.230)	**S>O** (106.9 %)	.675 (.362)	Not sig	1.38 (.479)	**S>O** (51.6%)
OBESE	.461 (.217)		.584 (.160)		.332 (.233)		.481 (.132)		.910 (.201)	
HDB										
SLIM	.764 (.408)	Not sig	1.004 (.639)	Not sig	.894 (.243)	**S>O** (110.4 %)	.913 (.477)	Not sig	1.697 (.522)	**S>O** (69%)
OBESE	.450 (.241)		.741 (.161)		.425 (.247)		.582 (.153)		1.004 (.206)	
CSF										
SLIM	.953 (.303)	**S>O** (50.3%)	1.454 (.648)	**S>O** (49.4%)	.459 (.277)	Not sig	1.11 (.384)	**S>O** (55.2%)	1.471 (.542)	**S>O** (66.2%)
OBESE	.634 (.280)		.973 (.128)		.265 (.236)		.715 (.136)		.885 (.131)	
LSL										
SLIM	.786 (.198)	**S>O** (44%)	.616 (.256)	Not sig	.579 (.216)	**S>O** (103.2 %)	.718 (.228)	Not sig	1.443 (.517)	**S>O** (82%)
OBESE	.546 (.265)		.662 (.184)		.285 (.232)		.586 (.180)		.793 (.102)	
LST										
SLIM	.627 (.395)	Not sig	1.259 (.428)	**S>O** (39.1%)	.637 (.164)	Not sig	.928 (.333)	**S>O** (58.9%)	1.588 (.464)	**S>O** (76.6%)
OBESE	.409 (.345)		.905 (.172)		.452 (.242)		.584 (.172)		.899 (.248)	

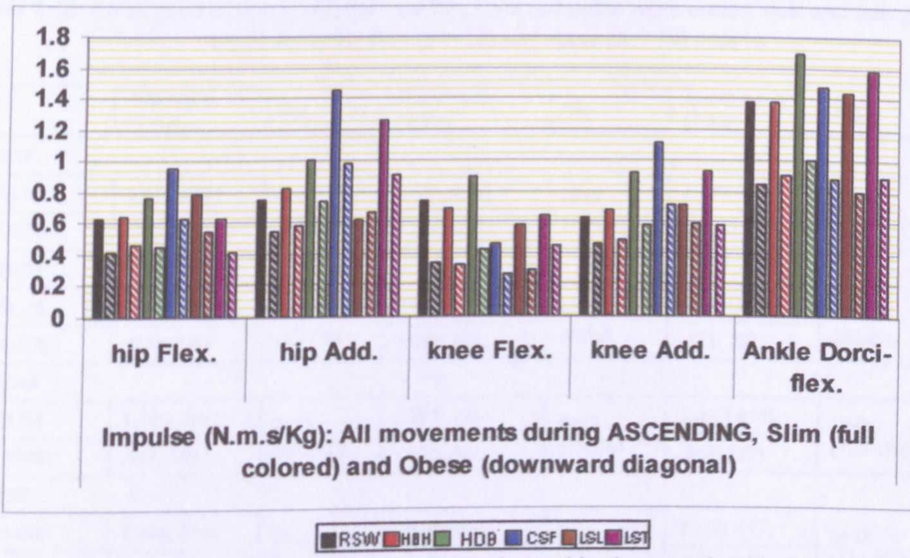


Figure 4.40: Bar chart representation of the mean maximum hip, knee, and ankle impulse during stair ascending of all movements for slim and obese people.

4.6.6 Total work

Table 4.30 and the corresponding Bar chart (**Figure 4.41**) shows the mean maximum total work observed at the hip, knee, and ankle joints during stair ascent phase of all movements for obese and slim people. At the hip, slim people required higher work for all the movements [RW (p<.05), HBH (p<.05), HDB (p<.05), CSF (p<.01), LSL (p<.01), LST (p<.05)] compared to obese people. At the knee, slim people required more work for all the movements [RW (p<.001), HBH (p<.01), HDB (p<.001), CSF (p<.01), LSL (p<.01), LST (p<.001)] compared to obese people. At the ankle, slim people required more work for all the movements [RW (p<.01), HBH (p<.01), HDB (p<.01), CSF (p<.01), LSL (p<.01), LST (p<.001)] compared to obese people.

Table 4.30: Mean (SD) of maximum external hip, knee and ankle work during stair ascending of all movements for slim (n = 10) and obese (n = 10) people.

	Hip work (J/Kg)	Sig.	Knee work (J/Kg)	Sig.	Ankle work (J/Kg)	Sig.
RW						
SLIM	1.434(.693)	S>O (83.1%)	2.324(.604)	S>O (79.6%)	1.239(.500)	S>O (102.8%)
OBESE	.783(.159)		1.294(.343)		.611(.258)	
HBH						
SLIM	1.478(.659)	S>O (82.7%)	2.266(.611)	S>O (69%)	1.237(.466)	S>O (80.8%)
OBESE	.809(.205)		1.341(.402)		.684(.282)	
HDB						
SLIM	1.589(.768)	S>O (102.9%)	2.882(.793)	S>O (85.1%)	1.659(.645)	S>O (108.4%)
OBESE	.783(.289)		1.557(.367)		.796(.339)	
CSF						
SLIM	1.994(.856)	S>O (115.6%)	2.014(.635)	S>O (80.6%)	1.112(.497)	S>O (113.8%)
OBESE	.925(.207)		1.115(.309)		.520(.178)	
LSL						
SLIM	1.616(.702)	S>O (103.5%)	2.058(.630)	S>O (71.5%)	1.407(.617)	S>O (104.8%)
OBESE	.794(.170)		1.200(.383)		.687(.213)	
LST						
SLIM	1.323(.717)	S>O (106.7%)	2.437(.501)	S>O (90.8%)	1.586(.479)	S>O (127.2%)
OBESE	.640(.167)		1.277(.304)		.698(.291)	

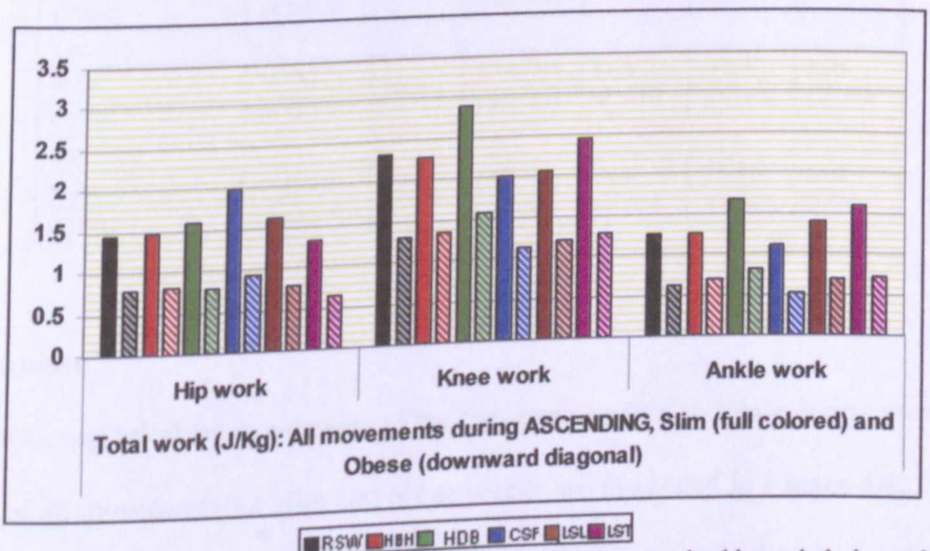


Figure 4.41: Bar chart representation of the mean maximum hip, knee, and ankle work during stair ascending of all movements for slim and obese people.

4.7 Slim Versus Obese People: Descending

4.7.1 Temporal parameters

Table 4.31 summarizes the mean foot off, stride time, and speed during descent phase of all movements for obese and slim people. Obese people require longer stride time for all the movements [RW (p<.05), HBH (p<.05), HDB (p<.05), CSF (p<.05), LSL (p<.01), LST (p<.01)] compared to slim people. No significant differences were found in the stance phase between obese and slim people. The speed was higher for slim people compared to obese people for all the movements [RW (p<.05), HBH (p<.05), HDB (p<.05), CSF (p<.05), LSL (p<.01), LST (p<.01)].

Table 4.31: Mean (SD) of time parameters during stair descending of all movements for slim (n = 10) and obese (n = 10) people

	Foot off (%)	Sig.	Stride time (s)	Sig.	Speed (m/s)	Sig.
RW						
SLIM	63.6(2.8)	Not sig	1.39(.11)	S<O (12.9%)	.58(.050)	S>O (11.5%)
OBESE	64.3(2.0)		1.57(.192)		.52(.070)	
HBH						
SLIM	64.11(3.1)	Not sig	1.38(.083)	S<O (13.8%)	.59(.044)	S>O (13.5%)
OBESE	65.65(2.50)		1.57(.250)		.52(.079)	
HDB						
SLIM	64.98(2.8)	Not sig	1.32(.111)	S<O (15.2%)	.62(.075)	S>O (17%)
OBESE	66.35(2.58)		1.52(.221)		.53(.075)	
CSF						
SLIM	62.57(2.6)	Not sig	1.69(.198)	S<O (10.1%)	.48(.058)	S>O (17.1%)
OBESE	64.37(2.9)		1.86(.177)		.41(.065)	
LSL						
SLIM	64.39(2.7)	Not sig	1.50(.256)	S<O (25.3%)	.53(.07)	S>O (29.3%)
OBESE	66.42(3.35)		1.88(.287)		.41(.054)	
LST						
SLIM	63.48(2.7)	Not sig	1.48(.176)	S<O (17.6%)	.55(.052)	S>O (17%)
OBESE	65.56(2.70)		1.74(.194)		.47(.066)	

4.7.2 Angles

The mean sagittal plane movements of the hip, knee, and ankle joints during ascending phase of all movements for slim and obese people are illustrated in **Figure 4.42**. **Table 4.32** and the corresponding Bar chart (**Figure 4.43**) summarizes the mean maximum angles observed at the hip, knee, and ankle joints during stair descent phase of all movements for slim and obese people. No significant differences were found between obese and slim people in the hip/knee flexion angle and in the ankle dorsiflexion and plantarflexion angles.

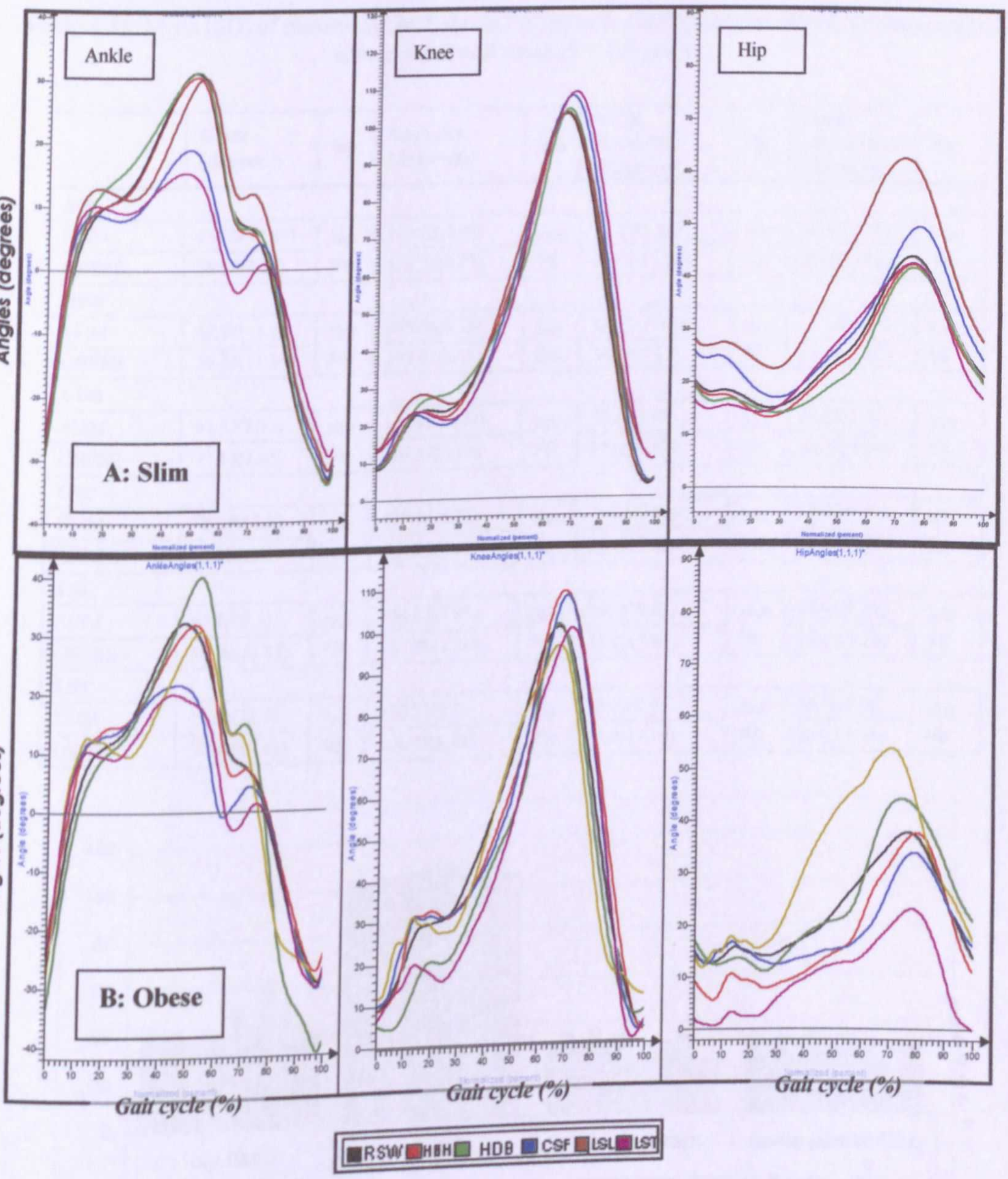


Figure 4.42: Mean sagittal plane angles of the hip, knee, and ankle joint during stair descent phase of all exercises. A) Slim (n=10). B) Obese (n=10).

Table 4.32: Mean (SD) of maximum hip, knee and ankle angles during descending of all movements for slim (n = 10) and obese (n = 10) people.

	Hipflex. (degrees)	Sig.	Knee flex. (degrees)	Sig.	Ankle dorsi-flex. (degrees)	Sig.	Ankle plantar-flex. (degrees)	Sig.
RW								
SLIM	44.32(12.44)	Not sig	104.83(7.72)	Not sig	32.24(7.13)	Not sig	33.60(5.49)	Not sig
OBESE	38.90(8.78)		102.21(4.47)		35.017(7.36)		30.63(6.96)	
HBH								
SLIM	42.74(11.7)	Not sig	105.08(6.58)	Not sig	31.47 (6.94)	Not sig	33.97(4.06)	Not sig
OBESE	39.65(11.31)		105.43(6.51)		36.59(8.17)		31.40(7.62)	
HDB								
SLIM	42.53(11.7)	Not sig	106.48 (5.74)	Not sig	32.28(5.86)	Not sig	34.26(5.40)	Not sig
OBESE	39.14(8.45)		107.17(6.19)		37.07(7.67)		30.81(7.30)	
CSF								
SLIM	50.09(12.0)	Not sig	110.21(6.21)	Not sig	21.63(5.49)	Not sig	33.08(4.97)	Not sig
OBESE	43.92(10.01)		107.81(4.79)		28.68(9.16)		29.79(7.66)	
LSL								
SLIM	63.1(10.3)	Not sig	104.13(7.03)	Not sig	30.55(6.57)	Not sig	32.04(6.20)	Not sig
OBESE	54.29(12.87)		102.42(4.78)		33.29(5.65)		28.44(7.16)	
LST								
SLIM	43.51(12.4)	Not sig	110.21(7.8)	Not sig	22.68(7.43)	Not sig	30.36(7.56)	Not sig
OBESE	39.62(13.41)		104.43(6.48)		22.08(7.10)		28.83(5.54)	

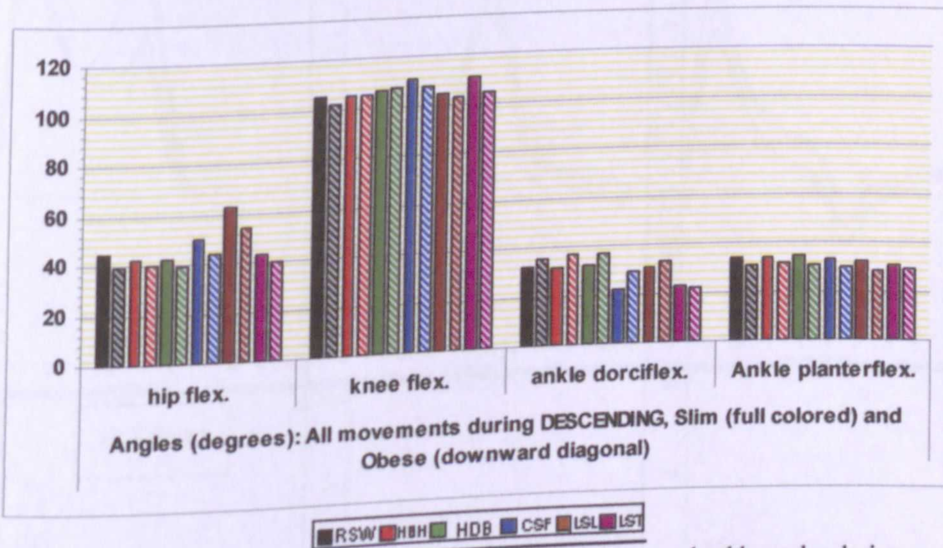


Figure 4.43: Bar chart representation of the mean maximum hip, knee, and ankle angles during descending of all movements for slim and obese people.

4.7.3 Moments

The mean sagittal plane moments of the hip, knee, and ankle joints during descending phase of all movements for obese persons is illustrated in **Figure 4.44**. The corresponding values for the frontal plane moments are plotted in **Figure 4.45. Table 4.33** and the corresponding Bar chart (**Figure 4.46**) shows the mean maximum external moments observed at the hip, knee, and ankle joints during stair descent phase of all movements for obese and slim people. At the hip, no significant difference in the hip flexion moment was found between obese and slim people for all movements. The external hip adduction moments for CSF ($P<.05$) and LST ($p<.05$) were greater for obese people compared to slim people. At the knee, obese people require lower flexion moment for RW ($P<.05$), HBH ($p<.01$), HDB ($p<.05$), LSL ($p<.05$), and LST ($p<.05$), compared to slim people. No significant difference was found in the external knee adduction moments between obese and slim people. At the ankle, slim people required higher dorsiflexion moment for HBH ($p<.05$), LSL ($p<.05$), and LST ($p<.05$), compared to obese people.

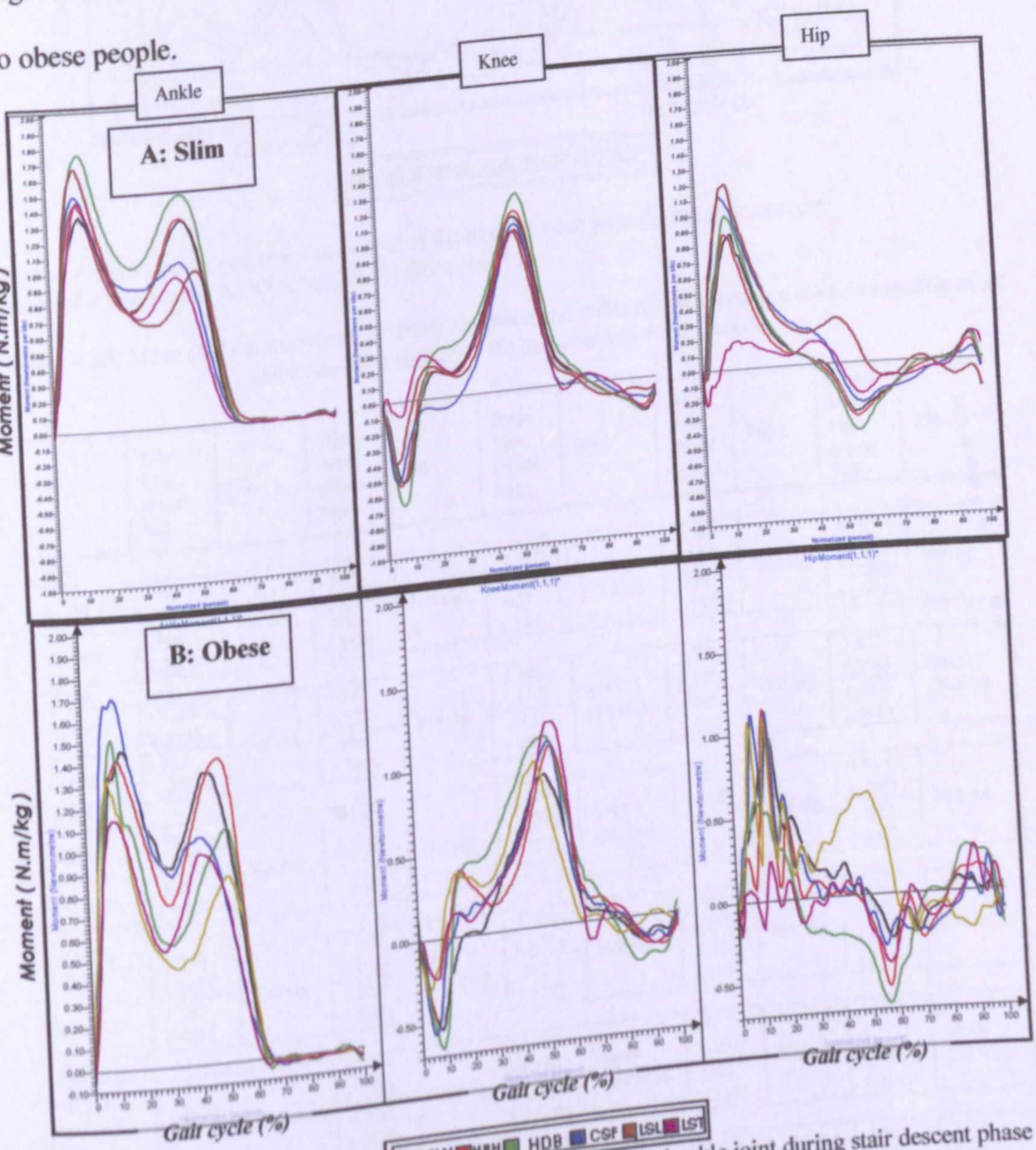


Figure 4.44: Mean sagittal plane moments of the hip, knee, and ankle joint during stair descent phase of all exercises. A) Slim (n=10). B) Obese (n=10).

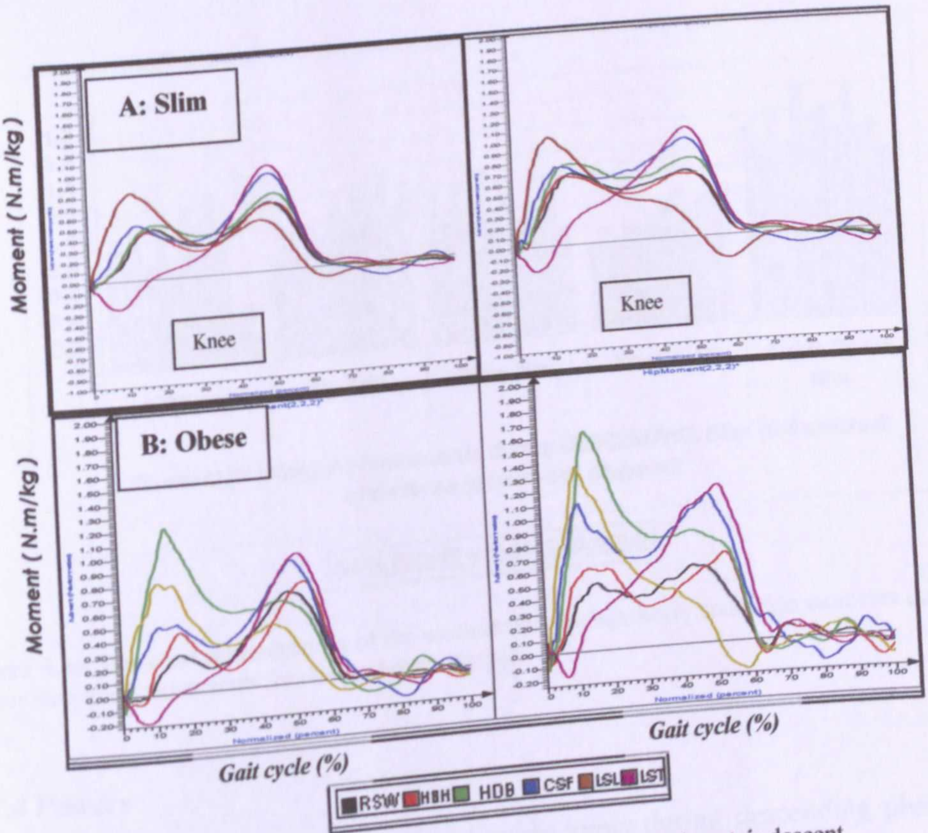


Figure 4.45: Mean frontal plane moments of the hip and knee joint during stair descent phase of all exercises. A) Slim (n=10). B) Obese (n=10).

Table 4.33: Mean (SD) of maximum external hip, knee and ankle moments during stair descending of all movements for slim (n = 10) and obese (n = 10) people.

	Hip Flex. (N.m/kg)	**Sig.**	**Hip Add. (N.m/kg)**	**Sig.**	**Knee Flex. (N.m/kg)**	**Sig.**	**Knee Add. (N.m/kg)**	**Sig.**	**Ankle Dorsi-flex. (N.m/kg)**	**Sig.**
RW										
SLIM	.918 (.195)	Not sig	.747 (.177)	Not sig	1.164 (.135)	S>O (25.6%)	.673 (.151)	Not sig	1.509 (.218)	Not sig
OBESE	.796 (.360)		.952 (.257)		.927 (.248)		.788 (.194)		1.352 (.206)	
HBH										
SLIM	.9380 (.313)	Not sig	.766 (.228)	Not sig	1.206 (.119)	S>O (32.1%)	.707 (.170)	Not sig	1.637 (.268)	S>O (20.6%)
OBESE	.763 (.391)		.975 (.302)		.913 (.254)		.786 (.207)		1.357 (.186)	
HDB										
SLIM	.961 (.270)	Not sig	.895 (.216)	Not sig	1.304 (.176)	S>O (28.7%)	.787 (.148)	Not sig	1.820 (.296)	Not sig
OBESE	.820 (.410)		1.127 (.299)		1.013 (.297)		.869 (.233)		1.577 (.253)	
CSF										
SLIM	1.228 (.292)	Not sig	1.047 (.155)	S<O (22.3%)	1.108 (.138)	Not sig	.965 (.153)	Not sig	1.622 (.262)	Not sig
OBESE	1.087 (.461)		1.280 (.293)		.903 (.312)		1.015 (.216)		1.463 (.231)	
LSL										
SLIM	1.31 (.328)	Not sig	1.12 (.222)	Not sig	1.029 (.149)	S>O (24.6%)	.872 (.197)	Not sig	1.767 (.247)	S>O (21.4%)
OBESE	1.034 (.463)		1.320 (.267)		.826 (.239)		.983 (.169)		1.456 (.213)	
LST										
SLIM	.342 (.134)	Not sig	1.077 (.079)	S<O (18.5%)	1.046 (.150)	S>O (28.7%)	1.021 (.171)	Not sig	1.52 (.257)	S>O (18.1%)
OBESE	.440 (.257)		1.276 (.286)		.813 (.264)		1.075 (.213)		1.287 (.182)	

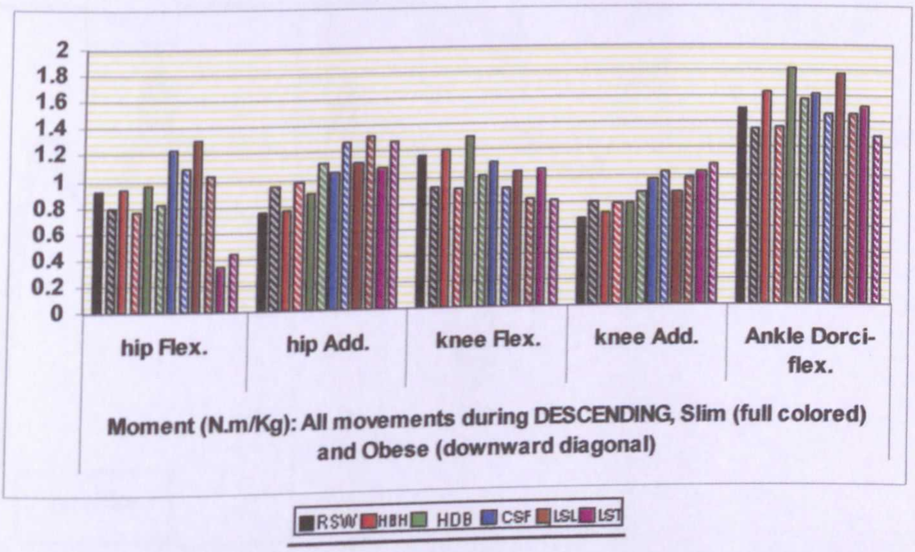


Figure 4.46: Bar chart representation of the mean maximum hip, knee, and ankle moments during stair descending of all movements for slim and obese people.

4.7.4 Powers

The mean powers at the hip, knee, and ankle joints during descending phase of all movements for obese and slim people are illustrated in **Figure 4.47**. **Table 4.34** and the corresponding Bar chart (**Figure 4.48**) shows the mean maximum absolute powers observed at the hip, knee, and ankle joints during stair descent phase of all movements for obese and slim people. At the hip, no significant difference between obese and slim people was found for all movements. At the knee, obese people absorbed less power for HBH ($p<.05$), HDB ($p<.05$), and LSL ($p<.01$), compared to slim people. At the ankle, slim people absorbed greater power for HDB ($p<.05$) and LSL ($p<.05$) compared to obese people.

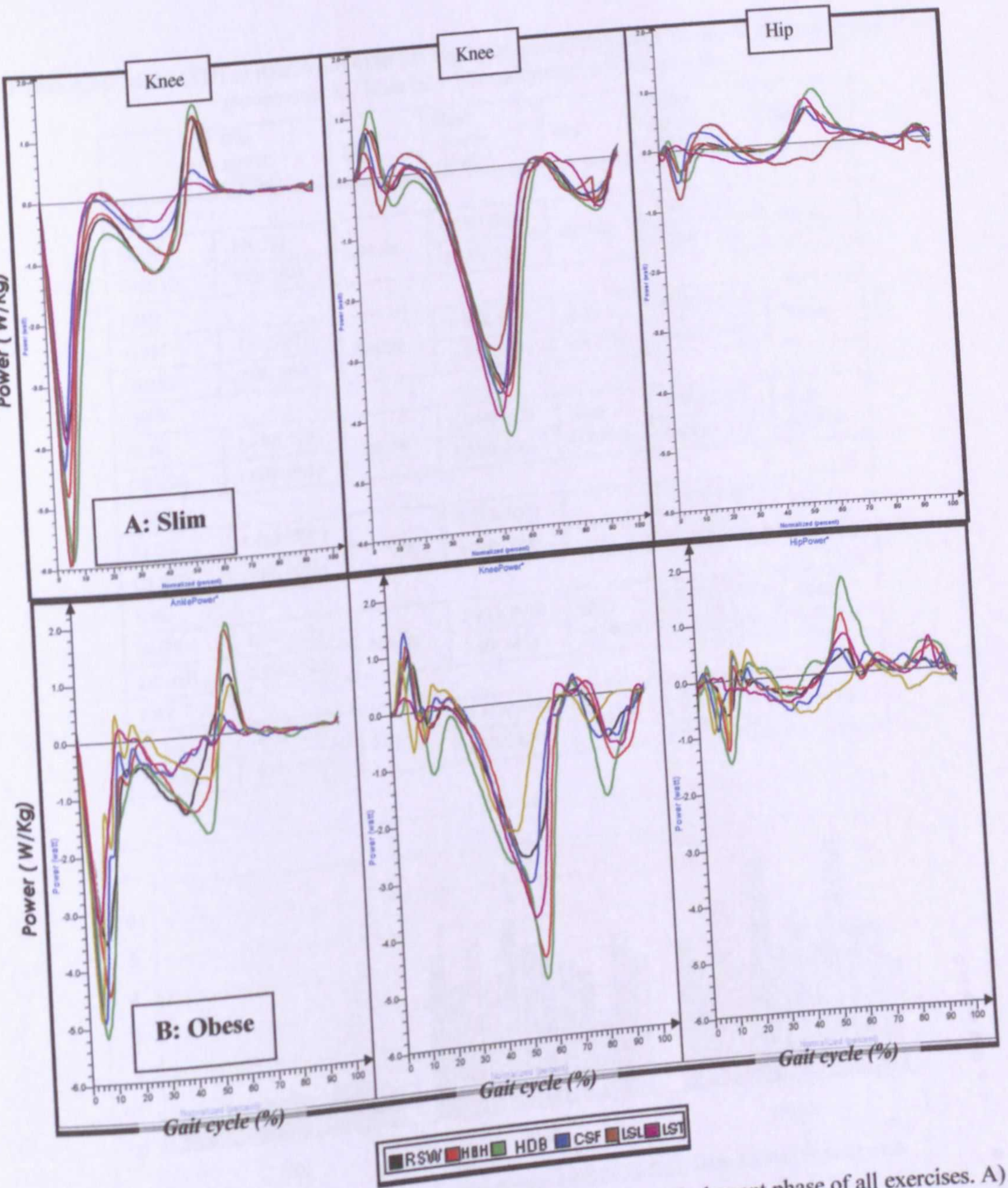


Figure 4.47: Mean power of the hip, knee, and ankle joint during stair descent phase of all exercises. A) Slim (n=10). B) Obese (n=10).

Table 4.34: Mean (SD) of maximum external hip, knee and ankle power during stair descending of all movements for Slim (n = 10) and obese (n = 10) people.

	Hip power (W/Kg)	Sig.	Knee power (W/Kg)	Sig.	Ankle power (W/Kg)	Sig.
RW						
SLIM	.82(.32)	Not sig	4.28(1.06)	Not sig	4.01(1.71)	Not sig
OBESE	.743(.284)		3.437(.738)		3.204(1.57)	
HBH						
SLIM	.757(.267)	Not sig	4.590(.945)	S>O (26.5%)	4.982(2.637)	Not sig
OBESE	.778(.276)		3.628(.902)		3.158(1.416)	
HDB						
SLIM	1.054(.378)	Not sig	5.044(.652)	S>O (19.3%)	5.954(2.32)	S>O (63.9%)
OBESE	1.001(.441)		4.229(.850)		3.632(1.82)	
CSF						
SLIM	1.063(.590)	Not sig	3.892(.650)	Not sig	4.525(2.091)	Not sig
OBESE	.940(.361)		3.730(.724)		3.752(1.521)	
LSL						
SLIM	1.20(.512)	Not sig	3.423(.678)	S>O (42.6%)	6.366(1.805)	S>O (48%)
OBESE	1.199(.822)		2.40(.669)		4.302(1.693)	
LST						
SLIM	.872(.223)	Not sig	4.313(.639)	Not sig	4.143(1.764)	Not sig
OBESE	.858(.402)		3.678(.850)		2.991(1.486)	

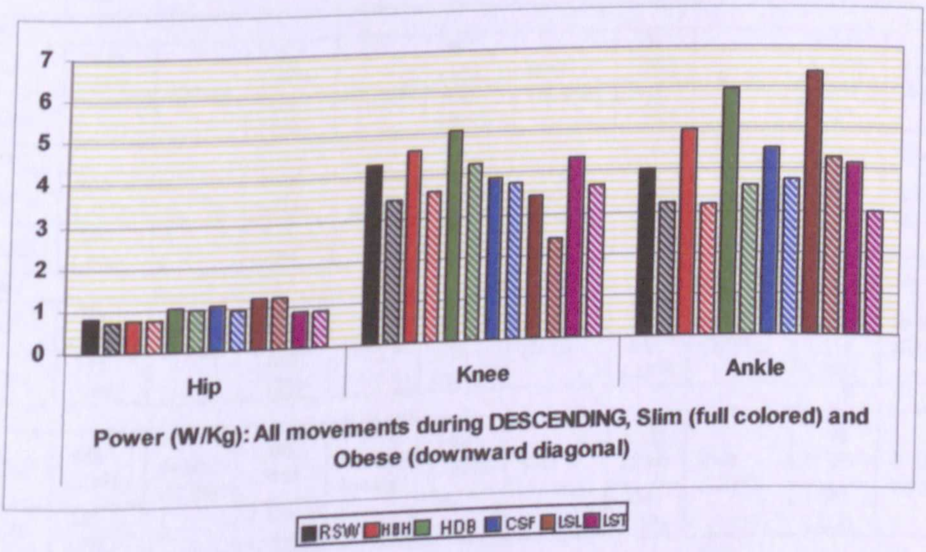


Figure 4.48: Bar chart representation of the mean maximum hip, knee, and ankle power during stair descending of all movements for slim and obese people.

4.7.5 Impulses

Table 4.35 and the corresponding Bar chart (**Figure 4.49**) shows the mean maximum impulses observed at the hip, knee, and ankle joint during stair descent phase of all movements for obese and slim people. At the hip, slim subjects demonstrated a greater hip flexion impulse for CSF ($P<.05$) compared to obese people. The hip adduction impulses were similar between slim and obese people for all movements. At the knee, obese people required lower flexion impulse for all movements [RW (P<.01), HBH (p<.01), HDB (p<.01), CSF (p<.01), LSL (P<.01), LST (p<.01)] compared to slim people. The external knee adduction impulses of HDB (p<.05), CSF (p<.05), and LST (p<.05) were lower for obese people compared to slim people. At the ankle, obese people required lower dorsiflexion impulse for all the movements [RW (p<.01), HBH (p<0.01), HDB (p<0.01), CSF (p<0.01), LSL (p<0.001), LST (p<.01)], compared to slim people.

Table 4.35: Mean (SD) of maximum external hip, knee and ankle impulse during stair descending of all movements for Slim (n = 10) and obese (n = 10) people.

	Hip Flex. (N.m.s/kg)	**Sig.**	**Hip Add. (N.m.s/kg)**	**Sig.**	**Knee Flex. (N.m.s/kg)**	**Sig.**	**Knee Add. (N.m.s/kg)**	**Sig.**	**Ankle Dorsi-flex. (N.m.s/kg)**	**Sig.**
RW										
SLIM	.624 (.342)	Not sig	1.039 (.342)	Not sig	.907 (.191)	S>O (74.4%)	.791 (.291)	Not sig	2.006 (.547)	S>O (64%)
OBESE	.360 (.232)		.828 (.208)		.520 (.217)		.591 (.200)		1.223 (.188)	
HBH										
SLIM	.586 (.357)	Not sig	1.030 (.354)	Not sig	.923 (.172)	S>O (70.9%)	.781 (.327)	Not sig	2.061 (.554)	S>O (63.2%)
OBESE	.349 (.276)		.828 (.194)		.540 (.276)		.570 (.191)		1.263 (.236)	
HDB										
SLIM	.739 (.532)	Not sig	1.259 (.370)	Not sig	1.123 (.262)	S>O (80%)	.932 (.315)	S>O (37.9%)	2.557 (.776)	S>O (80.8%)
OBESE	.353 (.268)		1.010 (.181)		.624 (.279)		.676 (.189)		1.414 (.268)	
CSF										
SLIM	.860 (.370)	S>O (82.2%)	1.395 (.306)	Not sig	.740 (.1579)	S>O (57.4%)	1.032 (.256)	S>O (36.1%)	1.980 (.528)	S>O (60.6%)
OBESE	.472 (.296)		1.134 (.196)		.470 (.214)		.758 (.186)		1.233 (.224)	
LSL										
SLIM	.970 (.461)	Not sig	1.023 (.366)	Not sig	.829 (.248)	S>O (65.8%)	.939 (.380)	Not sig	1.976 (.479)	S>O (71.8%)
OBESE	.582 (.395)		.913 (.117)		.500 (.231)		.695 (.130)		1.150 (.242)	
LST										
SLIM	.269 (.188)	Not sig	1.035 (.238)	Not sig	.892 (.313)	S>O (80.6%)	.755 (.188)	S>O (27.7%)	1.734 (.437)	S>O (68%)
OBESE	.226 (.167)		.916 (.152)		.494 (.191)		.591 (.158)		1.032 (.122)	

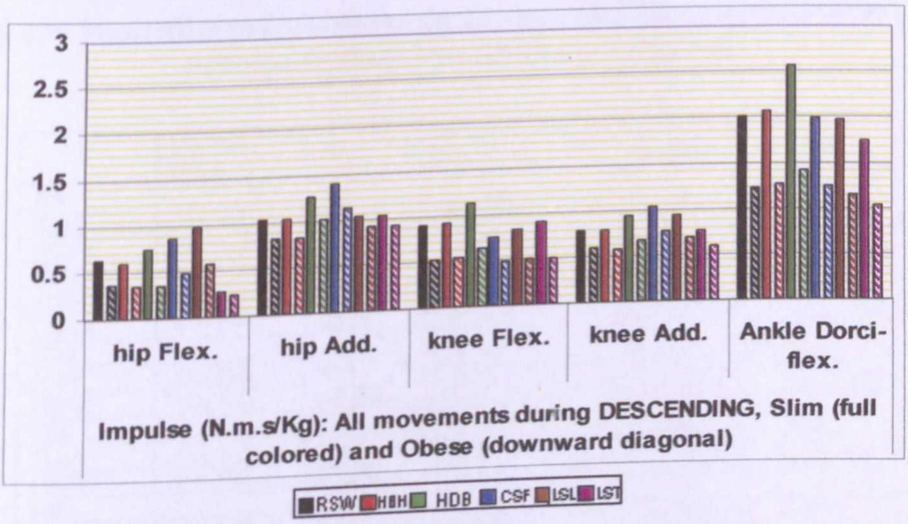


Figure 4.49: Bar chart representation of the mean maximum hip, knee, and ankle impulse during stair descending of all movements for slim and obese people.

4.7.6 Total work

Table 4.36 and the corresponding Bar chart (**Figure 4.50**) shows the mean maximum total work observed at the hip, knee, and ankle joints during stair descent phase of all movements for obese and slim people. At the hip, slim people required higher work for all the movements [RW ($p<.05$), HBH ($p<.05$), HDB ($p<.05$), CSF ($p<.05$), LSL ($p<.01$), LST ($p<.01$)] compared to obese people. At the knee, slim people required higher work for all the movements [RW ($p<.01$), HBH ($p<.001$), HDB ($p<.001$), CSF ($p<.001$), LSL ($p<.001$), LST ($p<.001$)] compared to obese people. At the ankle, slim people required higher work for all the movements [RW ($p<.01$), HBH ($p<.01$), HDB ($p<.01$), CSF ($p<.05$), LSL ($p<.01$), LST ($p<.001$)] compared to obese people.

Table 4.36: Mean (SD) of maximum external hip, knee and ankle work during stair descending of all movements for Slim (n = 10) and obese (n = 10) people.

	Hip work (J/Kg)	Sig.	Knee work (J/Kg)	Sig.	Ankle work (J/Kg)	Sig.
RW						
SLIM	.725(.388)	S>O (64.4%)	3.359(1.004)	S>O (73.1%)	2.556(.887)	S>O (90.2%)
OBESE	.441(.164)		1.941(.458)		1.344(.442)	
HBH						
SLIM	.670(.295)	S>O (54%)	3.504(.941)	S>O (76.4%)	2.695(.885)	S>O (90.5%)
OBESE	.435(.173)		1.986(.550)		1.415(.570)	
HDB						
SLIM	.854(.286)	S>O (60.5%)	4.021(.920)	S>O (79.7%)	3.439(1.250)	S>O (112.5%)
OBESE	.532(.233)		2.237(.605)		1.618(.677)	
CSF						
SLIM	.876(.387)	S>O (71.4%)	2.937(.613)	S>O (62.8%)	1.781(.780)	S>O (62.9%)
OBESE	.511(.136)		1.804(.366)		1.093(.534)	
LSL						
SLIM	.974(.467)	S>O (105.9%)	2.756(.822)	S>O (91.3%)	2.729(1.044)	S>O (124.4%)
OBESE	.473(.176)		1.441(.478)		1.216(.513)	
LST						
SLIM	.745(.224)	S>O (57.2%)	3.227(.725)	S>O (79.2%)	1.557(.378)	S>O (109%)
OBESE	.474(.060)		1.801(.400)		.745(.219)	

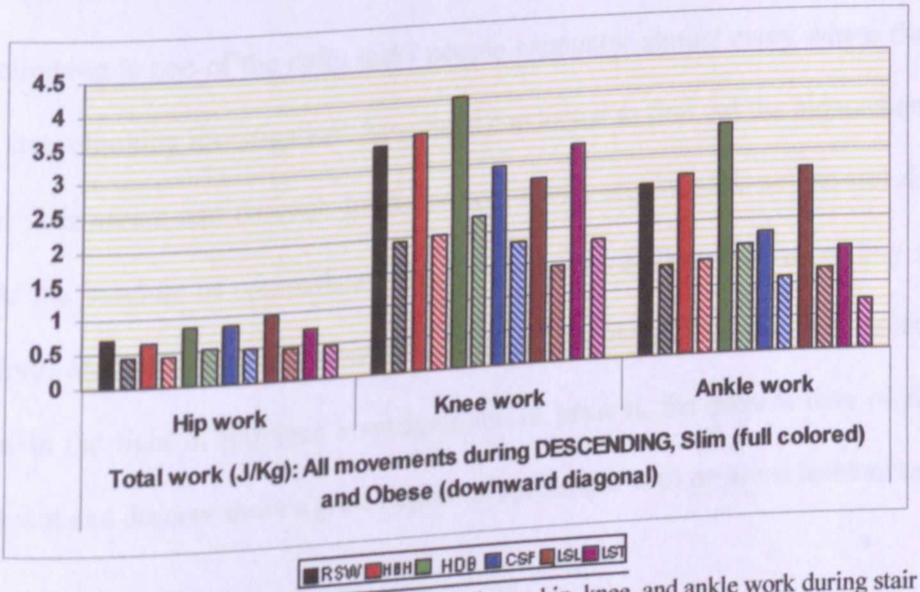


Figure 4.50: Bar chart representation of the mean maximum hip, knee, and ankle work during stair descending of all movements for slim and obese people.

CHAPTER FIVE: DISCUSSION

5.1 Introduction

The results obtained from the research are discussed in this chapter. Firstly, the current data for regular stair ascent and descent are discussed in the light of previous investigations. Then the load differences between the chosen exercises and regular stair walking are discussed. Finally, the way obese people perform all the movements as compared to slim people are discussed.

5.2 Regular Stair Climbing

Stair climbing is one of the daily tasks people encounter almost every where they go. Many stair climbing investigations have been conducted to find out the biomechanics of regular stair ascent and descent. In the present study, regular stair ascent and descent provide the baseline of comparison with other stair ascending and descending styles. Therefore, the following is a discussion of the present data of regular stair ascent and descent in the light of previous investigations. In general, the present data of regular stair ascent and descent show a great degree of agreement with previous researches.

Temporal parameters: In the present study, as in previous stair climbing researches (Livingston et al., 1991; Riener et al., 2002; Protopapadaki et al., 2007), cycle duration was lower during descent compared to ascent. The mean cycle duration during ascent was 1.5 sec. (SD0.090) , while during descent, it was 1.39 sec. (SD.11). Like the data reported by Protopapadaki et al. (2007) and Riener et al. (2002), no significant difference was found in the stance phase between ascent and descent. The mean stance phase during ascent was 62.4 % (SD 1.7), while during descent, it was 63.6 % (SD 2.8). In the current study, in agreement with Livingston et al. (1991) and Protopapadaki et al. (2007), the mean velocity during ascent was less compared to descent, which is consistent with an increased cycle duration during stair ascent compared to descent. The mean velocity during ascent was 0.49 m/s (SD0.039), while during descent it was 0.58 m/s (SD 0.05). In agreement with the present data, Protopapadaki et al. (2007) reported a mean velocity of 0.49 m/s (SD .05) and 0.56 m/s (SD 0.06) during ascent and descent, respectively. On the other hand, Livingston et al. (1991) reported that the mean velocity during ascent was 0.7 m/s (SD0.1), while during descent it was 0.8 m/s (SD0.1). Livingston et al. (1991) also reported that shorter subjects (mean height 155.9 cm (SD 2.1)) ascended and descended stairs at faster velocities than taller subjects (mean height 171.6 cm (SD 2.1)). The mean height of the subjects in the current study (mean height 165.2 cm) is greater than that in Livingston et al. (1991) study (mean height 163.5 cm). This factor may account for the difference in velocity of stair ascent and descent reported in this study and that of Livingston et al. (1991).

Angles: The current data for the hip, knee, and ankle angles are similar in shape to the previously published graphs by Protopapadaki et al. (2007) and Riener et al. (2002). At the foot contact of stair ascent, the hip and the knee joints were flexed and the ankle was dorsiflexed. In contrast, at foot contact of descent, the hip was only slightly flexed, the knee was almost fully extended, and the ankle was plantarflexed. In the subsequent phases, during ascent, the hip and the knee joints extended and the ankle joint globally plantarflexed, while during descent , the hip and the knee joints flexed and achieved the higher degree of flexion at the late stance/early swing. The ankle remained dorsiflexed for most of the stance phase during descent and started to plantarflex at the late stance. During the swing phase, the maximum knee and hip flexion angles occurred later during ascent than during descent.

In agreement with the results reported by Andriacchi et al. (1980), Livingston et al. (1991) and Protopapadaki et al. (2007), the current subjects required significantly greater hip flexion angle to ascend stairs compared to descent. At the knee joint, no significant difference in flexion angle was found between ascending and descending. This result agrees with the data reported by Andriacchi et al. (1980), Laubenthal et al. (1972), and Ried et al. (2007). The mean maximum knee flexion angle during ascent was 107.22 deg. (SD 5.95), while during descent it was 104.83 deg. (SD7.72). Andriacchi et al. (1980) reported flexion angle of 83.3 deg. (SD5.2) during ascent and 87.9 deg. (SD4.4) during descent. Laubenthal et al. (1972) reported 83 deg. of knee flexion angle during both ascent and descent, and Ried et al. (2007) reported 83.5 deg. (SD4.9) of flexion angle for ascending and 83.3 deg. (SD6.1) for descending. Livingston et al. (1991) reported that short subjects used greater mean knee flexion angle than taller subjects. On the other hand, Riener et al. (2002) reported that knee flexion angle increases with increased stair inclination. The stair dimension used in the current study is similar to the one used by Andriacchi et al. (1980) (Rise=21.1cm, deep=25.5 cm). However, the mean subject height in the present study was shorter (165.2 cm) compared to Andriacchi et al. (1980) (179 cm). These factors may account for the differences in knee flexion angles during ascent and descent between this study and other published studies.

Similar to the findings reported by Andriacchi et al. (1980) and Protopapadaki et al. (2007), the current study showed significantly greater dorsiflexion angle at the ankle during descent stairs compared to ascent. The plantar flexion angle was greater during descent compared to ascent, which agrees with the data reported by Protopapadaki et al. (2007). However, Protopapadaki et al. (2007) reported mean maximum flexion angle of 40.08 deg. during descent, which is greater than the value obtained in the current study

(33.6 deg.). On the other hand, Andriacchi et al. (1980) and Livingston et al. (1991) reported mean maximum plantar flexion angle during descent of 25.6 deg. and 30 deg., respectively. Different subject heights, step dimensions, marker placements, and motion analysis devices may be the factors contributing toward the different results among studies.

The moment: The present data showed no significant differences in the mean maximum external hip flexion moment between ascent 0.893 N.m/Kg (SD0.199)) and descent 0.918 N.m/Kg (SD 0.195). The external hip moment was positive during ascent and descent for the most of stance phase, creating an external hip flexion moment. However, there was a period in the late stance during ascent and descent when the external hip moment was negative, creating an external hip extension moment. Variability in the hip moment patterns during stair ascent and descent is reported in the literatures (Andriacchi et al., 1980; Costigan et al., 2002; Protopapadaki et al., 2007; Riener et al., 2002; Nadeau et al., 2003; Salsich et al., 2001; Macfadyen and Winter, 1988). Similar to current study, MacFadyen and Winter (1988), Riener et al. (2002), and Nadeau et al. (2003) reported internal hip extensor moment during stair ascent but observed internal hip flexor moment at the end of the stance phase. Andriacchi et al. (1980) and Protopapadaki et al. (2007) observed external flexion moment during ascent. However, the hip moment graph published by Protopapadaki et al. (2007) shows an external extension moment at approximately 63% of gait cycle. In contrast, Salsich et al. (2001) reported a short period of internal hip flexor moment at the beginning of stance ohase followed by internal hip extensor moment during stair ascent. During descent, similar to present study, Andriacchi et al. (1980) and Protopapadaki et al. (2007) reported external hip flexion moment with a short period of external hip extensor moment at the end of stance phase. In contrast, Riener et al. (2002) reported internal hip flexor moment only during the activity whereas Macfadyen and Winter (1988) reported internal hip extensor moment during mid-stance and hip flexor moment at the end of stance phase. Protopapadaki et al. (2007) noticed this variability in hip moment among studies and explained it by the different positions of the trunk. Different positions of the trunk may bring the line of the ground reaction force anterior or behind the hip joint, thus affecting the hip joint moments.

In the current study, during ascent, there was a short period of external knee extension moment at the beginning of the stance phase, followed by external flexion moment during most of stance phase, and a second period of extension at the end of stance phase. During descent, there was an external extension moment at the beginning of stance phase, followed by external flexion moment until the end of stance phase. The knee moment graphs presented in the current study agree mostly with previous stair climbing investigations (Kowelk et al., 1996; Riener et al., 2002; Protopapadaki et al., 2007; Costigan et al., 2002; Ried et al., 2007). The mean maximum external knee flexion angle was significantly decreased during ascent 0.878 N.m/Kg (SD0.24) compared to descent 1.164 N.m/Kg (SD0.135). This result agrees with the results reported by Andriacchi et al. (1980), Kowelk et al. (1996), Ried et al. (2007), and Crowell et al. (2002). Andriacchi et al. (1980) reported a mean flexion moment of 146 NM (equal to 2.05 NM/kg) during descent and 54.2 N.m (equal to 0.763 N.m/kg) during ascent. Kowelk et al. (1996) reported a (0.885 N.m/kg) of external knee flexion moment during ascent and a (1.45 N.m/kg) during descent. Ried et al. (2007) and Crowell et al. (2002) reported knee flexion moment of (0.96 N.m/kg) and (0.89 N.m/kg) for stair ascent, and (1.5 N.m/kg) and (1.53 N.m/kg) during stair descent, respectively. Riener et al. (2002) reported that maximum external moment values increased with increasing inclination. This may explain the slight differences reported in literature. The data presented by Andriacchi et al. (1980) and Kowelk et al. (1996), who used the same stair dimension as the present study, agreed with the present values to an acceptable degree, However, the slight differences between Andriacchi et al. (1980), Kowelk et al. (1996), and the present study, may be explained by the different subject heights used. The mean height in the present study is 165.2 cm, while in the Andriacchi et al. (1980) and Kowelk et al. (1996) studies, they were 179 cm and 174 cm, respectively. Furthermore, the current study calculated joint moments by using the link-segment method, while Andriacchi et al. (1980) use the ground reaction method. Wells (1981) found different values when comparing moment calculation using link-segment method and the ground reaction method.

At the ankle joint, the present data demonstrate no significant difference in the mean maximum external ankle dorsiflexion moment between ascent (1.279 N.m/Kg (SD0.193)) and descent (1.509 N.m/Kg (SD0.218)). This agrees with previous stair climbing investigations (Protopapadaki et al., 2007; Andriacchi et al., 1980; Lin et al., 2004; Salashi et al., 2001). The external ankle moment was positive in stance phase during stair ascent and descent, creating bi-phasic shaped external dorsiflexion moment. During ascent, the peak value occurred at the end of the stance phase, while the peak value occurred at the beginning of the stance phase during descent. The current ankle moment patterns during ascent and descent agree with previously published studies (Protopapadaki et al., 2007; Riener et al., 2002; Lin et al., 2004; Salashi et al., 2001).

In the frontal plane, both the hip and the knee adduction-abduction moments were included in the current study. At the hip joint, the mean maximum hip adduction moment significantly increased during descent (0.552 N.m/Kg (SD0.233)) compared to ascent (0.747 N.m/Kg (SD0.177)). Andriacchi et al. (1980) and Lin et al. (2004)

included the frontal plane hip joint moment in their studies. Both studies, in agreement with the current data, show that the hip adduction moment during descent is higher compared to ascent. The current graphs show that the frontal plane hip joint moment was positive in the stance phase of stair ascent and descent, creating an external hip adduction moment, with a two-peak pattern which agrees with the graphs published by Andriacchi et al. (1980) and Lin et al. (2004) during ascent and descent, and with Costegin et al. (2002) and Nadeau et al. (2003) during ascent.

At the knee joint, as in previous investigations (Kowelk et al., 1996; Ried et al., 2007; Stuart et al., 1997), no significant difference was found in the adduction moment between ascent and descent. The mean maximum knee adduction moment was 0.695 N.m/Kg (SD0.151), while during descent it was 0.673 N.m/Kg (SD0.151). Kowelk et al. (1996), who used the same stair dimension as the present study, reported a 0.613 N.m/kg (SD0.133) of external knee adduction moment during ascent and a 0.716 N.m/kg (SD0.113) during descent, which agrees to an acceptable extent with the present values. The current graphs show that the frontal plane knee joint moment was positive in the stance phase of stair ascent and descent, creating an external hip adduction moment, which is in agreement with the graphs published by Kowelk et al. (1996), Ried et al. (2007), and Stuart et al.(1997).

<u>Powers</u>: In the present study, the power generation and absorption phases at the hip, knee, and ankle joints agree perfectly with previous stair climbing investigations (Riener et al., 2002; Macfadyen and winter, 1988; Lin et al., 2004; Duncan et al., 1997; Ried et al. 2007). During ascent, all the joints generate energy. Power is generated at the hip and knee joints during the stance phase, mainly at the knee, to facilitate the raising of the contralateral limb to the next step. As soon as the contralateral limb has

approached the next step, during the late stance of the ipsilateral limb, a large power generation occurring at the ankle supports the transfer of the body weight to the leading limb and reduces the need for higher hip and knee joints moments.

During descent, all the joints absorb energy. The energy associated with the initial contact of the stance phase is absorbed primarily at the ankle, with small peaks occurring at the hip and knee joints. However, the largest power absorption happens at the knee during late stance, in order to control the lowering of the contralateral limb from one step to the next.

When comparing the absolute power values, in agreement with Riener et al. (2002), the power is higher at the hip joint during ascending compared to descending. At the knee joint, the absolute power is higher during descending compared to ascending. The absolute power at the ankle joint is equal (i.e. no significant difference) between ascending and descending.

<u>Impulse</u>: Angular impulse is the area under a moment curve while flexion, dorsiflexion, and adduction impulses represent the areas under the positive phases of the moment curves in this current study. An angular impulse quantifies the total contribution of a joint moment toward producing movement. In other words, it gives some indication about the shape of the moment curve.

In the current study, in agreement with the obtained results for moment, the descending phase requires greater knee flexion impulse and hip adduction impulse, compared to ascending phase. No significant difference was found in hip flexion impulse, which also agrees with hip flexion moment results. The ankle dorsiflexion impulse and the knee adduction impulse were higher during descent compared to ascent, although the moment peaks showed no significant difference between ascend and descend. A quick look at the ankle dorsiflexion moment and the knee adduction moment curves can show that the area under the descending curves are greater than ascending curves.

Total work: The total work is the absolute area under the power curve. In agreement with the power data at the hip and the knee, the total work was higher at the hip and lower at the knee during ascending, compared to descending. The total work at the ankle joint was higher during descending compared to ascending, although the power data at the ankle show no significant difference between ascent and descent. The ankle power curve during descending showed a peak of power production at the end of stance phase, In addition, the peak of power absorption occurred at the beginning of stance phase, while the ankle power curve during ascending shows only one peak of power production at the end of stance phase. This explains the result obtained for total work at the ankle joint.

5.3 Staircase Exercises

Four type of staircase exercises were chosen in the present study: Hands behind head (HBH), Holding dumbbells (HDB), Cross step forward (CSF), and Lateral Stepping (LS). However, since in LS activity, each limb performs a different function, this movement was divided into: LSL activity, where the leg of interest is the one responsible for forward progression, and LST activity, where the leg of interest is the other (trailing) leg. Studying the kinematic and kinetic patterns of staircase exercises can provide very important and useful information. The staircase exercises chosen in this study are multiple-joint exercises which stimulate several muscle groups simultaneously. However, the joint-specific differences in the kinematic and kinetic patterns between such exercises and regular stair climbing may be used to target a specific muscle group. The following is a discussion of the results obtained when comparing staircase exercises to the regular stair ascent and descent, and when comparing the ascent and descent phases of each exercise.

At the hip joint, both CSF and LSL activities place greater demands on the hip extensors compared to regular stair walking. During the performance of the CSF activity, participants demonstrated greater flexion moment (AS= 27.2 %; DE=33.8%), impulse (AS= 52.7 %; DE=37.8%), power (AS=25.2 %), and total work (AS=39%) than regular stair walking. On the other hand, the results showed no significant difference in the flexion moment and impulse between ascent and descent phases of CSF activity, while the power and work were greater during ascent compared to descent. Therefore, it can be concluded that CSF activity can be used to target the hip extensors during the ascent and descent phases equally. However, the ascending phase of CSF activity places greater power and work demands on the hip extensors compared to regular stair walking.

For LSL activity, both ascent and descent phases generate greater flexion moment (AS= 16.2%; DE=42.7%), and impulse (AS= 26 %; DE=55.4%) than regular stair walking. On the other hand, descending phase of LSL activity shows greater power (DE=46.7%) and work (DE= 34.3%) requirements than regular descending, while no significant difference was found in power and work between the ascending phase of LSL activity and regular ascending. The phase comparison in LSL activity shows no significant difference in power demands, even though the descent phase generates greater power compared to regular ascent. Moreover, the work demands were higher during LSL ascent compared to descent, although the work was greater during LSL descent compared to regular descent. In addition, the LSL phase differences showed no significant difference in impulse. However, the flexion moment was higher during descent compared to ascent. Therefore, it can be concluded that LSL activity places only greater moment and impulse demands on the hip than regular stair walking, and that the descent phase is more demanding than ascent. In contrast, the descending phase of LST activity lower the moment (62.7%) and impulse (56.9%) demands compared to regular descending.

At the knee joint, only HDB activity places greater demands on the knee extensors compared to regular stair walking. Participants demonstrated greater flexion moment (AS= 20 %; DE=12%), impulse (AS= 20.5 %; DE=23.8%), power (DS=17.9 %), and total work (AS=24%; DE= 19.7) during performance of HDB activity compared to regular stair walking. Comparing the ascending and descending phases of HDB activity showed that descending required greater moment, impulse, power, and work. Therefore, HDB activity should be used when wishing to target the knee extensors. Moreover, the descent phase placed greater demands on the knee extensors than ascent.

On the contrary, both CSF and LSL activities lowered the demands on the knee extensors compared to regular stair walking. CSF activity required less flexion moment (AS= 26.8 %), impulse (AS= 38 %; DE=18.4%), and total work (AS=13.3%; DE= 12.6%) than regular stair walking. However, LSL activity required less flexion moment (AS=18.1%; DE=11.6%), power (DE= 20%), and work (AS=11.4%; DE= 18%) than regular stair walking.

At the ankle joint, similar to the knee joint, the HDB activity demonstrated greater flexion moment (AS= 13 %; DE=20.6 %), impulse (AS= 22.7%; DE=27.5%), power

(DS=48.5 %), and total work (AS=33.9%; DE= 34.5%) compared to regular stair walking. The phase differences, similar to the knee joint, showed that descending required greater moment, impulse, power, and work. Thus, when wishing to target the ankle plantar flexors, HDB activity should be chosen, especially during descending. In addition to HDB activity, the descent phase of LSL activity showed greater dorsiflexion moment (17.1%) and power (58.8%) compared to regular descent. The LSL phase differences revealed that descending phase generated greater moment and power than ascending. Therefore, the descending phase of LSL activity can be also used to target the ankle plantar flexor.

In the frontal plane, both the hip and the knee analyses were included in the present investigation. At the hip, the HDB and CSF activities showed increased demands on the hip abductor over regular stair walking. The HDB activity generated greater adduction moment (AS=31.2%; DE=19.8%) and impulse (AS=33.7%; DE=21.2%). The CSF activity generated greater adduction moment (AS=113.6%; DE=40.16%) and impulse (AS=93.6%; DE=34.3%) over regular stair walking. On the other hand, both HDB and CSF showed no significant phase difference in adduction moment and impulse. Therefore, both activities placed greater demands on the hip abductors during ascent and descent phases equally.

In addition to the HDB and CSF activities, both ascent and descent phases of LST activity generated greater adduction moment (AS=166.9%; DE=44.2%) than regular stair walking. On the other hand, the ascending phase of LST activity showed greater impulse (67%) than regular ascending, while no significant difference was found in impulse between descending phase of LST activity and regular descending. The phase comparison in LST showed no significant difference in impulse, even though the ascent phase required greater impulse compared to regular stair walking. Moreover, the moment during ascent was higher than during descent. Hence, it can be concluded that LST activity only placed greater moment demand during ascent and descent phases compared to regular stair walking, and that the ascent phase was more demanding than descent. The descent phase of LSL activity also showed greater adduction moment (50%) than regular descent. Moreover, the LSL phase differences revealed that descent phase needed greater adduction moment than ascent. Thus, the descend phase of LSL activity placed more demands on the hip abductor than regular stair ascent and descent.

Comparatively, as seen by the increased percentages of HDB, CSF, LSL, and LST activities over regular stair walking, and by the phase differences, it is more appropriate to choose CSF and LST activities during ascending, and to choose CSF and LSL activities during descending, when wishing to target the hip abductors.

At the knee joint, in the frontal plane, HDB and CSF activities showed increased demands on the knee abductor over regular stair walking. HDB activity generated greater adduction moment (AS=30.5%; DE=16.9%) and impulse (AS=45.8%; DE=17.8%). The CSF activity also generated greater adduction moment (AS=40.2%; DE=43.4%) and impulse (AS=77.3%; DE=30.5%) over regular stair walking. On the other hand, HDB activity showed no significant phase difference in impulse, while the moment was higher during ascent compared to descent. The CSF phase comparisons showed no significant difference in adduction moment and impulse. Therefore, both activities placed greater demands on the knee abductors during ascent and descent phases. However, the HDB activity placed higher demands during ascent phase than descent, while CSF place equal demands during ascent and descent.

In addition, both the ascent and descent phases of LSL activity generated greater adduction moment (AS=45.2%; DE=29.6%) than regular stair walking. On the other hand, descending phase of LSL activity showed greater impulse (18.7%) than regular descending, while no significant difference was found in impulse between ascending phase of LSL and regular ascending. The phase comparison in LSL activity showed no significant difference in moment demands, and that descending phase generated greater impulse than ascending. Therefore, it can be concluded that the LSL activity placed greater moment demands during ascent and descent, and greater impulse during descent compared to regular stair walking.

LST activity also generated greater adduction moment (AS=22.2%; DE=52%) than regular stair walking. The ascending phase of LST activity showed greater impulse (48%) than regular ascending, while no significant difference was found in impulse between descending phase of LST activity and regular descending. The phase comparison in LST showed no significant difference in impulse, even though the ascent phase required greater impulse compared to regular stair walking. Moreover, the moment during descent was higher than during ascent. Hence, it can be concluded that LST activity only placed greater moment demand during ascent and descent phases compared to regular stair walking, and that the descent phase is more demanding than ascent.

Comparatively, as seen by the increased percentages of the adduction moment and impulse for the HDB, CSF, LSL, and LST activities over regular stair walking, and by the phase differences, it is more appropriate to choose CSF activity during ascending, and to choose CSF and LST activities during descending, when wishing to target knee abductors.

The HBH activity did not show any significant difference compared to regular stair walking, except an increase in ankle dorsiflexion moment during descent. However, this increase was just 8.5% greater than regular descending, and it was lower than the increased demonstrated by HDB and LSL activities. Therefore, this movement can be ignored.

For the lateral stepping (LS) activity, unlike other movements, each limb performed a different function. As discussed above, the limb which was responsible for forward progression (LSL) placed greater demands on hip extensors during ascent and descent and on plantar flexors and hip abductors during descent, while the other (trailing) leg placed greater demands on hip abductors during ascent and on the knee abductors during descent. Therefore, based on these results, a choice can be made on which limb to use as the one responsible for forward progression and as the trailing leg.

5.4 Slim Versus Obese People

Obesity is one of the critical health problems the world faces nowadays. Obesity is associated with numerous health risks including an increased risk for cardiovascular disease, insulin resistance, and osteoarthritis (Devita and Hortobagyi, 2003). Osteoarthritis is the most common joint disease caused by joint degeneration, a process that includes progressive loss of articular cartilage accompanied by attempted repair of articular cartilage, remodeling and sclerosis of subchondral bone, and osteophyte Formation (Buckwalter and Mankin, 1997; Buckwalter and Martin, 1995). One major mechanism associated with pathogenesis of osteoarthritis is increased load across the articular cartilage (Mow et al., 1995; Radin et al., 1995). Obesity is considered as one of the important risk factors for development of osteoarthritis. Sturmer et al. (2000) and Felson (1988) reported a strong association between obesity and bilateral knee osteoarthritis but no association between obesity and hip osteoarthritis. Researchers suggest that increased weight associated with obesity directly increases knee loads that subsequently lead to knee osteoarthritis (Felson, 1988; Felson and Zhang, 1998; Hochberg et al., 1995; Korner and Eberle, 2001).

Obese people are encouraged to participate in some sort of exercises such as the chosen staircase exercises. However, those types of exercises may place loading conditions at the knee joint which may cause degenerative knee joint diseases. These facts show the importance of studying the biomechanics of staircase exercises for obese people in comparison to their slim counterparts.

The obese participants who volunteered as subjects in the present study were young individuals free of any health problems except obesity. The obese and slim groups matched in age, gender, and height, and only differed in weight and the body mass index (BMI). The obese participants were, an average, 51.4 % more massive than the slim participants. Therefore, it was assumed that all observed gait differences were due to factors related to body composition and weight.

The knee flexion and adduction moments are the gait parameters which are usually connected to the development and progression of knee osteoarthritis (Kerrigen et al., 2000; Deluzio and Astephen, 2007). Researchers have suggested that the knee adduction moment, which gives an estimation of the distribution of loads transferred through the medial and lateral compartments of the knee, is the signal most important extrinsic load factor related to the knee osteoarthritis. Therefore, the external knee adduction moment during gait has been used as an indirect measure of the medial knee loading for many years (Goh et al, 1993; Noyes et al, 1992; Prodromos et al, 1985; Schipplein and Andriacchi, 1991; Wang et al, 1990). The use of this reliable measure as a proxy for medial load has been supported by studies of bone mineral density distribution, tibial cartilage thickness and direct measurement of the contact forces (Maly, 2008). Direct measurement of the contact forces within the medial compartment of the knee *in vivo* is difficult and has not been widely reported. To date, direct measurement has been achieved in only one individual with a knee implant instrumented with four load cells. The external knee adduction moment was highly correlated with medial contact force (Zhao et al, 2007). Moreover, the adduction moment has been found to cause osteoarthritic changes in the medial compartment of the rabbit's knees (Ogata et al., 1977).

The knee flexion and adduction moments showed some significant differences between the obese and slim people for the ascending and descending phases of all movements. During ascending, the obese people showed reduction in the knee flexion moment for RW (34.6 % less), HBH (36% less), and HDB (33.7% less) activities. However, they maintain the same flexion moment as slim people for CSF, LSL, and LST. For the adduction moments, the obese people maintain equal frontal plane moment as the slim people for all movements except for the LST which showed reduction of 14.4 % compared to slim people.

During descending, the obese people showed reduction in the knee flexion moments for RW (20.4% less), HBH (24.3% less), HDB (22.3% less), LSL (19.7% less), and LST (22.3% less) activities, and maintained the same flexion moment for CSF activity, compared to their slim counterparts. The adduction moment showed no significant differences between obese and slim people for all movements.

The previous discussion has shown that only HDB activity increases the flexion moment over regular stair ascent and descent. The obese people reduced this load by 33.7% during ascending and by 22.3% during descending compared to slim people. On the other hand, all the activities, except HBH, showed an increase in the knee adduction moments over regular stair ascent and descent. The obese people maintain the same adduction moments as the slim people in all of these activities during ascent and descent phases. However, the knee adduction moment was lowered for obese people by 14.4% for LSL activity during ascending compared to slim people. Therefore, it can be observed that obese people, when compared to slim people, are able to reduce or maintain the same flexion and adduction moments values, which are the most important gait parameters related to the development of knee joint degenerative joint disease.

The knee powers were equal between obese and slim people during the ascending phase of all movements. During descending, the obese subjects reduced power absorption by 21% for HBH, 16.2% for HDB, and 29.9% for LSL, and maintained the same power absorption for RSW, CSF, and LST. Obese people reduced the flexion angular impulse during ascending phase by 54.3% for RSW, 51.7% for HBH, 52.5% for HDB, and 51% for LSL compared to slim people. The knee adduction impulses reduced by 35.6% for CSF, and by 37% for LST for obese people compared to slim people. During descending, obese people show reduction in knee flexion impulse by 42.7% for RSW, 41.5% for HBH, 44.4% for HDB, 36.5% for CSF, 39.7% for LSL, and 44.6% for LST. In the case of obese people, the knee adduction impulses were reduced by 27.5% for HDB, 26.6% for CSF, and 21.7 for LST. The total work was reduced for obese people for all movements during ascending and descending compared to slim people. Accessing the knee joint loads clarifies that obese people are able to mainly reduce or maintain the same loading conditions as the slim people for all the movements, during ascending and descending phases.

At the hip, the flexion moments were equivalent between obese and slim people during ascending and descending for all movements. In the case of obese people, the hip adduction moments were higher by 40.7% for LSL during ascending, as well as by 22.25% for CSF and 18.5% for LST during descending. The hip power only shows reduction for CSF activities during ascending in the case of obese people. The flexion impulses were lowered for CSF activity during both ascending and descending but in LSL, only during ascending. The hip adduction impulses were higher, in case of obese people, only for CSF and LST during ascending phase. The work was lower at the hip for all movements during ascending and descending phases.

At the ankle, obese people showed reduction in the ankle dorsiflexion moments for LSL and LST during both ascending and descending, for HDB and CSF during ascending, and for HBH during descending. The ankle powers were reduced, in the case of obese, for HDB and LSL, during both ascending and descending, and for RSW and LST, during ascending. The total work and the dorsiflexion impulses were reduced for all movements during ascending and descending compared to slim people.

Gait analyses of obese individuals have identified some kinematics adaptations including slower velocity, shorter step length, and increased stance phase time, compared to lean individuals (Devita and Hortobagyi, 2003). Unlike level walking, the step length during stair climbing is restricted by the stair dimensions. During ascending, the obese people were walking with lower speed and relatively higher stance phase for all movements. During descending, the obese people were walking with lower speed, but no significant difference in the stance phase was found between the obese and non-obese subjects.

CHAPTER SIX: CONCLUSION AND RECOMMENDATIONS FOR FUTURE WORK

6.1 Conclusion

People are encouraged to include some kinds of physical activity into their daily routine. However, many people cannot find time to go to the gymnasium because of work, traffic, or inappropriate surrounding. Moreover, exercise equipments are bulky and expensive. Therefore, a staircase might be the practical solution to these problems, since the staircase provides free and easy access as a tool for exercising. A wide variety of exercises has been proposed to be done on a staircase. Among them, four types of staircase exercises were included in the current study, namely, walking up and down stairs with the hands behind the head, walking holding dumbbells, walking in cross-step manner, and lateral stepping.

The objectives of the current study were to find out the differences in the kinematics and kinetic patterns between the mentioned exercises and regular stair climbing during ascending and descending a staircase, and to find out how people who are obese perform when doing those exercises and to compare their performance to that of those who are slim.

In the sagittal plane, the results of the study indicate that, in young healthy adults, the cross step forward and the lateral stepping (leading limb) activities place greater demand on the hip extensors, while holding dumbbells activity places greater demand on the knee extensors and on the ankle dorsiflexors. Besides, the descent phase of the lateral stepping (leading limb) activity places greater demand on the ankle dorsiflexors.

In the frontal plane, the results indicate that, in young healthy adults, the cross-step forward activity places greater demand on the hip abductor during ascent and descent. In addition, both the leading limb of the lateral stepping activity during descent and the trailing limb during ascent place greater demand on the hip abductors. At the knee, the cross-step forward activity during ascent and descent and the descent phase of the lateral stepping (trailing limb) place greater demand on the knee abductors.

These findings may be used to more effectively target specific lower-extremity muscle groups when recommending exercise for young individuals so that they can benefit from the stair at the office, in the home or at the shopping mall to build and maintain healthy bones, muscles, and joints.

Compared to slim people, the obese people were able to reduce or maintain the same load on the knee joint when performing those exercises during ascending and descending a staircase. There were some significant differences in the temporal, joint motion, and joint moment, power, impulse, and work data between the obese and the non-obese participants. The obese individuals might adjust their gait characteristics in response to their heavy bodies to reduce or maintain the same load on the knee joint as the slim people.

6.2 Recommendations For Future Work

The current research investigates the kinematics and kinetics of four types of the proposed exercises that can be done on a staircase by slim and obese people at their self selected speed. This work provides pioneering research conducted on the biomechanics of staircase exercises, besides including the study of obese people doing stair climbing. However, many other related aspects can be covered in future research, namely:

- Types of proposed staircase exercises other than those chosen in the current research.

- Variation in the exercises speed. Future research can be done to find out the effect of velocity on the kinematics and kinetic of those exercises.

- Ways to increase the intensity of those exercises. Suggested ways to do so may include walking with backpack, climbing larger steps, and climbing two or more step at a time.

- The number of repetitions to be performed. Fatigue effects following repetitions will likely change the kinetics associated with the exercise. Therefore, the fatigue response could be considered in future work.

References

Allied Dunbar National Fitness Survey (1990). *Summary Report. Activity and Health Research*. Health Education Authority/Sports Council, London.

Anderson M., Hall S.J., and Martin M. (2000). Knee conditions. In: *Sports Injury Management* (2nd ed., pp. 431-482). Philadelphia: Lippincott Williams and Wilkins.

Andriacchi T.P., Anderson G.B.J., Fermier R.W., Stern D., and Galante J.O. (1980). A study of lower-limb mechanics during stair-climbing. *Journal of Bone and Joint Surgery* **62**(5), pp. 749–757.

Andriacchi T.P., Galante J.O., and Fermier R.W. (1982). The influence of total knee-replacement design on walking and stair climbing. *Journal of Bone and Joint Surgery* **64**, pp. 1328–1335.

Arnheim D.D. and Prentice W.E. (1997). The knee and related structure. In: *Principles of Athletic Training* (9th ed., pp. 469-515), WCB McGraw-Hill/Mosby.

Beaulieu F.D., Pelland L., and Robertson D.G.E. (2007). Kinetic analysis of forwards and backwards stair descent. *Gait and Posture* **27**, pp. 564-571.

Boreham C.A.G., Wallace W.F.M., and Nevill A. (2000). Training effects of accumulated daily stair climbing exercise in previously sedentary young women. *Preventive Medicine* **30**,pp. 277-281.

Boreham C.A.G, Kennedy R.A., Murphy M.H., Tully M., Wallace W.F.M., and Young I. (2005). Training effected if short bouts of stair climbing on cardio-respiratory fitness. *British Journal of Sports Medicine* **39**, pp. 590-593.

Brechter J. and Powers C.M. (2002). Patellofemoral joint stress during stair ascent and descent on persons with and without patellofemoral pain. *Gait and Posture* **16**(2), pp. 115-123.

Brownell K.N., Stunkard A., and Albaum J. (1980). Evaluation and modification of exercise patterns in the national environment. *American Journal of Psychiatry* **137**, pp. 1540-1545.

Buckwalter J.A and Martin J.A. (1995). Degenerative joint disease. *Clinical Symposia*, Ciba-Geigy, Summit NJ, pp. 2-32.

Buckwalter J.A. and Mankin H.D. (1997). Articular cartilage II: Degeneration and osteoarthrosis, repair, regeneration and transplantation. *Journal of Bone and Joint Surgery* **79A**(4), pp. 612-632.

Catani F., Bendetti M.G., Defelice R., Buzzi R., and Giannini P.A.S. (2003). Mobile and fixed bearing total knee prosthesis functional comparison during stair climbing. *Journal of Clinical Biomechanics* **18**, pp. 410-418.

Copper C., Mcalindon T., Coggen D., Egger P., and Dieppe P. (1994). Occupational activity and osteoarthritis of the knee. *Annals of Rheumatic Disease* **53**, pp. 90-93.

Costigan P.A., Deluzio K.J., and Wyss U.P. (2002). Knee and hip kinetics during normal stair climbing. *Gait and Posture* **16**, pp. 31–37.

Coupland C.A., Cliffe S.J., Bassey E.J., Grainge M.J., Hosking D.J., and Cilvers C.E. (1999). Habitual physical activity and bone mineral density in postmenopausal women in England. *International Journal of Epidemiology* **28**, pp. 241-247.

Crossley K.M., Cowan S.M., Bennell K.L., and Mcconnel J. (2004). Knee flexion during stair ambulation is altered in individuals with patellofemoral pain. *Journal of Orthopedic Research* **22**, pp. 267-274.

Deluzio K.J. and Astephen J.L. (2007). Biomechanical features of the gait waveform data associated with knee osteoarthritis: an application of principal component analysis. *Gait and Posture* **25(1)**, pp. 86–93.

DeVita P. and Hortobagyi T. (2003). Obesity is not associated with increased knee joint torque and power during level walking. *Journal of Biomechanics* **36**, pp. 1355-1362.

Dolan M.S., Weiss L.A., Lewis R.A., Pitrobelli A., Heo M., and Faith M.S. (2006). "Take the stairs instead of the escalator": Effect of environmental prompts on community stair use and implications for national 'Small steps' compaign. *Obesity Reviews* **7**, pp. 25-32.

Dunleavy M.A. (1985). Anatomy and Physiology of the Human Knee Joint. Retrieved on October 12 2008 from Yale-New Haven Teachers Institute: http://www.yale.edu/ynhti/curriculum/units/1985/7/85.07.06.x.html.

Edward P. (1983). Stair walking: A few steps to better health. *Journal of Public Health* **74**, pp. 63-65.

Eves F.F., Webb O.J., and Mutrie N. (2006). A workplace intervention to promote stair climbing: greater effects in overweight. *Obesity* **14**(12), pp. 2210-2216.

Felson D.T. (1988). Epidemiology of hip and knee osteoarthritis. *Epidemiological Reviews* **10**, pp. 1–28.

Felson D.T. and Zhang Y. (1998). An update on the epidemiology of knee and hip osteoarthritis with a view to prevention. *Arthritis and Rheumatism* **41**, pp. 1343–1355.

Flangan S.P., Wang M-Y, Greeandale G.A., Azen S., and Salem G.J. (2004). Biomechanical attributes of lunging activities for older adults. *Journal of Strength and Conditioning Research* **18**(3), pp. 599-605.

Frind M. (2007). Brief Overview of Anatomy and Physiology of the Knee. Retrieved on October 12 2008 from Bob's ACL WWWBoard On-Line Knee Library: http://www.factotem.org/library/database/Knee-Articles/Knee-anatomy-physiology.shtml.

Goh J., Bose K., and Khoo B. (1993). Gait analysis study on patients with varus osteoarthritis of the knee. *Clinical Orthopedics and Related Research* **294**, pp. 223-231.

Guccione, A.A., Felson D.T., Anderson J.J., Anthony J.M., Zhang Y., Wilson P.W., Kelly-Hayes M., Wolf P.A., Kreger B.E., and Kannel W.B. (1994). The effects of specific medical conditions on functional limitations of elders in the Framingham study. *American Journal of Public Health* **84**, pp. 351-358.

Health Canada. (2005). Stairway to Health. Retrieved on January 12 2009 from: http://www.phac-aspc.gc.ca/sth-evs/english/index-eng.php.

Hochberg M.C., Lethbridge-Cejku M., Jr.Scott W.W., Reichle R., Plato C.C., and Tobin J.D. (1995). The association of body weight, body fatness and body fat distribution with osteoarthritis of the knee data from the Baltimore longitudinal study of aging. *Journal of Rheumatology* **22**, pp. 488–493.

Hughes C.A., Kaufman K.R., Morrey B.F., Morrey M.A., and An K.N. (2000). Gender differences in knee kinematics and kinetics during stair climbing and level walking in adults with osteoarthritis of the knee. *Proceedings of the 24th American Society of Biomechanics conference*.

Ilmarinen J., Ilmarinen R., Koskela A., Korhonen O., Fardy P., Raranen T., and Rutenfranz J. (1979). Training effects of stair climbing during office hours on female employees. *Ergonomics* **22**(5), pp. 507-516.

Kerr J., Eves F., and Carroll D. (2001). Six-month observational study of promoted stair climbing. *Preventive Medicine* **33**(5), pp. 422-427.

Kerr N.A., Yore M.M., Ham S.A., and Dietz W.H. (2004). Increasing stair use in a worksite through environmental changes. *American Journal of Health Promotion* **18**, pp. 312-315.

Kerrigen D.C., Riley P.O., Nieto T.J., and Della C.U. (2000). Knee joint torques; comparison between women and men during barefoot walking. *Archives of Physical Medicine and Rehabilitation* **18**, pp. 1162–1165.

Korner J. and Eberle M.A. (2001). An update on the science and therapy of obesity and its relationship to osteoarthritis. *Current Rheumatology Reports* **3**, pp. 101–106.

Kowalk D.L., Duncan J.A., and Vaughan C.L. (1996). Abduction–adduction moment at the knee during stair ascent and descent. *Journal of Biomechanics* **29**, pp. 383–388.

Lin H.C., Liu T.W., and Hsu H.C. (2006). Kinetic alterations of lower-limb during stair locomotion in ACL injured subjects. *5th World Conference of Biomechanics*: Munich, German.

Livingston L.A., Stevenson J.M., and Olney S.J. (1991). Stair climbing kinematics on stairs of differing dimensions. *Archives of Physical Medicine and Rehabilitation* **72**, pp. 398–402.

Maalindon T.E., Wilson P.W., Aliabadi P., Weissman B., and Felson D.T. (1999). Level of physical activity and the risk of radiographic and symptomatic knee osteoarthritis in the elderly: the Framingham study. *American Journal of Medicine* **106**, pp. 151-157.

Maly M.R. (2008). Abnormal and Cumulative Loading in Knee Osteoarthritis. *Current Opinion in Rheumatology* **20**(5), pp. 547-52.

McFadyen B.J. and Winter D.A. (1988). An integrated biomechanical analysis of normal stair ascent and descent. *Journal of Biomechanics* **21**(9), pp. 733–744.

Mow V.C., Setton L.A., Guilak F., and Ratcliffe A. (1995). Mechanical factors in articular cartilage and their role in osteoarthritis. In: Kuettner KE, Goldberg VM, editors. *Osteoarthritic Disorders*. Rosemont, IL: American Academy of Orthopedic Surgeons, pp. 147–171.

Nadeau S., McFadyen B.J., and 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. *Journal of Clinical Biomechanics* **18**(10), pp. 950–959.

Noyes F.R., Schipplein O.D., Andriacchi T.P., Saddemi S.R., and Weise M. (1992). The anterior cruciate ligament-deficient knee with varus alignment: an analysis of gait adaptations and dynamic joint loadings. *American Journal of Sports Medicine* **20**, pp. 707-716.

Ogata K., Whiteside L.A., Lesker P.A., and Simmons D.J. (1977). The effects of varus stress on the moving rabbit knee joint. *Clinical Orthopedics and Related Research* **129**, pp. 313-318.

Paffenbarger R.S., Jr. Hyde R.T., Wing A.L., Lee I-M, Jung D.L., and Karnpett J.B. (1993). The association of changes in physical activity level and other lifestyle characteristics with mortality among men. *New England Journal of Medicine* **328**(8), pp. 538-545.

Prodromos C., Andriacchi T., and Galante J. (1985). A relationship between gait and clinical changes following high tibial osteotomy. *Journal of Bone and Joint Surgery* **67**(A), pp.1188-1194.

Protopapadaki A., Drechster W.I., Cramp M.C., Cochs F.J., and Scott O.M. (2007). Hip, knee, and ankle kinematics and kinetics during stair ascent and descent in healthy young individuals. *Journal of Clinical Biomechanics* **22**, pp. 203–210.

Radin E.L., Schaffler M., Gibson G., and Tashman S. (1995). Osteoarthritis as the result of repetitive trauma In: Kuettner KE, Goldberg VM, editors. *Osteoarthritic Disorders*. Rosemont, IL: American Academy of Orthopedic Surgeons, pp. 197-203.

Ried S.M., Lynn S.K., Musselman R.P., and Costigan P.A., (2007). Knee biomechanics of alternate stair ambulation pattern. *Medicine and Science* in *Sports* and *Exercise* **39**(11), pp. 2005-2011.

Riener R., Rabuffetti M., and Frigo C. (2002). Stair ascent and descent at different inclinations. *Gait and Posture* **15**, pp. 32–44.

Salsich G.B., Brechter J.S., and Powers C.M. (2005). Lower extremity kinematics and kinetics during level walking and stair climbing in subjects with triple arthrodesis or subtalar fusion. *Gait and Posture* **21**(3), pp. 263-270.

Schipplein O. and Andriacchi T. (1999). Interaction between active and passive knee stabilizers during level walking. *Journal of Orthopedic Research* **9**(1), pp. 113-119.

Schmalz T., Blumentritt S., and Jarasch R. (2004). A Comparison of Different prosthetic knee joints during step over step stair descent. *Orthopädie-Technik Quarterly, English edition* **II** (7), pp. 586-592.

Schmalz T., Blumentritt S., and Marx B. (2006). Biomechanical analysis of stair ambulation in lower limb amputees. *Gait and Posture* **25**(2), pp. 267–278.

Shenassa E.D., Frye M., Braubach M., and Daskalakis C. (2008). Routine stair climbing in place of residence and body mass index: A Pan-European population based study. *International journal of obesity* **32**, pp. 490-494.

Shurr D. and Michael J.W. (2002). *Prosthetics and orthotics*. Pearson education, Inc. Capital J and W.

Sturmer T., Gunther K.P., and Brenner H. (2000). Obesity, overweight and patterns of osteoarthritis the Ulm Osteoarthritis Study. *Journal of Clinical Epidemiology* **53**, pp. 307–313.

Thambyah A., Thiagrajan P., and Goh-Cho-Hong J. (2004). Knee joint moments during stair climbing of patients with anterior cruciate ligament deficiency. *Journal of Clinical Biomechanics* **19**(5), pp. 489-496.

Thompson C.W. and Floyd R.T. (2001). The knee joint. In Kane, K.T. and Malinee, V. (Eds.), *Manual of structural kinesiology* (14th ed, pp. 144-158).

US Surgeon General (1996). Physical activity and health: a report of the Surgeon General. Atlanta, GA: U.S. Department of Health and Human Services, Centers for Disease Control and Prevention, National Center for Chronic Disease Prevention and Health Promotion. Retrieved on January 12 2009 from: http://aspe.hhs.gov/health/reports/physicalactivity/

Venicek N., Strike S., McNaughton L., and Polman R. (2007). Biomechanical analysis of stair climbing in transtibial amputees. *Journal of Biomechanics* **40**(S2), p. S501.

Wang J., Kuo K., Andriacchi T., and Galante J. (1990). The influence of walking mechanics and time on the results of proximal tibial osteotomy. *Journal of Bone Joint Surgery* **72**(A), pp. 905-909.

Whittle M.W. (2002). *Gait analysis: an introduction.* Butterworth-Heinemann, third edition.

Williams L. (1989). America Goes stair crazy. Time magazine. Retrieved on January 12 2009 from: www.time.com/time/magazine/article/0,9171,959350-2,00.html. .

Winter D.A. (1990). *Biomechanics and motor control of human movement.* Toronto: Wiley-Interscience Publication.

Yu S., Yarrell J.W.G., Swetnam P.M., and Muray L. (2003). What level of physical activity protects against premature cardiovascular death?. The Caerphilly study. *Heart* **89**, pp. 502-506.

Zhao D., Banks S.A., Mitchell K.H., D'Lima D.D., Colwell C.W., and Jr. Fregly B.J. (2007). Correlation between the knee adduction torque and medial contact force for a variety of gait patterns. *Journal of Orthopedics Research* **25**, pp. 789-797.

LIST OF PUPLICATIONS

The research described in this dissertation had led to the publication of the following papers:

A. JOURNALS

Sami Almashaqbeh, Wan Abu Bakar Wan Abas, and Noor Azuan Abu Osman (2009). Biomechanics of regular and lateral stair climbing. *Journal of Mechanics In Medicine and Biology*. (Accepted with some revisions).

Sami Almashaqbeh, Wan Abu Bakar Wan Abas, and Noor Azuan Abu Osman (2009). biomechanics of staircase exercises. *Journal of Applied Biomechanics*. (submitted).

B.PROCEEDINGS

Sami Almashaqbeh, Wan Abu Bakar Wan Abas, and Noor Azuan Abu Osman (2009). Biomechanics of stair ascending exercises. *In the proceeding of XXIInd Congress of the International Society of Biomechanics*; Cape Town, South Africa, July 5- 9, 2009, pp. 274.

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APPENDIX: Gait Analysis And The Human Knee

A.1 Movement Terminologies

The location of any part of the human body is described using specific terms called the directional terms as shown in **Figure A.1 (A).** Distal indicates that the location is farther away from the trunk, and Proximal indicates that it is closer to the trunk. Lateral means that the location is away from the mid line, and Medial means that it is closer to the mid line. Anterior and posterior refer to the front and back parts of the body. Superior means closer to the head, and Inferior means farther away from the head. Plantar indicates that the location is at the bottom of the foot, and Dorsal is on the top of it.

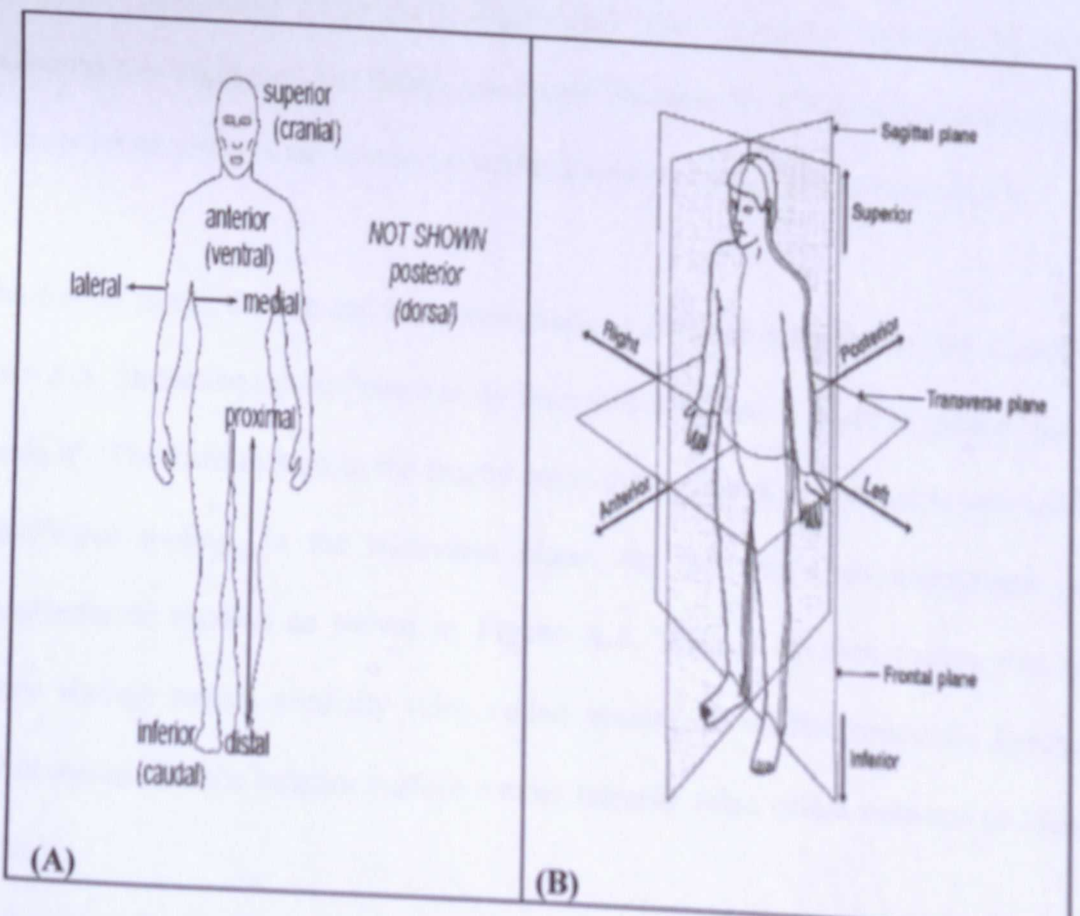

Figure A.1: A) The directional terms. B) The three reference planes and six fundamental directions of the human body, with reference to the anatomical position.

The anatomical position is the position in which a person is standing upright with the foot together and the arms by the side of the body, with the palms facing forward

(Whittle, 2002). The motion of the body segment is described to happen in three planes that are referenced to the anatomical position as shown in **Figure A.1** above. These planes are the Sagittal plane, Frontal (or coronal) plane, and the Transverse plane. The Sagittal plane is the centroidal vertical plane that divides the body into the right and left parts. The Frontal plane is the centroidal vertical plane that divides the body into the anterior and posterior parts. The Transverse plane is the centroidal horizontal plane that divides the body into the inferior and superior parts.

The joint motion can be described using the definitions of motion in the three planes. In the sagittal plane, the hip and knee movement is Flexion/Extension, and at the ankle is Planerflexion/Dorsifexion as shown in **Figure A.2**. Flexion means "decrease the angle between the two segments" and Extension means "increase it". Plantarfexion means that the toes point up towards the shin and dorsiflexion means that the toes point down.

In the frontal plane, the hip and knee movement is Abduction/Adduction as shown in **Figure A.3**. Abduction means "move away from mid-line" and Adduction means "move towards it". The knee motion in the frontal plane during the stance phase is also called Valgus/Varus motion. In the transverse plane, the hip and knee movements are internal/external rotation as shown in **Figure A.3**. Internal rotation means that the anterior surface rotates medially (also called inward or medial rotation). External rotation means that the anterior surface rotates laterally (also called outward or lateral rotation).

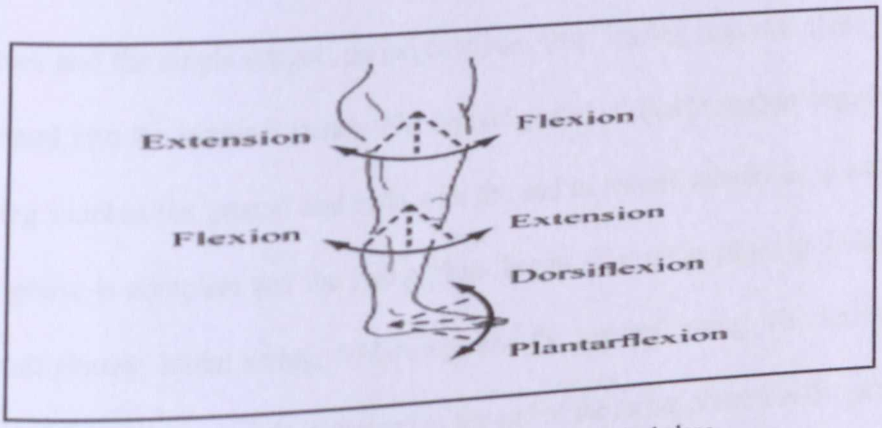

Figure A.2: Movements about the hip, knee and ankle joints in the sagittal plane.

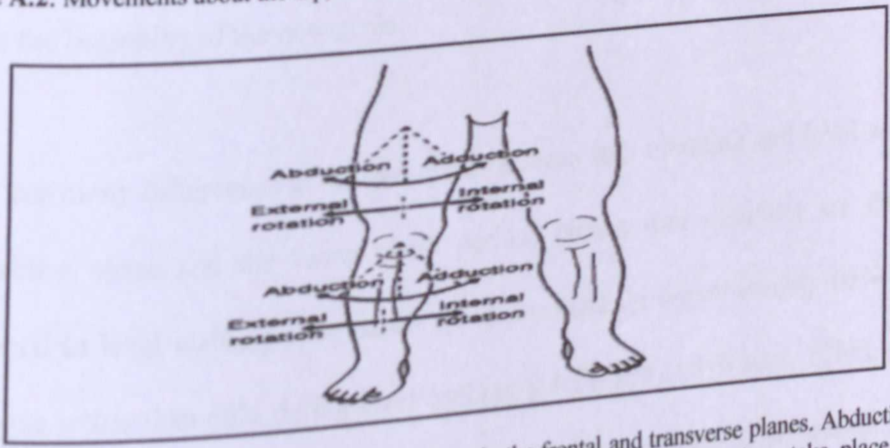

Figure A.3: Movements about the hip and knee joints in the frontal and transverse planes. Abduction and adduction take place in the frontal plane while the internal and external rotations take place in the transverse plane.

A.2 The Gait Cycle

The gait cycle is the sequential repetition of (approximately) the same movements of the major joints of the body during ambulation (Shurr and Michael, 2002). It is also defined as one complete step of walking beginning and ending with the same event (e.g. heel strike to heel strike of the same foot). Gait cycle is composed of two phases: stance phase which is the period at which the foot of concern is touching the ground, and swing phase which is the period at which the same foot is in the air.

The stance and swing phases are further divided into sub-phases as shown in **Figure A.4**. The stance phase begins with heel strike (heel contact or initial contact). The loading response refers to the period where the weight is being transferred to the foot in question. The first period of double supports ends with the beginning of loading response, and the single support period continues from loading response, through mid-stance and into the terminal stance. The second period of double support begins as the other leg touches the ground and ends with the end of toe-off sub-phase, at which the stance phase is complete and the swing phase begins. The swing phase is divided into three sub-phases: initial swing, mid-swing, and the terminal swing. The second heel contact of the foot in question is defined as the end of the swing phase and the gait cycle and as the beginning of the new cycle.

There are many differences in the gait cycle between stair climbing and level walking. The stance phase and the swing phase periods during stair climbing are different compared to level walking. The stance phase accounts for approximately 65% of the gait cycle rather than 60% during level walking (McFadyen and Winter, 1988), and so the swing phase is shorter during stair climbing. The stance phase of stair ascent can be broken down into three parts: weight acceptance (WA), pull-up (PU), and forward continuance (FCN) while the swing phase can be divided into two parts: foot clearance (FCL) and foot placement (FP) (Mcfadyen and Winter, 1988) as shown in **Figure A.5 (A)**. The stance phase whilst walking down stairs can be broken down into three sub-phases described as weight acceptance (WA), forward continuance (FCN) and controlled lowering (CL). The swing period had two phases, leg pull-through (LP) and preparation for foot placement (FP) (McFadyen and Winter, 1988) as shown in **Figure A.5 (B)**.

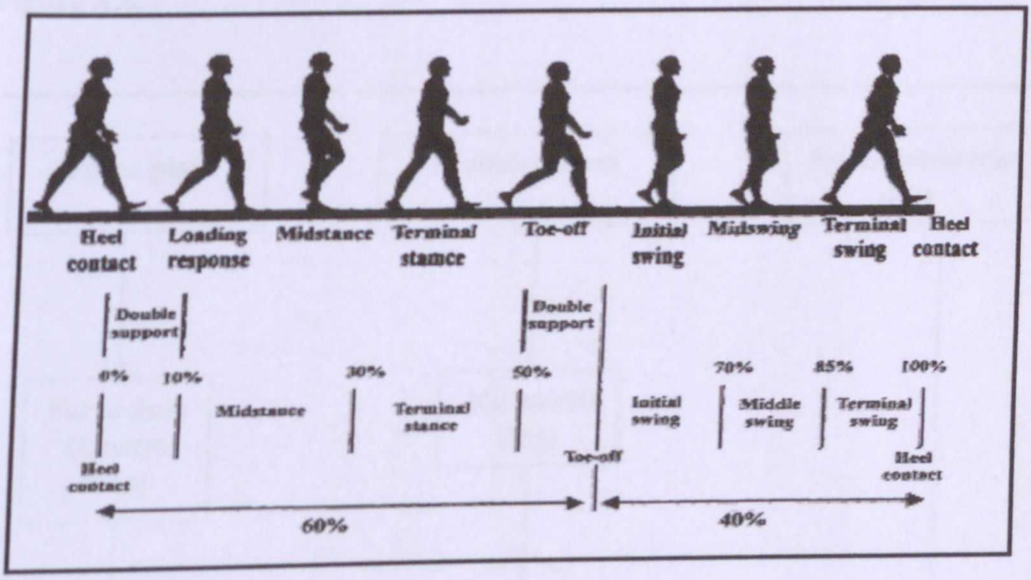

Figure A.4: The swing and stance phases during level walking with its respective subdivisions and corresponding percentages of the gait cycle.

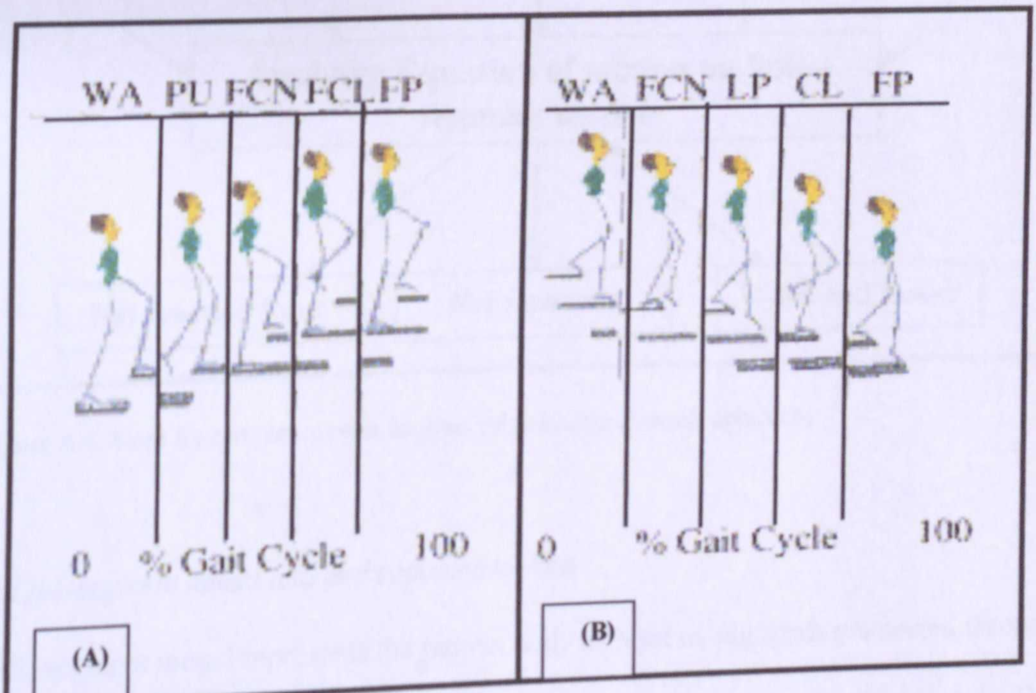

Figure A.5: The gait cycle during (**A**) stair ascent and (**B**) descent.

A.3 Motion Analysis Using Inverse Dynamic Approach

Three pieces of information are needed in order to calculate the joint kinetics (i.e. moments, work, power, and reaction forces) using the inverse dynamic solution: 1) link-segment model and anthropometric data, 2) Kinematics data, 3) force data, as shown in **Figure A.6**.

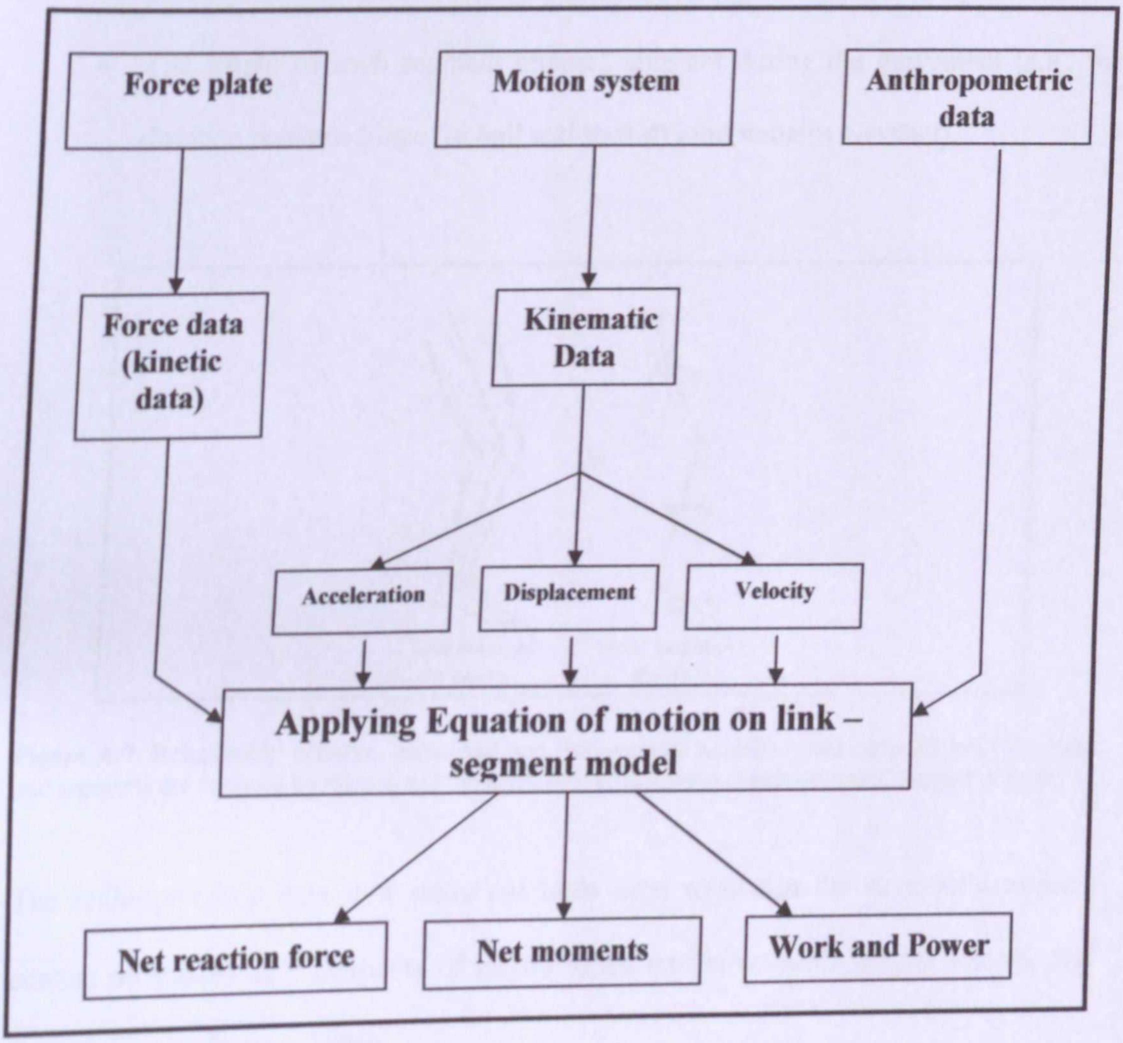

Figure A.6: Steps for complete motion analysis using inverse dynamic approach.

1) Link-segment model and anthropometric data

Link-segment model represents the human body as a set of segments connected through points representing the center of rotation of each joint as shown in **Figure A.7**. The following assumptions are made with respect to the link-segment model (Winter, 1990):

- Each segment has affixed mass located as a point mass at its center of mass (which will be the center of gravity in the vertical direction).
- The location of each segment's center of mass remains fixed during the movement.

- The joints are considered to be hinge (or ball and socket) joints.
- The mass moment of inertia of each segment about its mass center (or about either proximal or distal joints) is constant during the movement.
- The length of each segment remains constant during the movement (e.g., the distance between hinge (or ball and socket) joint remains constant).

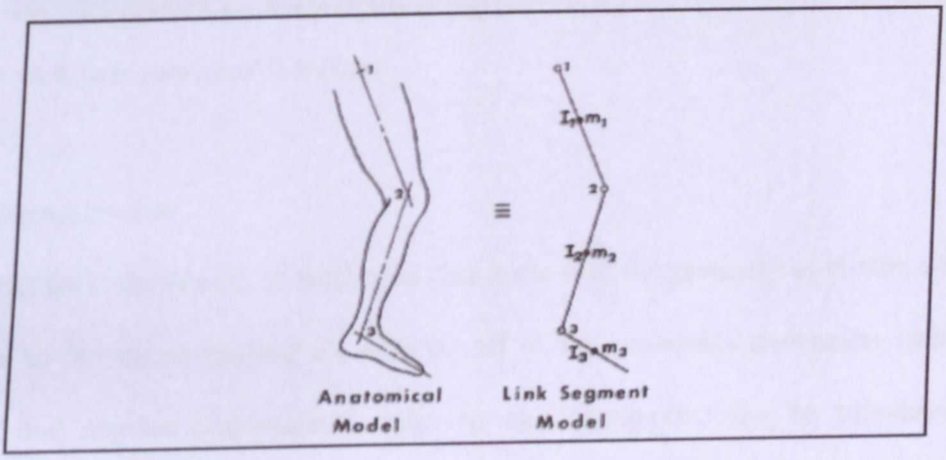

Figure A.7: Relationship between anatomical and link-segment models. Joints replaced by hinge joints and segments are replaced by masses and moments of inertia located at each segment's center of mass.

The anthropometric data is a statistical table used to obtain the segment's masses, centers of masses, and moments of inertia based on the person's height, weight, and sometimes sex (Winter, 1990).

2) Force data (kinetic data)

Force data refers to the external forces acting on the human body. The most common force acting on the body is the ground reaction force. This is usually acquired through the use of a force plate as the one shown in **Figure A.8**. The force plate is a device used to produce a force vector that is proportional to the applied force (Winter, 1990), and to determine the location of the center of pressure.

Figure A.8: force plate placed in staircase.

3) Kinematics data

Kinematics is the branch of mechanics that deals with the geometry of motion without regard to the forces causing the motion. All of the kinematics parameters including linear and angular displacement, velocity, and acceleration can be calculated by knowing the position and orientation of each body segment in space with respect to time. The position and orientation data are traditionally acquired through the use of video analysis in which the positions of segment markers are tracked over time (Winter, 1990).

Two coordinate systems are required to describe the geometry of motion: Global and Local coordinate systems. The Global coordinate system, also called the fixed coordinate system, is defined by orthogonal (X, Y, Z) axis system and provides the 3-dimensional environment that the human movement occurs within. The Local coordinate system is a Cartesian coordinate system fixed on a moving rigid body. The movement of the local coordinate system with respect to global coordinate system over time is used to find the position data.

A.4 The Human Knee

The point at which two or more bones are connected is called a joint. Each joint has several types of structures, including cartilage, muscles, ligaments and tendons that help the joint to do its job by providing support, stability, and movement. Knee joint, which is the junction of three leg bones (thigh bone, shine bone, and the knee cap) is considered as the largest, one of the most complex, and the most frequently injured joint in the human body. Usually, the knee joint is described as a hinge joint since its major movement is flexion and extension. However, along with the hinge movement, there is some gliding and slight rotation occurring (Dunleavy, 1985). Like any other joints, the knee joint is composed of: 1) *bones*, 2) *muscles and tendons*, 3) *ligaments*, and 4) *cartilage*, as shown in the **Figure A.9**. The following gives a brief overview of each.

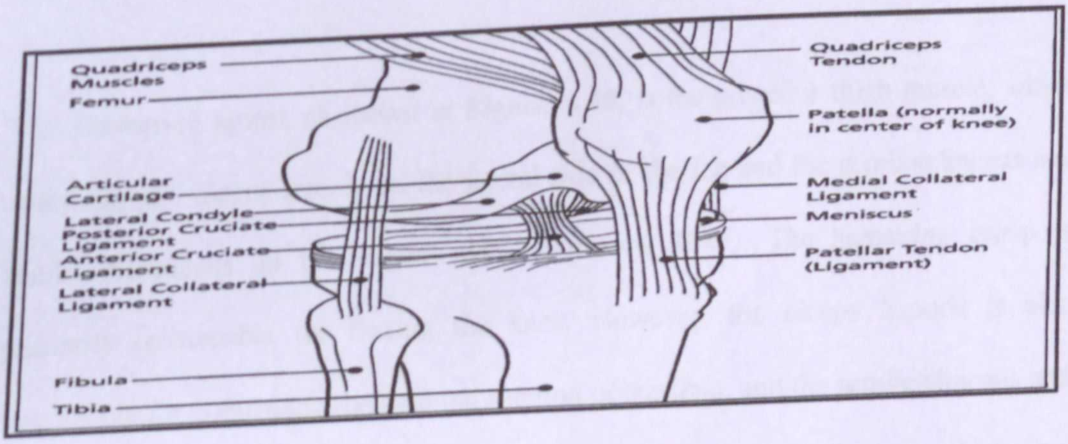

Figure A.9: Parts of the human knee.

A.4.1 Bones

As mentioned earlier, the knee joint is the junction of three leg bones: thighs bone (the femur), shine bone (the tibia), and the knee cap (patella). The femur is the largest bone in the body, and it runs from the hip to the knee. The distal head of the femur has two large bony knobs called the medial and lateral condyles (Frind, 2007). The tibia is the largest bone of the lower leg, and it runs from the ankle to the knee. The proximal end of this bone forms the lower portion of the knee, also known as the tibial plateau (Frind, 2007). The patella, which is the third bone that forms the knee joint, is a little sesamoid (sesame -seed-shaped) bone that simply serves as a pulley for the extensor muscle to act more efficiently (Frind, 2007).

A.4.2 Muscles and tendons

There are two major groups of muscles working at the knee: the Quadriceps and Hamstring groups. These muscle groups work synergistically to provide protection as well as flexion, extension, and rotatory movements of the knee (Thompson and Floyd, 2001). The Quadriceps group, as shown in **Figure A.10,** is the anterior thigh muscles, which is responsible for extending the knee. The quadriceps group comprises the vestus lateralis, vestus intermedius, rectus femoris, and vestus medialis (Anderson et al., 2000).

The Hamstring group, as shown in **Figure A.10**, is the posterior thigh muscle, which comprises the biceps femois on the lateral side of the leg and the semitendinosus and semimembranosus on the medial side (Dunleavy, 1985). The hamstring group is primarily responsible for flexing the knee. However, the biceps femoris is also responsible for controlling the external rotation of the tibia, and the semitendinosus and semimembranosus along with other muscles, are responsible for the internal rotation (Anderson et al., 2000). The Gastrocneius muscle is primarily responsible for extending the ankle, but it also helps in flexing the knee.

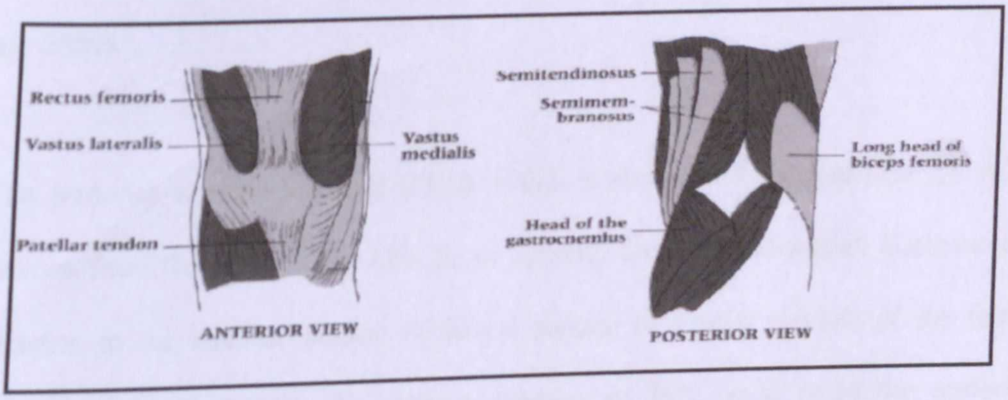

Figure A.10: Anterior and posterior view of the knee muscles.

Tendons are a strong band of connective tissue that connects a muscle group to a bone. The tendons in the knee joint are quadriceps tendon and patellar tendon. The quadriceps tendon connects to the top of the patella and allows extending of the leg. The patellar tendon connects the bottom of the patella and attaches to the top of tibia. Because of this, patellar tendon is considered as ligament rather than tendon.

A.4.3 Ligaments

Bones are joined to bones by strong, elastic bands of tissue called ligaments. The major ligaments crossing the knee joint are: the Cruciate ligaments and the Collateral ligaments. The Cruciate ligaments are two ligamentous bands that cross one another within the joint cavity of the knee (Anderson et al., 2000), including, the anterior cruciate ligament and the posterior cruciate ligament.

The anterior cruciate ligament (ACL) attaches in front of the tibia; then, passing backward, it attaches laterally to the inner surface of the lateral condyle (Anderson et al., 2000). The primary function of the ACL is to prevent the anterior translation of the tibia. It also stabilizes the tibia against excessive internal rotation and serves as a secondary restraint for valgus or varus stress with the collateral ligaments (Anderson et al., 2000).

The posterior cruciate ligament (PCL), which is shorter and stronger than the ACL, crosses from the back of the tibia in an upward, forward, and medial direction and attaches to the anterior portion of lateral surface of medial condyle of the femur (Anderson et al., 2000). The primary function of PCL is to resist the posterior translation of the tibia. However, PCL also plays a role in the internal/external rotation of the tibia and in the valgus/varus movement (Anderson et al., 2000). Because of this, the PCL is usually referred to as the primary stabilizer for the knee joint.

The collateral ligaments of the knee include the medial collateral ligament and the lateral collateral ligament, as shown in **Figure A.11**. The medial collateral ligament, which runs along the inside of the knee joint, is the primary restraint to the valgus rotation of the knee. However, it is also considered to be a secondary restraint to the anterior/posterior translation of the tibia (Anderson et al., 2000). The lateral collateral ligament, which connects fibula to femur laterally, is the primary restraint for varus rotation. However, it is also considered to be a secondary restraint for external rotation of the tibia (Anderson et al., 2000).

Figure A.11: The cruciate ligaments at the knee

A.4.4 Cartilages

In the knee joint, there are two types of cartilages: articular cartilage and minsical cartilage. The articular cartilage, which is a hyaline cartilage, is a tough, elastic material that covers the end of the knee bones and helps in shock absorption, and allows the knee to move smoothly (**Figure A.12**).

The menisci are two oval fibrocartilages (meniscus) that deepen the articular facets of the tibia and cushion any stresses placed on the knee joint (Anderson et al., 2000). Included also are the lateral and medial meniscus, named according to their location on the tibia, as shown in the **Figure A.12**. They serve several functions, such as absorption and dissipation of force, lubrication and nourishment of the joint structure, and congruency of the joint surface to improve weight distribution (Anderson et al., 2000).

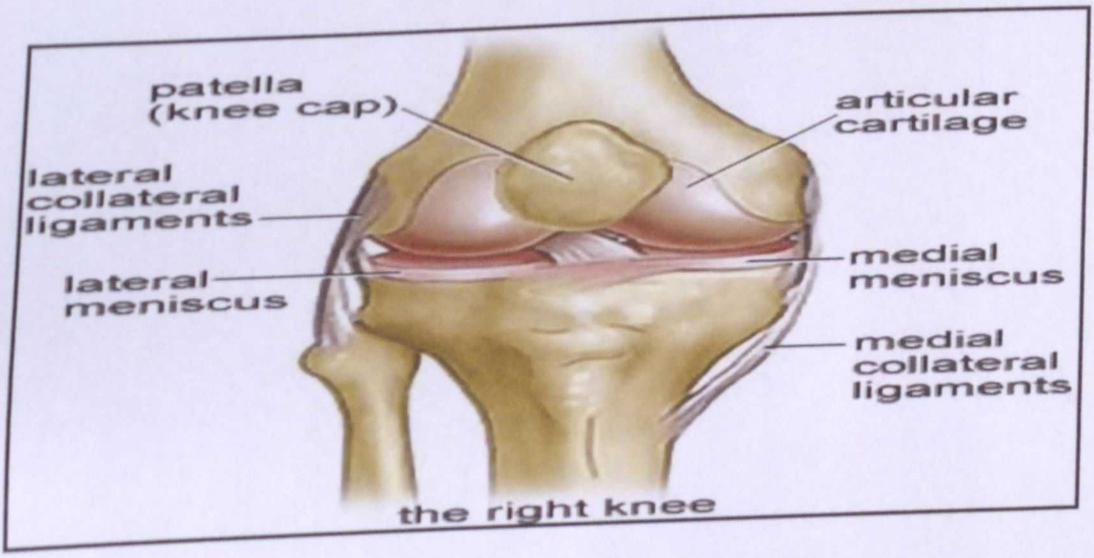

Figure A.12: Collateral ligaments, menisci, and articular cartilage of the right knee.