Title page

Cover page

EFFECTS OF 3-INCH HIGH-HEELED SHOE ON SELECTED BIOMECHANICAL PARAMETERS AND AEROBIC CAPACITY OF FEMALE UNDERGRADUATES' BODY SOMATOTYPES OF THE UNIVERSITY OF BENIN

BY

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A PROJECT SUBMITTED TO THE DEPARTMENT OF PHYSIOTHERAPY,
SCHOOL OF BASIC MEDICAL SCIENCES, COLLEGE OF MEDICAL SCIENCES,
UNIVERSITY OF BENIN, BENIN CITY

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF
BACHELOR OF PHYSIOTHERAPY (B.PT) DEGREE

OCTOBER, 2025

CERTIFICATION

This dissertation by Edowaye Mary Oluwafunbi is accepted in its presented form as satisfying the dissertation requirement of the degree of Bachelor of Physiotherapy of the School of Basic Medical Sciences, College of Medical Sciences of the University of Benin.

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DEDICATION

This dissertation is dedicated to God Almighty, who is the Alpha and Omega of my life and in His infinite mercy has brought me this far, my parents Mr and Mrs Edowaye and my amazing siblings (Racheal and Gabriel).

ABSTRACT

Background/Purpose of Study: High-heeled shoes are widely used among females for aesthetic, social, and cultural reasons. However, empirical studies examining the effects of high-heeled shoes on biomechanical alterations and energy expenditure of different body somatotypes are scarce.

Aim: The study investigated the effect of 3-inch high-heeled shoe on selected biomechanical parameters (lumbar flexibility (LF), quadriceps angle (QA), limb length discrepancy (LLD), quadriceps muscle length (QL) and gastrocnemius muscle length (GL) and aerobic capacity (total lap covered (TLC), oxygen saturation rate (SPO_2), systolic blood pressure (SBP) and diastolic blood pressure (DBP), pulse rate (PR)) in female undergraduate's body somatotypes (ectomorph, mesomorph and endomorph) in the University of Benin.

Method: A single-blind randomized controlled trial of 75 female undergraduates recruited through consecutive sampling and blocked randomized into ectomorph, mesomorph, and endomorph using Sheldon's body types classification questionnaire. Participants biomechanical parameters (LF, QA, LLD, QL and GL) were measured using standardized procedures. Aerobic capacity of TLC was assessed using the 6-minute walk test, while SBP, DBP, SPO_2 and PR were measured using Omron digital blood pressure. All measurements of biomechanical parameters and aerobic capacity of participants were taken under two footwear conditions: normal heel and 3-inch high-heeled shoes. Descriptive statistics of mean, standard deviation, frequency and percentages were used to summarise data. Inferential statistics of Wilcoxon's test, paired t-test, Kruskal Wallis, Mann Whitney-U, ANOVA were used to analyse data at $p<0.05$.

Results: Biomechanical parameters (LF, QA, LLD, QL and GL) and aerobic capacity of TLC were significantly ($p<0.001$) reduced following the application of 3-inch heel shoe in the three body types, whereas aerobic capacity of SBP, PR, and SPO_2 were significantly ($p<0.001$) increased. Only DBP of mesomorph was significantly ($p<0.001$) increased.

Conclusion: This study indicates that 3-inch high-heeled shoe has significant effects on biomechanical parameters and aerobic capacity of female undergraduate's body somatotype.

Keywords: High-heeled shoes, biomechanical parameters, aerobic capacity, body somatotypes, female undergraduates.

ACKNOWLEDGEMENTS

I express my profound gratitude to God Almighty for His divine provision, protection, guidance, faithfulness, love, mercy and for the successful completion of this journey.

Special thanks to my supervisor Dr. Saturday Nicholas Oghumu for his assistance and guidance during the course of the research study. Despite his busy schedule he devoted his time to listen to me, answer my questions, read through my work and also make corrections. May the good Lord reward you greatly.

I also appreciate the acting Head of Department, Dr. Mrs.C.O.Obaseki and all the lectures of the Department of Physiotherapy, University of Benin, Prof .K. I Oke, Dr Joseph Umunnah, Dr. Obinna Ezeukwu, Mr. Okhuahesuyi Eguagie, Prof Mrs. A.I Aiyegbusi, Dr Mrs.S. Kubeyinje, Dr. H. Adebisi, Rev Sister Fawole, Dr. Bolarinde, Prof. Muhammed Jibril and Dr. ND Ekechukwu who imparted knowledge in me during my stay in school. I also appreciate the Non-academic staff, especially Mr. Nosa Osunbor, Mrs Juliet Walter, Mr Okundaye of the Department of Physiotherapy for their priceless contribution to the success of my undergraduate program.

Special thanks to the Head of Department (UBTH), Mr Taiwo Oyewumi, the directors, Mr Okhuhesuyi Eguagie, Mrs.C.O.Obaseki, and also Mrs. Susan Kubeyinje and also the chiefs most especially PT Johnbosco, interns and other clinicians in the Department of Physiotherapy, University of Benin Teaching Hospital, I appreciate the knowledge and skills impacted in me during my studentship in the University of Benin Teaching Hospital.

My deepest appreciation goes to my parents, Mr and Mrs Edowaye and my wonderful siblings, (Racheal and Gabriel) for your priceless and invaluable support, love, encouragement throughout my academic journey, I also appreciate my big daddy Professor. F.O. Agoreyo for his constant support and encouragement throughout my academic journey. Special thanks to brother Raphael and brother Omotola for their show of love and concern towards the achievement of this milestone.

I would like to acknowledge myself for the dedication, determination, effort and commitment into this work that made this achievement possible.

I would also like to thank my friends: Grace (for her generosity and care), Emanuel, Joshua, Shalom, Favour, and Mercy for their support, encouragement and love. God bless you guys for your assistance and for making my stay in school memorable and worthwhile.

I would also like to express my gratitude to all my course mate and participants who volunteered and consented for their time and cooperation in making this study successful and to others whom the confines of this page will not permit me to mention.

May God bless you all.

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CHAPTER ONE

INTRODUCTION

1.1 Background of the Study

High-heeled shoes are distinctive form of footwear characterized by elevated heels than the toes (Oghumu et al., 2025). High-heeled shoes, also known as "'high heels" (colloquially shortened to "'heels'"), are a type of shoe with an upward-angled sole, the heel in such shoes is raised above the ball of the foot (Han & Dongwook, 2015). High heels causes the legs to appear longer, make the wearer appear taller, and accentuate the calf muscle (Han & Dongwook, 2015). Different types of heels offer different aesthetic and functional qualities, catering to diverse preferences and occasions.

Understanding the heights of heels and their implications on comfort, style, and biomechanics is essential for both wearers and designers to explore the evolution of foot wear styles and the cultural significance of different heel heights throughout history. Heights of high heel analyze how changing fashion trends, societal norms, and technological advancements are influenced by the design and popularity of heels (Charles & Keith, 2024). There are many types of high heels in varying styles, heights, and materials. High heels have been used in various ways to convey nationality, professional affiliation, gender and social status. High heels have been an important statement piece of fashion for centuries in the west (Reilly & Barry, 2020).

Young adulthood is a unique developmental period that occurs between the ages of 18 and 25 years, during which there are key developmental tasks that allow the young adult to participate in self-exploration and identity formation. In order to optimize care, young adulthood needs to be recognized as its own distinct developmental period. Young adults differ from adolescents and middle-aged adults because they experience their own unique developmental tasks and have higher rates of risk-taking behaviors, which places them at greater risk for preventable causes of morbidity and mortality (Higley & Elena, 2019). A woman wearing high heel looks more elegant, graceful, stylish and looks aesthetical taller, slender. Surveys have shown that up to 69% of women regularly wear high-heeled shoes (Jency et al., 2021). Historically, the use of high heeled shoes is purported to have started during the 14th century when wooden slips called lateens were placed on the bottom of foot wear to protect them from getting dirty. Ever since then females across all ages, culture, society and religion have continued to use high heels shoes. However, whether it is to gain a height advantage, look professional or stay with the trend of fashion (Jency et al., 2021).

Biomechanical parameters refer to measurable characteristics that describe the mechanical aspects of movement in the human body. These include variables related to posture, motion, force, and muscle activity, and are commonly analyzed in fields like kinesiology, physical therapy, ergonomics, and sports science. (Hamill et al., 2015). Today varieties of different parameters of various types exist and are readily used to examine and explain human gait. In the research settings, numerous parameters have been used to quantitatively describe gait. Parameters of various types such as the spatio - temporal parameters, ground reaction forces, joint kinematics etc (Robert et al., 2017). High heel shoes alter the alignment of the body, thus influencing the body’s centre of gravity and adversely affecting gait biomechanics and postural stability, impairing static and dynamic balance, and increasing the risk of falls for high heel shoe wearers (Ziwei et al., 2023).

A systematic review by Barnish et al (2018) found that with wearing high heels there are deviations to the neuromechanics of walking gait, and kinematics and kinetics of structures within the body, from the spine to the toes. This creates a risk for various conditions such as musculoskeletal pain, hallux valgus, ankle inversion injuries, and osteoarthritis. There can also be deviations in foot and ankle kinematics, kinetics, knee and hip flexion, gait, posture, and balance. Increased lumbar lordosis due to an increased pelvic tilt can be associated with the risk of low back pain. The Achilles tendon force is increased with high heels, and results in achilles tendon stiffness. With the use of high heels there is a great increase in hind foot dorsiflexion, which may disturb body balance and gait stability (Wang et al., 2018). Literatures have shown that high heeled shoes cause alterations in gait parameters, biomechanics of ankle joints, knee joints, venous pumping of calf muscles and even the spinal curvature (ka et al., 2012).

Various studies have investigated the effect of high heel shoes on gait, posture and relevant injuries on young women. A meta-analysis found that walking in high-heeled shoes increased knee flexion moment, flexion angle and varus moment during the early stance phase. However, to date, meta-analyses of the effects of high heel shoes on gait spatio-temporal outcomes, joint kinematics, kinetics, muscle activity and balance in female have been lacking. Changes in women's gait parameters when wearing high-heeled shoes and the associated neuromuscular and biomechanical adaptations can provide accurate and effective recommendations for future efforts to eliminate the negative effects of high heels (Zeng et al., 2023).

On the other hand, high heels may affect the walking distance or the duration of walk of an individual. Research indicates that maintaining posture and movement in high heels may place extra demands on the cardiovascular system, often raising heart rate and leading to decreased physical performance (Mika et al., 2012). Aerobic capacity refers to the maximum amount of oxygen the body can use at one time during an intense exercise. When any type of aerobic exercise is performed, the body is using oxygen to fuel metabolism (chemical reactions in cells that change food into energy) to give the body energy for movement (Ashley, 2022). Wearing high heels tends to increase the work load on the calf muscles, especially the gastrocnemius and soleus, causing them to get tired more quickly. This muscle fatigue can negatively impact endurance and limit aerobic performance (Polat & Kabakci, 2021). In particular, effect of high heels on biomechanical parameters and aerobic capacity may vary from one female to another depending on their body shape and built.

Sheldon's classification of body types indicates that the ectomorph body type is characterized by the degree of slenderness, angularity, fragile and a lean slender body built with slight muscular development. The mesomorph body type is marked by a medium frame with more muscle than fat (typically strong and solid, not overweight or underweight) having bodies that are rectangular in shape (an upright posture of square-shaped head, muscular chest and shoulders, large heart, muscular arms and legs and even weight distribution). The endomorph is characterized by higher body fat and less muscle, appears round and soft and seems to be heavier because they are more likely to gain weight than those who have other body types (Thomas, 2024).

Biomechanically, high heels alter gait patterns, posture, and joint alignment, leading to increased muscular strain and decreased stability, particularly in individuals with endomorphic and mesomorphic traits. Ectomorphic individuals, with their lighter frames, showed relatively better adaptation but still experienced reduced aerobic capacity under prolonged high heel usage (Connor & Douglas, 2023). These alterations contribute to compensatory movements and increased energy expenditure during locomotion. Consequently, this increased biomechanical demand reduces aerobic efficiency, as more energy is diverted toward maintaining balance and movement control rather than sustained cardiovascular performance. Overall, high-heeled shoes impose a dual strain on both the mechanical and physiological systems, highlighting the need for awareness regarding footwear choices, especially in relation to body type and long-term physical performance (Zeng et al., 2023).

1.2 Statement of the Problem

The increasing popularity of high-heeled shoes among female undergraduates, raises growing concerns about their potential effects on posture, biomechanics, and overall physical health. Despite their aesthetic appeal, high heels can alter the natural alignment of the body, potentially leading to musculoskeletal stress, reduced balance, and compromised gait mechanics (Cronin, 2014). These effects may vary significantly depending on individual body somatotypes (ectomorph, mesomorph, and endomorph), which influence biomechanical efficiency and energy expenditure during movement. However, limited research exists that comprehensively examines how 3-high-heeled shoe usage affects specific biomechanical parameters such as gait pattern, posture, and balance as well as aerobic capacity across different female somatotypes.

This research aimed to address this gap by examining how wearing 3-high-heeled shoes influences specific biomechanical factors (lumbar flexibility (LF), quadriceps angles (QA), limb length discrepancy (LLD), quadriceps muscle length (QL) and gastrocnemius muscle length (GL)) and aerobic capacity (total lap covered (TLC), oxygen saturation rate (SPO_2), systolic blood pressure (SBP) and diastolic blood pressure (DBP), pulse rate (PR)) in female undergraduates with varying body somatotypes in the university of Benin.

1.3 Research Questions:

This study was therefore designed to answer the following research questions:

i. What is the effect of 3-inch high-heeled shoes on selected biomechanical parameters (LF, QA, LLD, QL, and GL) in female undergraduate body somatotypes?

ii. What is the effect of 3-inch high-heeled shoes on aerobic capacity (TLC, SPO_2, SBP, DBP, and PR) in female undergraduate body somatotypes (ectomorph, mesomorph, and endomorph)?

iii. Do body somatotypes (ectomorph, mesomorph, and endomorph) influence selected biomechanical parameters (LF, QA, LLD, QL, and GL) and aerobic capacity (TLC, SPO_2, SBP, DBP, and PR) of undergraduate female that wears high heel shoe?

1.4 Aim of the Study

The aim of this study was to determine the effect of 3-inch high-heeled shoe on selected biomechanical parameters (LF, QA, LLD, QL, and GL) and aerobic capacity (TLC, SPO_2, SBP, DBP, and PR) in female undergraduate's body somatotypes (ectomorph, mesomorph and endomorph) in the University of Benin.

1.4.1 Specific Objectives

The specific objectives of this study were to:

i. Determine the effect of 3-inch high heeled shoes on selected biomechanical parameter (LF, QA, LLD, QL, and GL) in female undergraduate body somatotypes.

ii. Determine the effect of 3-inch high-heeled shoes on aerobic capacity (TLC, SPO_2, SBP, DBP, and PR) in female undergraduate body somatotypes.

iii. Determine if 3-inch high-heeled shoes of undergraduate females is influenced by body somatotypes (ectomorph, mesomorph, and endomorph), biomechanical parameters (LF, QA, LLD, QL, and GL) and aerobic capacity (TLC, SPO_2, SBP, DBP, and PR).

1.5 Hypothesis

1.51 Main Hypothesis

There would be no significant difference in biomechanical parameters (LF, QA, LLD, QL, and GL) of female undergraduate body somatotypes (ectomorph, endomorph and mesomorph) following the application of 3-high-heeled shoe, as well as, there would be no significant difference in aerobic capacity (TLC, SPO_{2}, SBP, DBP, and PR) of female undergraduate body somatotypes (ectomorph, mesomorph and endomorph) following the application of 3-inch high heeled shoes.

1.5.2 Sub Hypothesis

i. There would be no significant difference in lumbar flexibility of undergraduate female ectomorph before and after the application of 3-inch high-heeled shoes.

ii. There would be no significant difference in lumbar flexibility of undergraduate female endomorph before and after the application of 3-inch high-heeled shoes.

iii. There would be no significant difference in lumbar flexibility of undergraduate female mesomorph before and after the application of 3-inch high-heeled shoes.

iv. There would be no significant difference in quadriceps angle of undergraduate female ectomorph before and after the application of 3-inch high-heeled shoes.

v. There would be no significant difference in quadriceps angle of undergraduate female mesomorph before and after the application of 3-inch high-heeled shoes.

vi. There would be no significant difference in quadriceps angle of undergraduate female endomorph before and after the application of 3-inch high-heeled shoes.

vii. There would be no significant difference in limb length discrepancy of undergraduate female ectomorph before and after the application of 3-inch high-heeled shoes.

viii. There would be no significant difference in limb length discrepancy of undergraduate female mesomorph before and after the application of 3-inch high-heeled shoes.

ix. There would be no significant difference in limb length discrepancy of undergraduate female endomorph before and after the application of 3-inch high-heeled shoes.

x. There would be no significant difference in quadriceps length of undergraduate female ectomorph before and after the application of 3-inch high-heeled shoes.

xi. There would be no significant difference in quadriceps length of undergraduate female mesomorph before and after the application of 3-inch high-heeled shoes.

xii. There would be no significant difference in quadriceps length of undergraduate female endomorph before and after the application of 3-inch high-heeled shoes.

xiii. There would be no significant difference in gastrocnemius length of undergraduate female ectomorph before and after the application of 3-inch high-heeled shoes.

xiv. There would be no significant difference in gastrocnemius length of undergraduate female mesomorph before and after the application of 3-inch high-heeled shoes.

xv. There would be no significant difference in gastrocnemius length of undergraduate female endomorph before and after the application of 3-inch high-heeled shoes.

xvi. There would be no significant difference in the aerobic capacity of undergraduate female ectomorph before and after the application of 3-inch high-heeled shoes.

xvii. There would be no significant difference in the aerobic capacity of undergraduate female mesomorph following the application of 3-inch high-heeled shoes.

xviii. There would be no significant difference in the aerobic capacity of undergraduate female endomorph following the application of 3-inch high-heeled shoes.

1.6 Significance of the Study

i. **To Researchers:** The study findings may help researchers access inceptive information on the effect of high heeled shoes on selected biomechanical parameters and aerobic capacity of female undergraduate body somatotypes. Additionally, the findings of this study may identify gaps for future research.

ii. **To Physiotherapist:** The study outcomes may help inform physiotherapist about the prevalence of high heeled shoes among young adult females' body somatotypes in Benin City and this will guide them in developing and implementing strategies like offering personalized advice on footwear choices and educate female undergraduate about the long term risk of high heeled shoes.

iii. **To female undergraduate:** The study findings may enlighten the young adult females to understand how wearing high-heeled shoes affects their body movement, posture, and physical endurance based on their body type (somatotypes), it can also create awareness of potential health risk, guidance on making footwear choices based on their individual body structures and this knowledge can help prevent injuries and promote better physical wellbeing.

iv. **To policymakers:** The findings from this study may provide new evidence on the relationship between high heeled shoes and the selected biomechanical parameters in female undergraduate body somatotypes. The findings may also lead to considerations for the prevention of the effect of high heeled shoes on biomechanical parameters of female undergraduate.

1.7 Scope of the Study (Delimitation)

This study was delimited to a 3-inch universal high-heeled shoe, modified Schober's test to measure LF, a 360-degree goniometer to measure QA, a tape measure to measure LLD, QL, and GL of female undergraduate students of the University of Benin.

1.8 Limitations of the Study

This limitation of this study include:

i. The study was unable to assess the effects of different heel heights of shoes on the participants. Other shoe heel heights such as 2-inch, 4-inch and even 5-inch may have effects different from that reported in this study.

ii. This study cannot account for watch out effect in cardiovascular response between usage of flat shoe and 3-inch high-heeled shoe, although the recommended period of 15minutes interval between intake of cardiovascular parameters was maintained by this study.

1.9 Definition of Terms / Operational Definition of Terms

i. **High heeled shoes:** High-heeled shoes, also known as "'high heels"' (colloquially shortened to "'heels"'), are a type of shoe with an upward-angled sole. The heel in such shoes is raised above the ball of the foot. High heels will cause the legs to appear longer, make the wearer appear taller, and accentuate the calf muscle (Han & Dongwook, 2015).

ii. **Biomechanical parameters:** Biomechanical parameters refer to measurable characteristics that describe the mechanical aspects of movement in the human body. These include variables related to posture, motion, force, and muscle activity, and are commonly analyzed in fields like kinesiology, physical therapy, ergonomics, and sports science (Hamill et al., 2015).

iii. **Aerobic capacity:** Aerobic capacity refers to the maximum amount of oxygen your body can use at one time during an intense exercise, when you perform any type of aerobic exercise, your body is using oxygen to fuel metabolism (chemical reactions in cells that change food into energy) to give your body energy for movement (Ashley, 2022)

iv. **Young adult females**: Young adulthood is a unique developmental period that occurs between the ages of 18 and 25 years, during which there are key developmental tasks that allow the young adult to participate in self-exploration and identity formation (Higley, 2019).

v. **Body somatotypes:** A somatotype is a generalized set of body types, and there are three types of somatotypes: ectomorph, endomorph, and mesomorph.

vi. Somatotype is a theory proposed in 1940 by the American psychologist William Herbert Sheldon to categorize the human physique according to the relative contribution of three fundamental elements which he termed somatotypes, classified by him as ectomorph, mesomorph, and endomorph (Hollin & Clive, 2012).

1.10 List of Abbreviations

TLC: Total Lap Covered

SPO_2: Oxygen Saturation Rate

SBP: Systolic Blood Pressure

DBP: Diastolic Blood Pressure

PR: Pulse Rate

LF: Lumbar Flexibility

QA: Quadriceps Angle

LLD: Limb Length Discrepancy

QL: Quadriceps Muscle Length

GL: Gastrocnemius Muscle Length

CHAPTER TWO

LITERATURE REVIEW

2.1 Conceptual Framework

The use of high-heeled shoes is a prevalent fashion choice among women globally, including female undergraduates in Nigeria, driven by aesthetic, cultural, and professional factors. However, their impact on biomechanical parameters and aerobic capacity has garnered significant attention in recent literature due to potential health implications. High-heeled shoes alter the body's natural alignment, affecting posture, gait, and muscle activation patterns, which may lead to musculoskeletal issues and reduced physical performance (Mika et al., 2018). Additionally, the increased energy expenditure associated with high-heel use may influence aerobic capacity, particularly during prolonged activities (Park & Kim, 2020). The effects of high heels may vary across body somatotypes (ectomorph, mesomorph, and endomorph) due to differences in body composition, muscle distribution, and joint mechanics, yet this aspect remains underexplored, especially in African populations.

2.2 Epidemiology of High-Heel Use

High-heeled shoes are a prevalent fashion choice among women globally, particularly in urban settings. Studies indicate that approximately 60-70% of women in developed countries wear high heels regularly, with higher prevalence among younger populations, including university students (Moore et al., 2015). In Nigeria, the adoption of Western fashion trends has increased high-heel usage among female undergraduates, often for aesthetic and social reasons (Oke, 2020). However, prolonged use has been associated with musculoskeletal discomfort and altered gait patterns (Cronin, 2014). The choice of high heels is influenced by cultural, social, and professional factors. For instance, a study by Adeyemi et al. (2019) found that Nigerian female undergraduates frequently wear high heels to conform to societal expectations of femininity and professionalism. However, the same study noted a lack of awareness about the potential health risks, such as lower back pain and foot deformities, associated with prolonged high-heel use. This epidemiological perspective underscores the need to investigate the biomechanical and physiological effects of high heels in specific populations, such as female undergraduates with varying body somatotypes

2.3 High Heeled Shoes and Their Impact on the Human Body

High-heeled shoes, characterized by an elevated heel that raises the heel of the foot above the toes, are a popular footwear choice among women for aesthetic, cultural, and professional reasons. However, their use has been associated with significant biomechanical and physiological effects on the human body, particularly impacting posture, gait, joint mechanics, muscle function, and aerobic capacity.

2.3.1 Biomechanical Alterations

High-heeled shoes fundamentally alter the body's natural alignment by shifting the center of gravity anteriorly and superiorly, which affects posture and gait dynamics. The elevated heel forces the foot into a plantar flexed position, increasing the angle of the ankle joint and redistributing body weight toward the forefoot (Mika et al., 2018). This shift leads to compensatory changes in the lower limb and spine, including increased lumbar lordosis and anterior pelvic tilt, which can strain the lower back and hip joints (Lee & Park, 2019). Studies have shown that high heels significantly increase ground reaction forces during walking, particularly at the forefoot, leading to higher impact forces on the metatarsals and potential development of conditions like metatarsalgia (Cronin, 2014).

The knee joint also experiences increased stress due to high heels. The altered posture increases knee flexion during the stance phase of gait, elevating quadriceps muscle activity and joint loading, which may contribute to patellofemoral pain or osteoarthritis over time (Simonsen et al., 2021). Additionally, high heels reduce stride length and increase cadence, disrupting normal gait patterns and potentially leading to balance issues, especially in individuals unaccustomed to high-heel use (Park & Kim, 2020). These biomechanical changes are more pronounced with higher heel heights (e.g., ≥7 cm), which are common in fashion settings but exacerbate strain on the musculoskeletal system.

2.3.2 Physiological Responses

The physiological impact of high-heeled shoes extends to energy expenditure and aerobic capacity. Walking in high heels increases metabolic demand due to the altered biomechanics and increased muscle activation, particularly in the lower limb muscles such as the gastrocnemius and quadriceps (Ebbeling et al., 2018). This heightened energy expenditure can reduce aerobic efficiency, as measured by VO2 max, leading to quicker onset of fatigue during physical activities (Smith et al., 2020). For example, a study by Park & Kim (2020) found that women walking in 7 cm heels exhibited a 15–20% increase in oxygen consumption compared to flat shoes, indicating a significant impact on aerobic capacity. High heels can affect respiratory mechanics by altering thoracic posture. The forward tilt induced by high heels may compress the diaphragm, reducing lung capacity and increasing respiratory rate, particularly during prolonged wear or dynamic activities (Mika et al., 2018). These physiological changes are particularly relevant for young women, such as female undergraduates, who may wear high heels for extended periods during social or academic events, potentially compromising their physical performance and comfort.

2.3.3 Influence of Body Somatotypes

The impact of high-heeled shoes may vary across body somatotypes—ectomorph (lean), mesomorph (muscular), and endomorph (rounded)—due to differences in body composition, muscle mass, and joint stability. Ectomorph individuals with lower muscle mass and body fat, may experience greater joint stress due to limited soft tissue cushioning, increasing their susceptibility to high-heel-related injuries (Lee & Park, 2019). Mesomorph individuals with greater muscle mass, may exhibit better compensatory muscle activation but could still face increased joint loading due to higher body weight. Endomorphic individuals, with higher body fat, may experience amplified forefoot pressure and balance issues due to the anterior shift in body mass when wearing high heels (Simonsen et al., 2021).

2.3.4 Health Implications

Prolonged use of high-heeled shoes is associated with several health risks. Short-term effects include foot pain, blisters, and muscle fatigue, while long-term consequences may include chronic conditions such as plantar fasciitis, achilles tendon shortening, and lower back pain (Cronin, 2014). The increased lumbar lordosis and pelvic tilt caused by high heels can contribute to spinal misalignment, potentially leading to degenerative changes in the lumbar spine (Mika et al., 2018). Additionally, the risk of falls and ankle sprains is elevated due to reduced balance and altered proprioception, particularly in higher heels (Park & Kim, 2020). From a public health perspective, the widespread use of high heels among young women, including Nigerian undergraduates, necessitates awareness of these risks. Physiotherapists play a critical role in educating individuals about safe footwear practices and designing interventions to mitigate high--related injuries, such as strengthening exercises for the lower limbs and core muscles (Smith et al., 2020).

2.4 Anatomy of Structures Affected by High Heeled Shoes

2.4.1 Anatomy of the Back

The back is a key topographical region of the body, with crucial importance for posture, locomotion, and upper and lower limb movements. The back consists of skin and fascia overlying the spine, scapulae, muscle groups, nerves, vessels, and the pre-sacral vertebrae. The primary movements of the back are flexion/extension, lateral bending, and rotation of the neck. Some of the back muscles attach to the lateral and posterior processes of the vertebrae and help the spine maintain an upright posture, while others are involved in the upper extremity movement. (Modes & Fahrioglu, 2023).

Bones of the Back

The bones of the back is called the spine and is composed of 33 bones called vertebrae, which stack together to form the spinal canal. The spine consists of five sections. From the top of the spine to the bottom, these sections are:

The cervical spine: This is the top part of the spine. It runs from the neck to the upper back. It consists of seven vertebrae. The cervical spine protects the nerves connecting to the brain, allowing the head to move freely while supporting its weight.

The thoracic spine: This is the middle part of the spine, connecting the cervical and lumbar. It has 12 vertebrae. The thoracic spine helps keep the body upright and stable.

The lumbar spine; This is the lower part of the back. It is made up of five larger vertebrae. These support most of the body’s weight.

The sacrum: This is the bottom part of the spine, which connects to the hipbones. The sacrum has five vertebrae fused together.

The coccyx: This is the base, or tailbone, of the spine. This consists of four vertebrae fused together. Joins to ligaments and muscles around the pelvis. (Sissons & Martinez, 2023).

Muscles of the Back

As the central weight-bearing bony structure, the spine undergoes tremendous force. The muscles that attach to the spine help maintain posture and distribute the uneven force of the body's weight. They are divided into extrinsic and intrinsic back muscle groups.

The extrinsic muscles are further divided into superficial (trapezius, latissimus dorsi, levator scapulae, and the major and minor rhomboids) and intermediate (serratus posterior superior and serratus posterior inferior) groups. The superficial extrinsic muscles are involved in the movement of the upper limbs including movements of the scapula and humerus. The intermediate extrinsic muscles are involved in the rib movement to aid respiration.

The intrinsic back muscles are separated into 3 layers: superficial, intermediate, and deep (Figure 1). These muscles aid in the movement of the spine and maintain postures. The superficial layer is made up of the splenius capitis and splenius cervices. These are involved in neck flexion, rotation and extension. The intermediate layer is mostly made up of the paraspinal or erector spinae muscles, the iliocostalis, longissimus, and spinalis. As the name implies, the erector spinae are important in extending and maintaining the central curvature of the spine. The deep layer of the intrinsic back muscles include muscles that lie between the transverse and spinous processes of the vertebrae. They are sometimes called the paraventebral muscles and include three groups of muscles.

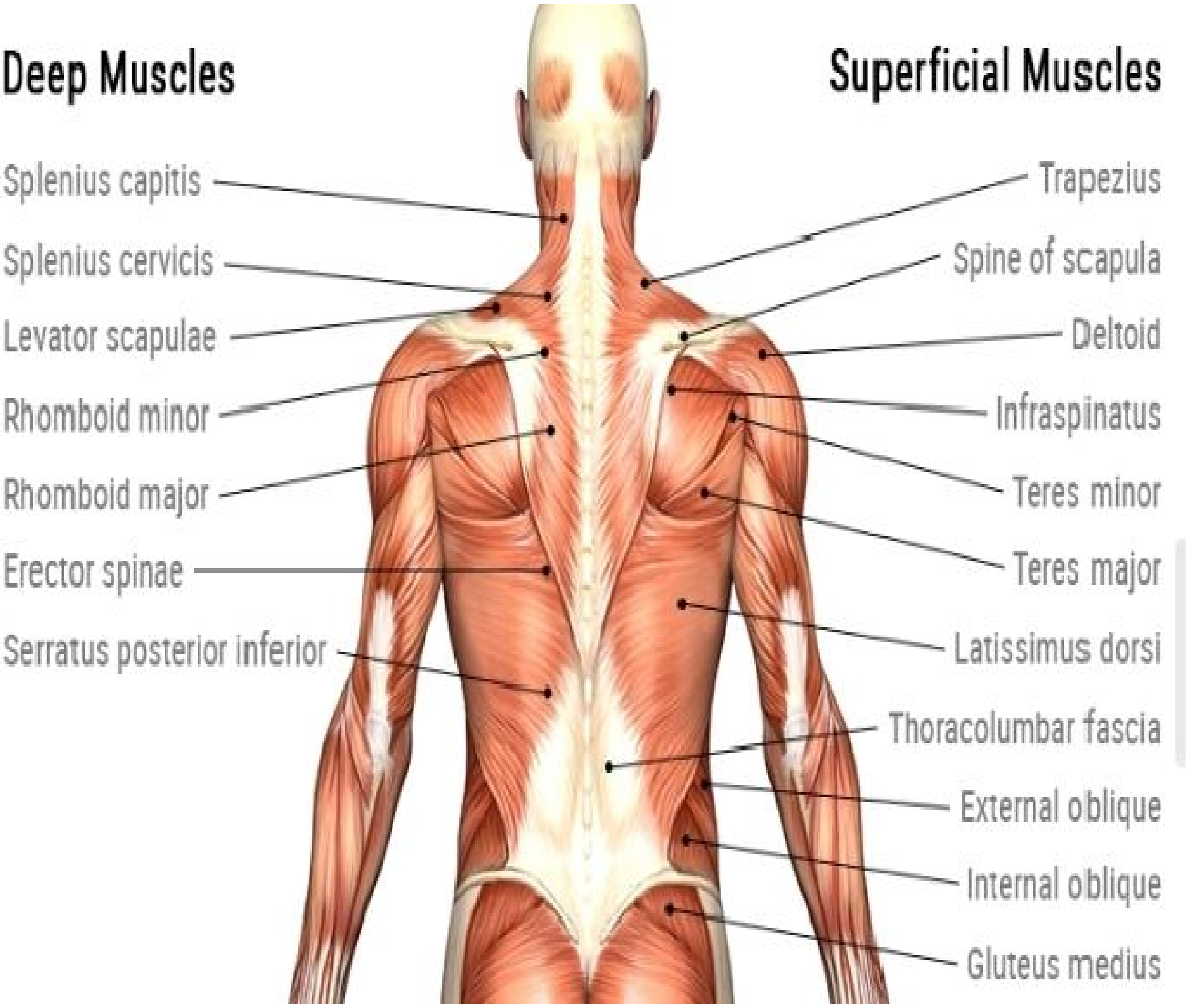

Figure 1. Muscles of the Back

The semispinalis is the most superficial; it is prominent in the thoracic and cervical regions. The multifidus is deep to the semispinalis and most prominent in the lumbar region. Finally, the rotators muscles are deepest and most prominent in the thoracic region (Desai et al., 2023).

Blood Supply of the Back

Blood supply to the skin and muscles in the back is primarily from the dorsal branches of the posterior intercostal arteries. In some variants, these arteries arise from intercostal arteries or directly from the descending aorta. The intercostal arteries run in a groove along with the intercostal vein and nerve caudal to the ribs. The thoracic aorta runs anteriorly to the vertebral column and slightly lateral on the left side. The azygos and hemiazygous veins may also be present anterior to the spinal cord. The anterior and posterior intercostal veins are responsible for the venous drainage of the back (Modes & Fahrioglu, 2023).

Nerve Supply

Nervous supply to the back primarily arises from the dorsal branches of spinal nerves, also known as posterior rami. The sensory innervation to the back organizes in a dermatomal pattern, which corresponds to a specific spinal nerve at different spinal nerves. In addition to providing sensation to the skin of the back, the dorsal branches also serve to innervate the intrinsic muscles of the back. This innervation contrasts the extrinsic muscles of the back, which are innervated by spinal nerves (Modes & Fahrioglu, 2023).

2.4.2 Anatomy of the Lower Limb

Like the upper limb, the lower limb is divided into three regions; thigh, leg, and foot. The thigh is that portion of the lower limb between the hip and knee joints. The leg is specifically the region between the knee joint and the ankle joint. Distal to the ankle is the foot. The lower limb contains 30 bones.

Bones of the Lower Limb

Femur: The femur or thigh bone is the longest bone in the human body (Figure 2). It consists of shaft and two extremities. The upper end of the bone comprises a head, a neck, a greater and a lesser trochanter. The head forms roughly more than half a sphere and id directed upwards, medially and slightly anteriorly. The neck connects the head to the shaft. The greater trochanter is a large quadrangular eminence located laterally at the junction of the neck with the shaft. The lesser trochanter is a smaller conical eminence projecting medially and posteriorly from the neck-shaft junction. The shaft of the femur is thinnest in its mid-portion, expanding slightly when traced upwards but widens noticeably towards the lower end of the bone. The lower end of the femur is widely expanded into two prominent masses, the insertion of the adductor magnus.

Patella: The patella (knee cap) is the largest of the sesamoid bones in front of the knee joint in the quadriceps femoris tendon. It is flat and triangular in shape, the apex pointing inferiorly. The apex is roughened in its lower part to give attachment to the ligamentum patellae.

Tibia: The tibia is the larger of the two bones on the medial side of the leg. It is the second largest bone in the body next to the femur. It consists of a shaft and two ends. The upper end is expanded, consisting of two prominent masses— the medial and lateral condyles. The medial condyle is larger than the lateral condyle. The shaft of the tibia is triangular in cross-section with medial, lateral and posterior surfaces. The lower end of the tibia is smaller than the upper end and projects downwards on the medial side beyond the rest of the bone to form the medial malleolus.

Fibula: The fibula is the lateral bone of the leg. It is very slender compared to the tibia. Not much weight transmission occurs through this bone in the leg. It consists of the head, an upper end, the shaft, and a lower end. The head of the fibula is slightly expanded. The lower end or lateral

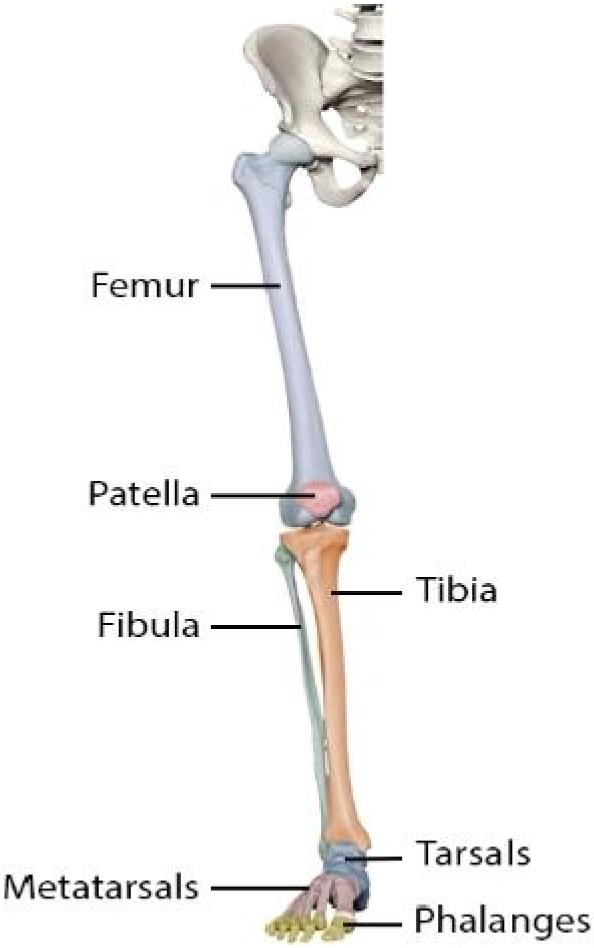

Figure 2: Bones of the Lower Limb

malleolus is expanded antero-posteriorly but is flattened from side to side. The lateral malleolus projects downwards to a lower level than the tibia on a more posterior plane.

Foot: The skeleton of the foot consists of three segments, the tarsal bones, the metatarsal bones, and the phalanges or bones of the toes. The tarsus comprises seven bones, making up the posterior half of the foot. The proximal row consists of the talus and the calcaneum. The distal row contains four bones, the medial cuneiform, the intermediate cuneiform, the lateral cuneiform and the cuboid. These bones lying side by side form the transverse arch of the foot. On the medial side, the navicular bone is interposed between the talus and the medial three bones of the distal row. The forefoot consists of five metatarsal bones and phalanges. Nather (2001).

Muscles of the Lower Limb Muscles of the iliac region: This group consists of the psoas major, iliacus. They are the flexors of the hip.

Muscles of the thigh: The anterior femoral muscles include the tensor fascia lata, the Sartorius and the quadriceps femoris─ the extensors of the leg (Figure 3). The quadriceps femoris consist of the vastus lateralis (the largest part), the vastus medialis, the vastus intermedius and the rectus femoris. The quadriceps femoris is supplied by the femoral nerve. The posterior femoral muscle consist of the hamstrings, the biceps femoris, the semitendinosus and semimembranosus. The hamstrings are supplied by the sciatic nerve. Acting from above, they flex the leg on the thigh. Acting from below, they draw the trunk backwards when it is raised from the stooping position.

Muscles of the leg: They are divided into three groups; anterior, lateral and posterior. The anterior leg muscles include the tibialis anterior, the extensor hallucis longus, the extensor digitorum longus and the peroneal tertius. These muscles supplied by the deep peroneal nerve are the dorsiflexors of the foot. The lateral leg muscles consists of the peroneus longus and peroneus brevis. They are supplied by the superficial peroneal nerve and evert the foot. The posterior leg muscles can be subdivided into superficial and deep. The superficial group forms the muscle mass of the calf of the leg. The superficial group contains gastrocnemius, soleus and the plantaris. They are supplied by branches of the tibial nerve. They are the main plantar flexors of the foot. The deep group consists of the popliteus, flexor hallucis longus, flexor digitorum longus and the tibialis posterior. They are supplied by the branches of the tibial nerve. This group is the principal invertor of the foot. (Nather, 2001).

Muscles of the foot: The extrinsic muscles of the foot include; peroneus longus, peroneus brevis, peroneus tertius, anterior tibialis, posterior tibialis, extensor digitorum longus, flexor digitorum longus, flexor hallucis longus, gastrocnemius, soleus. The intrinsic muscles are divided into dorsal and plantar groups. The dorsal group comprises the extensor digitorum brevis, dorsal interosseus, extensor hallucis brevis. The plantar group is made up of four layers. The first layer comprises abductor hallucis, flexor digitorum brevis, abductor digiti minimi. The second layer comprises quadratus plantae, lumbricals. The third layer is made up of flexor hallucis brevis, oblique and transverse head of the adductor hallucis, flexor digiti minimi brevis. The fourth layer is made up of the plantar interosseus.

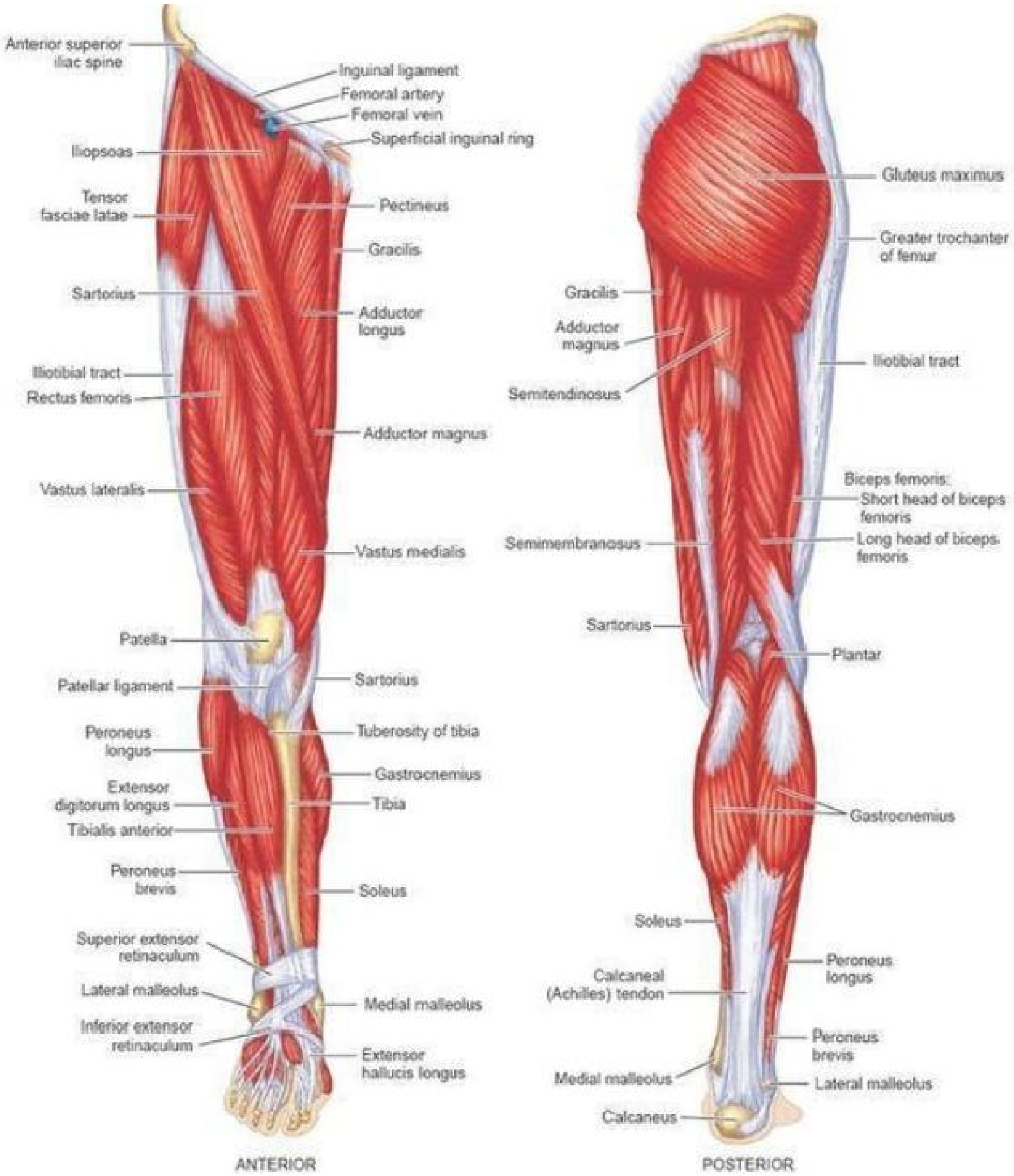

Figure 3. Muscles of the Lower Limb

Ankle Joint

The ankle joint is synovial in type and involves the talus of the foot and the tibia and fibula of the leg, the fibula and tibia create a deep bracket-shaped socket for the upper expanded part of the body of the talus to form a hinge synovial joint (Drake et al., 2014). The ankle joint sustains the greatest load per surface area of any joint of the body (Dutton, 2012). The ankle joint also called the talocrural joint, the roof of the socket is formed by the inferior surface of the distal end of the tibia, the medial side of the socket is formed by the medial malleolus of the tibia and the longer lateral side of the socket is formed by the lateral malleolus of the fibula (Drake et al., 2014). The malleoli grip the talus tightly as it rocks in the mortise during movements of the joint and the grip of the malleoli on the trochlea is strongest during dorsiflexion of the foot, hence the ankle is most stable when dorsiflexed (Moore et al., 2014; Drake et al., 2014). The ankle joint is relatively unstable during plantarflexion because the trochlea is narrower posteriorly and, therefore, lies relatively loosely within the mortise and most injuries of the ankle occur when it is in plantarflexion (Moore et al., 2014).

Ligaments of the Ankle Joint

Ligaments of the ankle joint can be divided into two main groups: lateral collateral and medial (deltoid) collaterals (Dutton, 2012).

Lateral Collateral Ligaments

The lateral collateral ligament complex consists of three separate bands, which function together as the static stabilizers of the lateral ankle and these ligaments are commonly involved in ankle sprains (Dutton, 2012).

i. **Anterior Talofibular Ligament (ATFL);** It is a flat, weak band that extends anteromedially from the lateral malleolus to the neck of the talus (Moore et al., 2014). The ATFL functions to resist ankle inversion in plantarflexion and provide resistance against anterior talar displacement from the mortise and resistance against internal rotation of the talus within the mortise, also regardless of ankle position, the ATFL is usually the first ankle ligament to be torn in an inversion injury (Dutton, 2012).

ii.**Posterior Talofibular Ligament (PTFL);** It is a thick, fairly strong band that runs horizontally medially and slightly posteriorly from the malleolar fossa to the lateral tubercle of the talus (Moore et al., 2014). The posterior talofibular ligament is the strongest of the lateral ligament complex, and serves to indirectly aid talofibular stability during dorsiflexion due to its anatomic location, where it can act as a true collateral ligament and prevent talar tilt into inversion and it is rarely injured except in severe ankle sprains (Dutton, 2012).

iii. **Calcaneofibular Ligament;** It is a round cord that passes postero-inferiorly from the tip of the lateral malleolus to the lateral surface of the calcaneus (Moore et al., 2014). It is larger and stronger than the ATFL and it effectively spans the ankle and subtalar joints, which have markedly different axes of rotation, thus its attachment is designed so that it does not restrict motion in either joint, whether they move independently or simultaneously (Dutton, 2012).

Medial Collateral Ligaments

The medial collateral ligament fans out from the malleolus, attaching distally to the talus, calcaneus, and navicular via four adjacent and continuous parts: the tibionavicular part, the tibiocalcaneal part, and the anterior and posterior tibiotalar parts (Moore et al., 2014). Collectively, these medial ligaments form a triangular-shaped ligamentous structure known as the deltoid ligament of the ankle (Dutton, 2012). The medial ligament stabilizes the ankle joint during eversion and prevents subluxation (partial dislocation) of the joint (Moore et al., 2014).

i. **Tibionavicular fibers**: These fibers extend from the medial malleolus to the tuberosity of the navicular and serve to resist lateral translation and external rotation of the talus (Dutton, 2012).

ii. **Posterior tibiotalar fibers:** These fibers travel in a posterolateral direction from the medial malleolus to the medial side of the talus and medial tuberosity of the talus. These fibers resist ankle dorsiflexion and lateral translation and external rotation of the talus (Dutton, 2012).

iii**. Calcaneotibial fibers**: These thin fibers extend from the medial malleolus to the sustentaculum tali. The fibers are oriented in such a way that they resist abduction of the talus, calcaneus, and navicular, when the foot and ankle are positioned in plantar flexion and eversion (Dutton, 2012).

iv. **Anterior talotibial fibers:** The fibers of this strong ligament extend from the tip of the medial malleolus to the anterior aspect of the medial surface of the talus. These fibers are oriented in such a way that they resist abduction of the talus, when it is in plantar flexion and eversion. Such is the strength of these fibers that an injury to this ligament is often associated with an avulsion fracture (Dutton, 2012).

Movement in the Ankle Joint

The main movements of the ankle joint are dorsiflexion and plantarflexion of the foot, which occur around a transverse axis passing through the talus (Figure 4). Because the narrow end of the trochlea of the talus lies loosely between the malleoli when the foot is plantarflexed, small amounts of abduction, adduction, inversion, and eversion is possible in this unstable position (Moore et al., 2014).

Blood Supply of Ankle Joint

The arteries are derived from malleolar branches of the fibular and anterior and posterior tibial arteries (Moore et al., 2014).

Nerve supply of ankle joint

The nerves are derived from the tibial nerve and the deep fibular nerve, a division of the common fibular nerve (Moore et al., 2014).

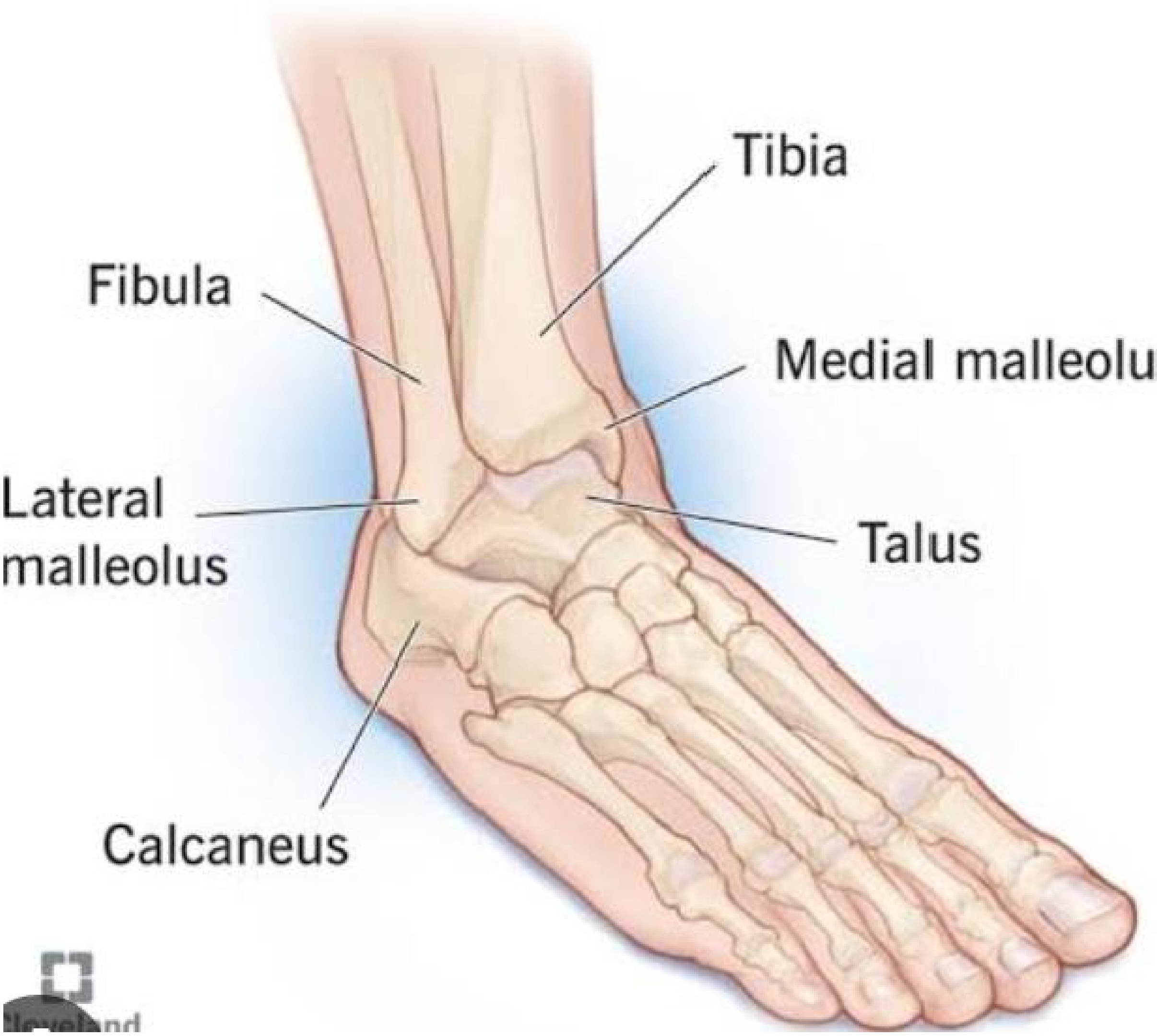

Figure 4. Ankle joint

Bones of the foot

The bones of the foot are 7 tarsal bones, 5 metatarsal bones, and 14 phalanges (Moore et al., 2014). The foot is the region of the lower limb distal to the ankle joint, it has a superior surface (dorsum of foot) and an inferior surface called the sole (Drake et al., 2012). The foot is divided into 3 regions: hindfoot, midfoot and forefoot.

Tarsal Bones

The tarsal bones are arranged in a proximal group and a distal group with an intermediate bone between the two groups on the medial side of the foot (Drake et al., 2012). The tarsus consists of seven bones: talus, calcaneus, cuboid, navicular, and three cuneiforms. Only one bone, the talus, articulates with the leg bones (Moore et al., 2014).

Proximal Bones of the Tarus

The proximal group consists of two large bones, the talus and the calcaneus.

Talus has a body, neck, and head, also the superior surface (trochlea of the talus) is gripped by the two malleoli and receives the weight of the body from the tibia and it is the only tarsal bone that has no muscular or tendinous attachments (Moore et al.,2014). The talus articulates above with the tibia and fibula to form the ankle joint and also projects forward to articulate with the intermediate tarsal bone (navicular) on the medial side of the foot (Drake et al., 2012). The talus transmits that weight in turn, dividing it between the calcaneus, on which the body of talus rests, and the forefoot (Moore et al., 2014).

The calcaneus, (heel bone) is the largest and strongest bone in the foot. The calcaneus transmits the majority of the bodyâ€™s weight from the talus to the ground when standing. The anterior two thirds of the calcaneusâ€™s superior surface articulate with the talus and its anterior surface articulates with the cuboid (Moore et al., 2014).

The intermediate tarsal bone on the medial side of the foot is the navicular (boat shaped) and it articulates behind with the talus and articulates in front and on the lateral side with the distal group of tarsal bones (Moore et al., 2014). One distinctive feature of the navicular is a prominent rounded tuberosity for the attachment of the tibialis posterior tendon, which projects inferiorly on the medial side of the plantar surface of the bone (Drake et al., 2012).

Distal Tarsal Bone

The cuboid, which articulates posteriorly with the calcaneus, medially with the lateral cuneiform, and anteriorly with the bases of the lateral two metatarsals-the tendon of the fibularis longus muscle lies in a prominent groove on the anterior plantar surface, which passes obliquely forward across the bone from lateral to medial (Drake et al., 2012).

Cuneiforms The three cuneiform bones are the medial (1st), intermediate (2nd), and lateral (3rd). The medial cuneiform is the largest he intermediate cuneiform is the smallest. Each cuneiform articulates with the navicular posteriorly and the base of its appropriate metatarsal anteriorly. The lateral cuneiform also articulates with the cuboid (Drake et al., 2012).

Metatarsal

There are five metatarsals in the foot, numbered I to V from medial to lateral. Metatarsal I is associated with the great toe, it is shortest and thickest while the second is the longest. Each metatarsal has a head at the distal end, an elongate shaft in the middle, and a proximal base. The head of each metatarsal articulates with the proximal phalanx of a toe and the base articulates with one or more of the distal group of tarsal bones. The plantar surface of the head of metatarsal I also articulate with two sesamoid bone (Drake et al., 2012). The base of the 1st and 5th metatarsals have large tuberosities that provide for tendon attachment; the tuberosity of the 5th metatarsal projects laterally over the cuboid and provide attachments for fibularis brevis muscle(Moore et al., 2014).

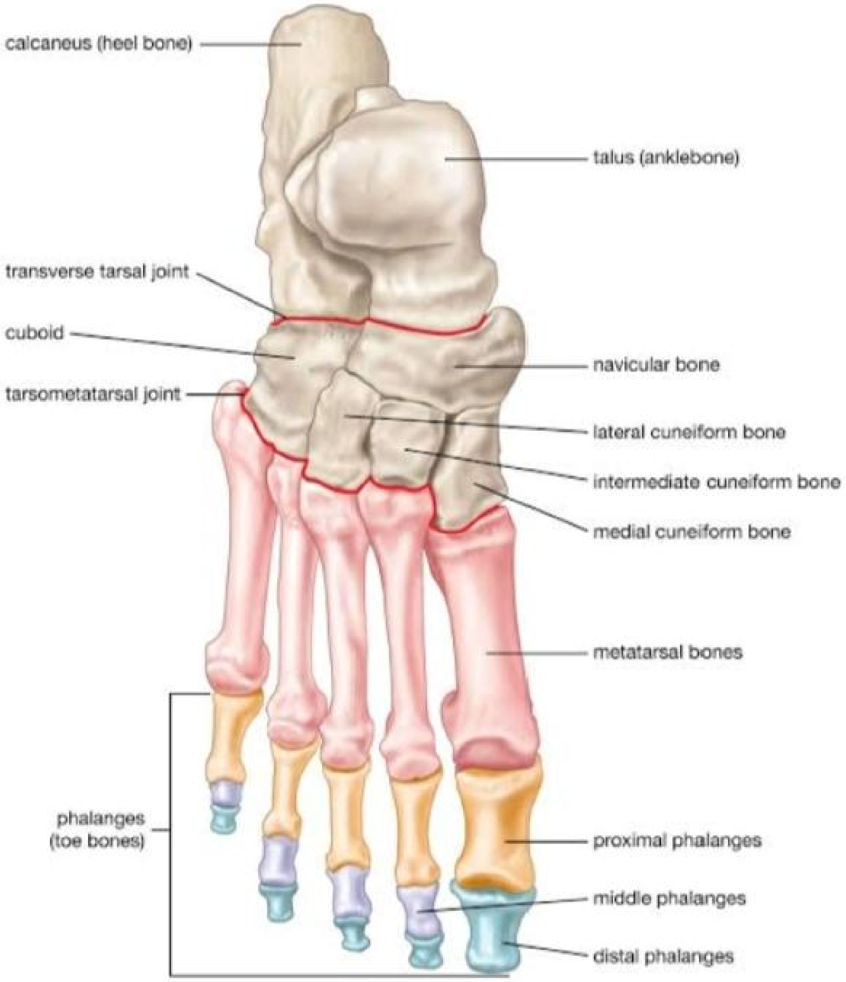

Figure 5: Bones of the Foot

Phalanges

The phalanges are the bones of the toes and each phalanx consists of a base, a shaft, and a distal head (Drake et al., 2012). The 14 phalanges of the lower limb are as follows: the 1st digit (great toe) has 2 phalanges (proximal and distal); (Figure 5) the other four digits have 3 phalanges each: proximal, middle, and distal (Moore et al., 2014).

ACHILLES TENDON

The Achilles tendon is the thickest, strongest tendon in the body. The Achilles tendon is formed from the conjoint tendons of the gastrocnemius and soleus muscles. As the Achilles tendon comes off the posterior calf muscles, it courses distally to attach approximately three-quarters of an inch below the superior portion of the os calcis, on the medial aspect of the calcaneus. The fibers from the gastrocnemius and soleus interweave and twist as they descend, producing an area of high stress above the distal tendon insertion. A region of relative avascularity exists in the same area, which correlates well with the site of some Achilles tendon injuries, including complete spontaneous rupture (Dutton, 2012).

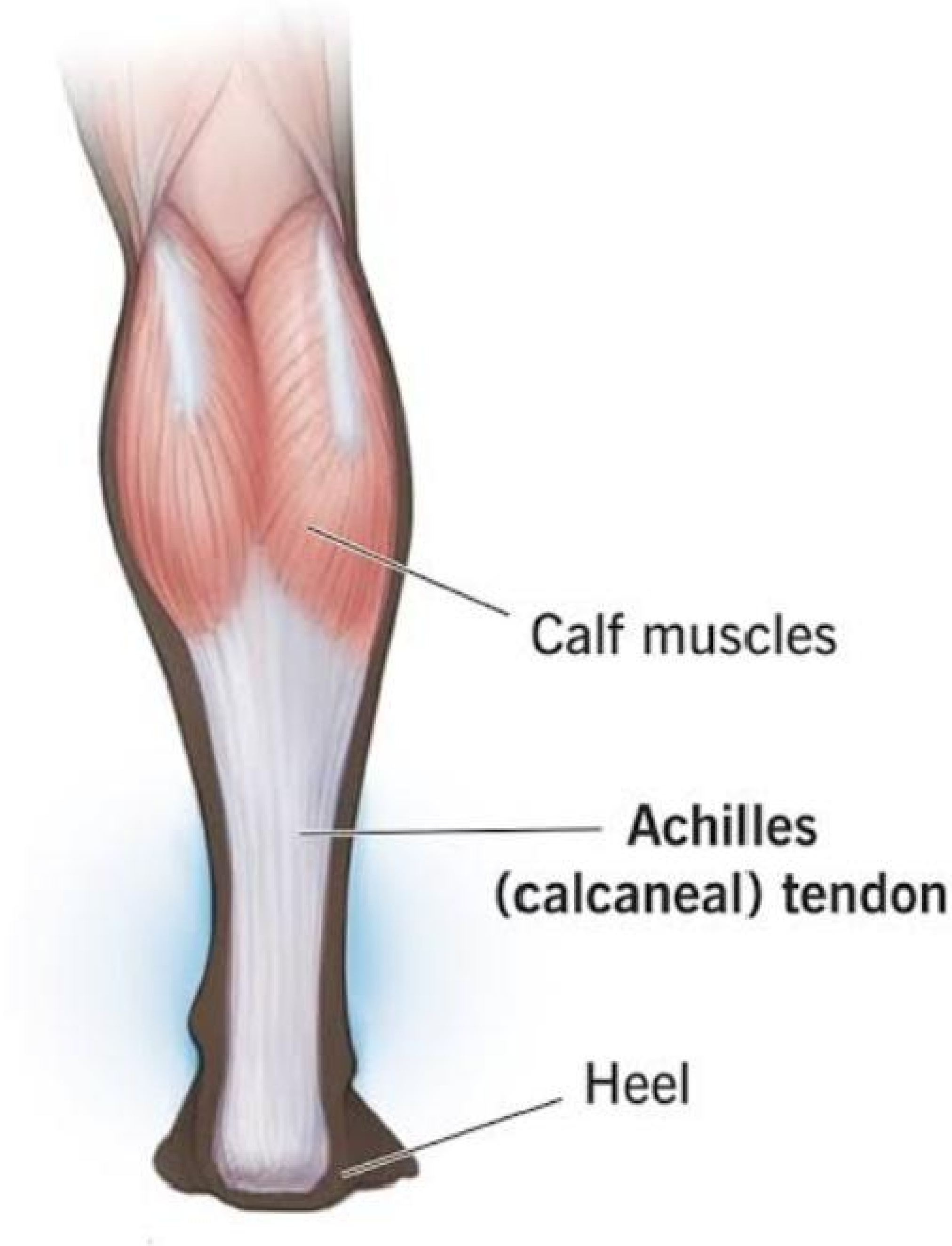

Figure 6: Achilles Tendon

2.5 Biomechanical Parameters Affected by High Heeled Shoes

High-heeled shoes, defined as footwear with a heel height of 7 cm or more, significantly alter the biomechanics of the human body, impacting posture, gait, joint mechanics, and muscle activation. These changes result from the elevated heel, which shifts the body's center of gravity anteriorly and superiorly, forcing compensatory adjustments in the lower limbs and spine.

2.5.1 Joint Angles

High-heeled shoes significantly alter joint angles across the lower limb and spine, primarily due to the plantarflexed foot position induced by the elevated heel. At the ankle, high heels increase plantarflexion, reducing the range of dorsiflexion during gait. This alteration restricts normal ankle motion, leading to compensatory changes in proximal joints (Cronin, 2014). A study by Lee & Park (2019) found that wearing 7 cm heels increased ankle plantarflexion by approximately 15–20 degrees during the stance phase compared to flat shoes, limiting shock absorption and increasing stress on the Achilles tendon. The knee joint also undergoes significant changes, with high heels increasing knee flexion during the stance phase to maintain balance. This increased flexion elevates joint loading and quadriceps muscle demand, potentially contributing to patellofemoral pain (Simonsen et al., 2021). Simonsen et al. (2021) reported a 10–15% increase in knee flexion angle in women wearing 8 cm heels, which was associated with higher compressive forces at the knee joint. At the hip, high heels induce greater hip flexion and anterior pelvic tilt to compensate for the forward shift in the center of gravity. This adjustment increases lumbar lordosis, which may strain the lower back (Mika et al., 2018). Mika et al. (2018) observed a 5–10-degree increase in lumbar lordosis in women wearing 7 cm heels, highlighting the potential for spinal misalignment and lower back pain with prolonged use.

2.5.2 Ground Reaction Forces

Ground reaction forces (GRF) are significantly altered by high-heeled shoes, particularly due to the redistribution of body weight toward the forefoot. The elevated heel shifts the point of contact from the heel to the metatarsal heads, increasing peak pressure in the forefoot by up to 30% compared to flat shoes (Cronin, 2014). This increased forefoot pressure can lead to conditions such as metatarsalgia or stress fractures over time. A study by Park & Kim (2020) found that 7 cm heels increased vertical GRF at the forefoot by approximately 25% during walking, contributing to higher impact forces and potential joint damage.

Additionally, high heels alter the temporal characteristics of GRF, reducing the time to peak force due to shorter stride lengths and increased cadence. This rapid force application exacerbates stress on the lower limb joints, particularly the ankle and knee (Simonsen et al., 2021). The lateral shear forces also increase, as the narrow heel base reduces stability, potentially leading to ankle sprains (Lee & Park, 2019).

2.5.3 Muscle Activation Patterns

High-heeled shoes modify muscle activation patterns, particularly in the lower limb and trunk muscles, to accommodate the altered posture and gait. The plantarflexed ankle position increases activation of the gastrocnemius and soleus muscles, which work harder to maintain balance and propel the body forward (Park & Kim, 2020). Park & Kim (2020) reported a 20–30% increase in gastrocnemius electromyography (EMG) activity in women wearing 7 cm heels compared to flat shoes, indicating higher muscle demand. The quadriceps muscles also exhibit increased activation due to greater knee flexion, which can lead to muscle fatigue and discomfort during prolonged wear (Simonsen et al., 2021). Conversely, the tibialis anterior, which controls dorsiflexion, shows reduced activity due to limited ankle motion, potentially weakening this muscle over time (Mika et al., 2018). In the trunk, the erector spinae muscles are more active to counteract the increased lumbar lordosis, contributing to lower back fatigue (Lee & Park, 2019).

2.5.4 Balance and Stability

High-heeled shoes compromise balance and stability due to the elevated heel and narrow base of support. The anterior shift in the center of gravity reduces the stability margin, increasing the risk of falls, particularly during dynamic activities (Cronin, 2014). A study by Lee & Park (2019) demonstrated that women wearing 8 cm heels exhibited a 15% reduction in balance scores on a stabilometry platform compared to flat shoes, indicating impaired postural control.The narrow heel base also reduces the contact area with the ground, decreasing proprioceptive feedback and increasing reliance on visual and vestibular systems for balance (Park & Kim, 2020). This effect is particularly pronounced in individuals unaccustomed to high heels or those with weaker lower limb muscles, such as ectomorphic body somatotypes, which may lack sufficient muscle mass to stabilize joints effectively (Simonsen et al., 2021).

2.5.5 Health Implications

The biomechanical changes induced by high-heeled shoes have significant health implications. Altered joint angles and increased GRF contribute to conditions such as plantar fasciitis, Achilles tendon shortening, and patellofemoral pain syndrome (Cronin, 2014). The increased lumbar lordosis and muscle activation in the lower back may lead to chronic lower back pain, particularly with prolonged use (Mika et al., 2018). Additionally, the compromised balance increases the risk of ankle sprains and falls, which can result in acute injuries or long-term joint instability (Lee & Park, 2019). These effects may vary across individuals, with body somatotype potentially influencing the degree of biomechanical stress. For instance, endomorphic individuals may experience greater forefoot pressure due to higher body mass, while ectomorphic individuals may face increased joint stress due to limited soft tissue cushioning (Simonsen et al., 2021). These variations underscore the need for targeted research, particularly in populations like Nigerian undergraduates, where high-heel use is prevalent but understudied**.**

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2.6 Aerobic Capacity and Its Measurement

Aerobic Capacity Overview: Aerobic capacity, commonly referred to as maximal oxygen uptake (VO2max), represents the maximum rate at which an individual can consume oxygen during intense, whole-body exercise while breathing air at sea level. It is a key indicator of cardiorespiratory fitness, reflecting the efficiency of the cardiovascular and respiratory systems in delivering oxygen to working muscles and the muscles' ability to utilize oxygen for energy production through aerobic metabolism (Bassett & Howley, 2000). VO2max is typically expressed in milliliters of oxygen per kilogram of body weight per minute (ml/kg/min) or in absolute terms (liters/min). It is influenced by factors such as genetics, age, sex, training status, and environmental conditions (Levine, 2015). Aerobic capacity is critical in physiotherapy, particularly for assessing functional endurance in clinical populations, such as those with cardiovascular, pulmonary, or musculoskeletal conditions. The 6-Minute Walk Test (6MWT) is a widely used field test to estimate aerobic capacity and functional exercise capacity, especially in individuals unable to perform maximal exercise tests (Holland et al.,2014).

2.6.1 Measurement of Aerobic Capacity

Aerobic capacity can be measured directly or indirectly through various methods, ranging from laboratory-based tests to field-based assessments. The choice of method depends on the setting, equipment availability, and the population being tested.

Laboratory-Based Tests (Direct Measurement): The gold standard for measuring VO2max is the Graded Exercise Test with gas analysis, conducted on a treadmill or cycle ergometer. Participants perform incremental exercise until volitional exhaustion, while oxygen consumption and carbon dioxide production are measured using a metabolic cart (Bassett & Howley, 2000). This method is highly accurate but requires expensive equipment and trained personnel, making it less feasible for routine clinical use.

Submaximal Exercise Test: Submaximal exercise tests, such as the Astrand-Rhyming Cycle Ergometer Test, estimate VO2max based on heart rate responses to a fixed workload. These tests are safer for clinical population but rely on assumptions about the heart rate-VO2 relationship, which may introduce inaccuracies (Grant et al., 2023).

Field-Based Tests: Field tests are practical for assessing aerobic capacity in clinical and community settings due to their simplicity and minimal equipment requirements. The 6MWT is one such test, widely used to evaluate functional exercise capacity and indirectly estimate aerobic capacity.The 6-Minute Walk Test (6MWT)The 6MWT measures the distance an individual can walk on a flat, hard surface in 6 minutes. It is a submaximal test of functional exercise capacity, particularly suited for patients with chronic conditions such as chronic obstructive pulmonary disease (COPD), heart failure, or musculoskeletal disorders (Holland et al., 2014). The test reflects the ability to perform daily activities and is strongly correlated with aerobic capacity, although it does not directly measure VO2max.6-Minute Walk Test: The

6MWT, which measures functional exercise capacity, has been adapted to assess the impact of footwear. A study by Park et al. (2021) found that women wearing 8 cm heels walked significantly shorter distances in the 6MWT compared to flat shoes, suggesting a reduction in functional aerobic capacity due to biomechanical constraints and increased energy cost.

Procedure: The 6MWT is conducted following standardized guidelines, such as those provided by the American Thoracic Society
(ATS, 2002):

- Setting: A flat, straight corridor (typically 30 meters long) with markers at each end.
- Instructions: Participants are instructed to walk as far as possible in 6 minutes at their own pace, covering as much distance as possible. They may rest if needed but are encouraged to resume walking as soon as possible.
- Measurements: The total distance walked (in meters) is recorded. Additional parameters, such as heart rate, oxygen saturation (SpO2), and perceived exertion (using the Borg Scale), may be monitored.
- Equipment: A stopwatch, measuring tape or pre-marked course, and optional pulse oximeter or heart rate monitor.
- Safety: The test is supervised to ensure participant safety, especially for those with cardiovascular or respiratory conditions.

The 6MWT distance correlates moderately and strongly with VO2max, particularly in clinical populations (Holland et al., 2014). Regression equations have been developed to estimate VO2max from 6MWT distance, adjusted for age, sex, weight, and height. For example, Burr et al. (2011) derived equations for patients with heart failure, showing that 6MWT distance is a reliable predictor of aerobic capacity in this group. The tests submaximal nature makes it more reflective of functional capacity during daily activities than maximal aerobic capacity, but it remains a valuable tool for estimating cardiorespiratory fitness in clinical settings.

Advantages

Simple and cost-effective, requiring minimal equipment.

- Safe for clinical populations, including older adults and those with chronic conditions.
- Reflects functional capacity relevant to daily activities.
- High test-retest reliability when standardized protocols are followed (Holland et al., 2014).

Limitations

- Influenced by motivation, pacing, and walking efficiency, which may affect results.
- Less accurate than direct VO2max measurement via GXT.
- Environmental factors (e.g., corridor length, surface) and patient factors (e.g., musculoskeletal limitations) can impact performance.
- Not suitable for healthy, athletic populations requiring precise VO2max measurements. A recent study by Jones et al. (2023) validated the 6MWT as a predictor of aerobic capacity in patients with COPD, reporting a strong correlation (r = 0.78) between 6MWT distance and VO2max measured via GXT. The study emphasized the tests utility in physiotherapy for monitoring treatment outcomes.

2.6.2 Factors Affecting Aerobic Capacity Measurements

- Training Status: Regular aerobic exercise increases VO2max, while detraining reduces it (Joyner & Coyle, 2008).
- Age and Sex: VO2max declines with age and is generally higher in males due to differences in muscle mass and hemoglobin (Levine, 2015).

- Environmental Conditions: Temperature, humidity, and altitude can affect 6MWT performance and other aerobic capacity tests (Poole & Jones, 2017).
- Health Status: Chronic conditions (e.g., COPD, heart failure) reduce aerobic capacity and 6MWT distance (Holland et al., 2014).
- Motivation and Effort: The 6MWT relies on participant effort, which can introduce variability (Jones et al., 2023).

2.7 Influence of High Heeled Shoes on Aerobic Capacity

In recent years, the impact of footwear, particularly high-heeled shoes, on physical performance and physiological parameters like aerobic capacity has gained attention due to their widespread use and potential effects on biomechanics and energy expenditure (Wiedemeijer & Otten, 2018).

2.7.1 Physiological Impact on Aerobic Capacity

The physiological effects of high-heeled shoes on aerobic capacity are primarily related to increased energy expenditure and reduced exercise efficiency. Key mechanisms include:

- Elevated Oxygen Consumption: Studies have shown that walking in high heels increases oxygen consumption (VO2) compared to flat shoes due to higher muscle activation and less efficient gait. Ebbeling et al. (2019) found that women walking in 7 cm heels exhibited a 1520% increase in VO2 compared to flat shoes at the same speed, suggesting a higher metabolic cost that could reduce aerobic capacity during prolonged activity.
- Increased Heart Rate: The additional effort required to walk in high heels elevates heart rate, reflecting greater cardiovascular demand. This may limit the duration and intensity of aerobic exercise, as individuals reach their maximum heart rate sooner (Simonsen et al., 2012).

- Fatigue and Reduced Endurance: Prolonged use of high heels leads to muscle fatigue, particularly in the calf and quadriceps, due to sustained contraction. This fatigue reduces the ability to maintain aerobic exercise, negatively affecting aerobic capacity (Chien et al., 2017).
- Impaired Ventilation: High heels may alter diaphragmatic movement and chest expansion due to postural changes, potentially reducing ventilatory efficiency and oxygen delivery during exercise (Wiedemeijer & Otten, 2018). These physiological changes suggest that high-heeled shoes may compromise aerobic capacity by increasing the energy cost of movement and inducing earlier onset of fatigue.

2.8 Body Somatotypes: Definition and Classification

Body somatotype refers to a classification system that categorizes human physique based on body composition and shape, reflecting the relative contributions of three primary components: endomorph (fatness), mesomorph (muscularity), and ectomorph (linearity or slenderness). Developed by William H. Sheldon in the 1940s (Aakanksha, 2023). Somatotypes are used to understand how body composition influences physical performance, health outcomes, and predisposition to certain diseases. The concept is widely applied in fields such as physiotherapy, sports science, and anthropology to assess physical characteristics and their implications for movement, rehabilitation, and fitness.

2.8.1 Classification of Body Somatotypes

Somatotypes are classified into three primary categories, each characterized by distinct physical traits:

Endomorph

Endomorph is characterized by a higher proportion of body fat, a rounded physique, and a tendency toward a softer, more curvaceous body shape. Individuals who are endomorph typically have a wider waist, larger bone structure, and greater fat accumulation in areas such as the abdomen, hips, and thighs.

Characteristics:

Predominance of adipose tissue.

Rounded shoulders and wide hips.

Shorter limbs relative to the torso.

Tendency to gain weight easily.

Mesomorph

Mesomorph is characterized by a muscular, athletic build with a high proportion of muscle mass, broad shoulders, and a narrow waist. Mesomorphic individuals are often associated with strength, power, and agility.

Characteristics:

Well-defined muscles and a rectangular body shape.

Broad shoulders and chest with a narrower waist.

Strong bone structure and low to moderate body fat.

High physical strength and ability to gain muscle mass easily.

Ectomorph

Ectomorph is characterized by a lean, slender physique with low body fat and muscle mass. Ectomorphic individuals typically have a linear body shape and a delicate bone structure.

Characteristics:

Long, thin limbs and a narrow frame.

Low body fat and minimal muscle bulk.

Difficulty gaining weight or muscle mass.

High metabolic rate.

2.9 Relationship between Body Somatotypes and Biomechanical Parameters

Body somatotypes, as classified by Sheldon's system, categorize human physique into endomorph (fatness), mesomorph (muscularity), and ectomorph (linearity) based on body composition and shape (Carter & Heath,1990).

2.9.1 Endomorphy and Biomechanical Parameters:

Individuals who are endomorph, characterized by greater body fat and a rounded physique, often exhibit distinct biomechanical characteristics. The increased body mass index (BMI) associated with endomorphy can lead to higher ground reaction forces during locomotion, increasing joint loading,particularly in the lower limbs (Browning & Kram, 2007). For instance, endomorphic individuals tend to have a wider base of support and altered gait patterns, such as reduced stride length and increased stance time, to maintain stability (Gilleard & Smith, 2010). These adaptations can elevate the risk of knee and hip joint stress, contributing to conditions like osteoarthritis. A 2021 study by Wang et al. found that endomorphic individuals displayed greater knee adduction moments during walking, which correlated with higher risks of medial compartment knee osteoarthritis. In physiotherapy, these findings suggest the need for interventions focusing on weight management and low-impact exercises to reduce joint stress.

2.9.2 Mesomorphy and Biomechanical Parameters:

Mesomorphic individuals, with their muscular build and low to moderate body fat, typically demonstrate biomechanical advantages in activities requiring strength and power. Their higher muscle mass contributes to greater force production and joint stability, resulting in efficient movement patterns during dynamic tasks like jumping or sprinting (Almeida et al., 2020). For example, mesomorphs exhibit lower joint moments and higher muscle activation efficiency during resistance exercises, which enhances performance and reduces injury risk (Santos et al., 2023). However, their robust musculature can sometimes lead to excessive muscle stiffness, potentially increasing the risk of muscle strains during high-intensity activities. Physiotherapy interventions for mesomorphs often emphasize flexibility training and dynamic warm-ups to optimize biomechanical performance and prevent overuse injuries.

2.9.3 Ectomorphy and Biomechanical Parameters:

Ectomorphic individuals, characterized by a lean and linear physique, often face biomechanical challenges due to their lower muscle mass and lighter bone structure. Their reduced muscle bulk can result in lower force-generating capacity, leading to compensatory movement patterns that may increase joint instability (Carter & Heath, 1990). For instance, ectomorphs may exhibit higher joint laxity and reduced ground reaction forces during running, which can predispose them to injuries like ankle sprains or stress fractures (Gaur et al., 2022). A 2022 study by Ribeiro et al. noted that ectomorphic adolescents showed increased spinal curvature during dynamic tasks, suggesting a higher risk of postural issues like scoliosis. In physiotherapy, ectomorphs benefit from strength training programs aimed at enhancing muscle mass and joint stability to improve biomechanical efficiency.

2.10 Interaction of High Heeled Shoes, Body Somatotypes, and Aerobic Capacity

Wearing high-heeled shoes alters the natural biomechanics of the lower extremities, spine, and overall posture, leading to changes in kinematic and kinetic parameters. These changes include:

Gait and Postural Changes: High heels reduce step length and increase cadence, leading to a slower gait speed. The forward shift in the center of mass (COM) increases vertical ground reaction forces (GRF) and alters plantar pressure distribution, with increased stress on the forefoot. A study by Hamandi and Ruken (2020) found that as heel height increases, ankle joint angles decrease, contributing to higher GRF and knee joint moments, which may elevate injury risk.

2.10.1 Joint Kinematics and Kinetics

High heels cause increased knee flexion and reduced ankle dorsiflexion during walking, concentrating biomechanical changes in the knee and foot-ankle complex. This results in greater loading on the knee and forefoot, potentially leading to discomfort and musculoskeletal issues. Lee, Jeong, and Freivalds (2024) reported that heel heights of 4.5 cm and 8 cm significantly decrease trunk flexion angle while increasing tibialis anterior and low back electromyography (EMG) activity, indicating heightened muscle stress.

2.10.2 Balance and Stability

High heels reduce the base of support, impairing static and dynamic balance. Zeng et al. (2023) conducted a systematic review and meta-analysis, finding that high heels significantly affect spatiotemporal parameters, kinematics, kinetics, and balance, increasing the risk of falls. Another study noted that higher heels (e.g., 8.2 cm) increase center of pressure (COP) path length and anteroposterior sway, further compromising stability.

2.10.3 Plantar Pressure Distribution

Wearing high heels shifts plantar pressure from the hindfoot to the medial forefoot, increasing the risk of forefoot pathologies such as metatarsalgia and callus formation. Hong et al. (2025) found that using total contact inserts (TCI) in high heels can reduce peak pressure in the medial forefoot, improving comfort.

Recent studies suggest interventions to mitigate the negative effects of high heels:

2.10.4 Use of Insoles

Total contact inserts can redistribute plantar pressure, reducing forefoot stress and improving comfort, potentially mitigating some aerobic capacity loss.

2.10.5 Limiting Heel Height

Hamandi and Ruken (2020) recommend avoiding heels higher than 5 cm to reduce biomechanical stress and injury risk.

2.11 Summary of Empirical Review of Literature

Authors	Title	Sample Size	Aim of the Study	Study design	Outcome measures	Findings
Barnish et al., 2016	High-heeled shoes and musculoskeletal injuries	Females without musculoskeletal conditions	To conduct the first systematic review from an epidemiological perspective regarding the association between high-heeled shoe wear and hallux valgus, musculoskeletal pain, osteoarthritis (OA)	A narrative systematic review	Epidemiology outcomes, musculoskeletal pain, first-party injuries, osteoarthritis.	Associated with hallux valgus, musculoskeletal pain, and firstparty injury. No conclusive evidence for osteoarthritis.
Ebbeling et al., 1994	Lower extremity mechanics and energy cost of walking in high-heeled shoes	15 females experienced high heel wearer	To examine the energy cost and lower extremity mechanics in shoes of different heel heights (1.25 cm, 3.81 cm, 5.08 cm, and 7.62 cm) in female subjects, including both experienced and inexperienced high-heel wearers, during walking at a speed of 4.2 km/hou	Kinematics and kinetic analysis	Kinematics and kinetic parameters, energy cost(Heart rate and oxygen consumption monitored during treadmill walking)	Increased ankle plantar flexion, knee flexion, and ground reaction forces with higher heels. Heart rate and oxygen consumption increased.
Hamandi & Ruken, 2024	Influence of high heels on walking motion: Gait analysis	5 young women(average age 22.4 years)	To examine the effects of high-heeled shoes and smooth-soled court shoes on walking biomechanics, focusing on changes in ankle joints, foot pressure distribution, muscle activity, and ground reaction	Experimental gait analysis	Kinematic parameters, Kinectic parameters, muscle activity	Decreased step length and ankle joint angle, increased cadence, and vertical ground reaction force with higher heels

			forces in healthy female volunteers accustomed to wearing high heels.			
Hasiuk et al., 2023	Effect of wearing high heels on the biomechanical parameters of the foot	1,501 participants (81 studies, as part of a broader review)	To assess how high-heeled shoes affect foot biomechanics, focusing on plantar pressure and balance	Systematic review analyzing studies on HHS effects, using regression models to evaluate sole pressure and balance changes.	Plantar pressure distribution, body balance, sole pressure on forefoot and heel, and gait biomechanics	High-heeled shoe with 8 cm and 10 cm heels significantly altered gait biomechanics, increased forefoot pressure and reduce balance tolerance
Hong et al., 2001	Effect of shoe heel height on walking stability in healthy young females	20 young female adults	To investigate the influence of varying heel heights (0 cm, 3 cm, and 7 cm) on walking stability in healthy young females, focusing on biomechanical parameters such as gait kinematics, foot pressure distribution, and balance control during walking	Experimental, cross sectional study with a within-subject design	Kinematic parameters, Kinectic parameters, balance control, muscle activity	Increased discomfort, medial forefoot pressure, and ground reaction forces with higher heels. Total contact inserts reduced forefoot pressure

Lee et al., 2001	Biomechanical effects of wearing high-heeled shoes	5 healthy young women	To examine the biomechanical effects of varying heel heights (0 cm, 4.5 cm, 8 cm) on trunk, leg, and low back during standing and walking	Experimental study with a small cohort, using motion analysis, electromyography (EMG), and center of mass measurement.	Trunk flexion angle, tibialis anterior EMG, low back EMG, vertical movement of body center of mass	Higher heel heights significantly decreased trunk flexion angle and increased tibialis anterior and low back EMG activity, indicating greater muscle effort.
Malik et al., 2020	Association of musculoskeletal discomfort with the use of high heeled shoes in females	50 young female student	To determine the association between high-heeled shoe use and musculoskeletal discomfort in young females	Cross-sectional study using purposive sampling and a structured questionnaire	Pain location, pain intensity (Visual Analogue Scale), functional ability	High-heeled shoe use was associated with increased musculoskeletal discomfort, particularly in the foot and lower back
Mika et al., 2012	Effects of high-heeled shoes on lower limb biomechanics	30 females	To investigate the effects of heel height on lower extremity kinematics and leg muscle activity during gait.	Experimental study with a controlled design	Kinematic parameters (joint angles), leg muscle activity (EMG)	Increased contact pressure at metatarsophalangeal joints, particularly at push-off phase. Reduced range of motion in ankle, knee

Park et al., 2020	The influence of high-heeled shoes on balance ability and walking in healthy women	30 healthy female subjects (mean age 21.23 ± 1.31 years)	To investigate the impact of different heel heights (3 cm, 6 cm, 9 cm) on balance ability and walking in healthy women.	Experimental study with balance and walking tests across three heel height conditions, using statistical analysis (ANOVA and post hoc tests)	Balance variables (time, anterior-posterior length, medial-lateral length, balance index), walking variables	Balance ability decreased with increasing heel height, with significant increases in anterior-posterior and medial-lateral sway and reduced balance index
Wang et al., 2021	Health view to decrease negative effect of high heels wearing	Not specified (systematic review of multiple studies)	To summarize strategies to mitigate adverse effects of high-heeled shoes, focusing on heel height, insole, and heel base support	Systematic review of studies	Heel height (3.76–4.47 cm optimal range), heel base support size, plantar pressure, center of pressure deviation, spatiotemporal parameters, kinematic and kinetic parameters, EMG activity	Optimal heel height (3.76–4.47 cm) and larger heel base support reduced ankle injury risk and improved gait stability
Zeng et al., 2023	Effects of high-heeled	1,501 participants	To compare spatiotemporal parameters, kinematics, kinetics,	Systematic review and	Spatiotemporal parameters (step length,	High-heeked shoe significantly altered gait by reducing step

	shoes on lower extremity biomechanics and balance in females	(81 studies)	and muscle function during walking and balance between wearing high-heeled shoes	meta-analysis following PRISMA guidelines	stride length, contact time), kinematic variables (joint angles, range of motion), kinetic variables (ground reaction force, plantar pressure), balance (static and dynamic), and muscle function (EMG activity)	length, stride length, and flight time while increasing ground contact time to enhance stability

CHAPTER THREE

METHODS

3.1 Participants

Participants were female undergraduate students aged 18 years and above from the University of Benin with different body somatotypes (ectomorph, mesomorph and endomorph). Somatotype classification was determined using the somatotype survey questionnaire.

3.1.1 Inclusion Criteria

The following were included in this study:

i. Female undergraduate with the different body somatotypes in university of Benin halls of residence.
ii. Female undergraduate aged 18 years and above.
iii. Female undergraduate who were willing to voluntarily participate in this study.

3.1.2 Exclusion Criteria

The following were excluded from this study:

i. Female undergraduate with any form of LLD
ii. Female undergraduate who have any congenital deformity of the spine, knee, foot and ankle joint.
iii. Female undergraduate student who have disabilities in the lower extremities.
iv. Female undergraduate who have any injury or history of surgery to their low back, ankle and foot.

Female undergraduate who do not fit in into the universal size of the 3-inch high-heeled shoe.

3.2 Materials

3.2.1 Apparatus/ Instruments

The following instrument was utilized for this study:

1. i. Measuring tape
2. ii. Goniometer
3. iii. Weighing Scale
4. iv. Height meter
5. v. Heel size of shoes
6. vi. Omron body composition monitor
7. vii. Pulse oximeter
8. viii. Digital sphygmomanometer

Description of Instruments:

Measuring tape: Measuring tape (Stanley® PowerLock® Tape Measure, United States) was used for this study. The measuring tape is a flexible, portable tool commonly used for anthropometric measurements in research and clinical settings. It is designed to accurately measure distances, lengths, and circumferences of various body parts, allowing for precise quantification of anatomical dimensions (height, weight, waist-hip ratio, waist circumference, limb length description). The measuring tape typically consists of a thin, flexible strip of material marked with linear increments in metric (centimeters) and/or imperial (inches) units with a validity of 85-90% and reliability of 90-95% (Wang et al, 2000).

Goniometer: The Circle Universal Manual Goniometer is a commonly used tool in both clinical and research environments for evaluating joint range of motion (ROM) and other biomechanical factors. It is specifically designed to measure joint angle changes with high accuracy, making it ideal for assessing mobility and flexibility. In this study, it was employed to determine the quadriceps angle (Q-angle). This particular model, the Baseline® 180 Degree Economy Plastic Goniometer (USA), features a circular protractor with two movable arms or rulers that pivot from the center. The protractor is marked in degrees, allowing measurements from 0 to 180 degrees in both clockwise and counterclockwise directions. The arms can be aligned with anatomical reference points to accurately gauge joint angles and may include a locking feature to hold them steady during use. The Baseline® goniometer is calibrated in degrees (°), with clear markings to facilitate precise angular measurements within the 0 to 180-degree range. Its design ensures dependable and accurate ROM assessments, enabling practitioners and researchers to effectively track joint mobility and detect changes over time. The Goniometer has a validity of 80-90% and a reliability of 80-95% (Hanks et al, 2023).

Weighing Scale (TANITA 876 MODEL): A weighing scale, also known as a mass scale, weight scale, mass balance, or weight balance, is a crucial device used for the precise determination of an object's weight or mass. These scales come in a variety of sizes and types, from small laboratory balances to heavy-duty industrial models, and are calibrated to display measurements in specific units such as grams, kilograms, ounces, or pounds, depending on the intended use. Calibration is an essential process to ensure the accuracy and reliability of the scale's weight measurements, involving adjustments and testing to guarantee consistent and precise readings. It has a validity of 95-99% and a reliability of 95-98% (Frija-Masson et al, 2021).

Height Meter (SECA 213 MODEL): A height meter, also known as a standiometer, is a device used to measure human height accurately. It typically consists of a vertical ruler or scale attached to a stable base, often with a sliding headpiece that rests on the top of the head. Height meters are widely used in medical, fitness, and research settings to assess growth, monitor health conditions, and collect anthropometric data. A height meter measures the distance from the floor to the top of a person's head while they stand upright. Height meter are widely recognized as valid tools for measuring height when used properly (subject standing straight, heels together, head in Frankfort plane) (Liu et al., 2021). A study using digital standiometers found Intra class Correlation Coefficients (ICCs) > 0.98, indicating excellent reliability (Martins et al., 2022).

Heel size of shoes: A universal size of 3 inches high-heeled shoe and a normal heeled shoe. A systematic study found out that high-heeled shoes is averagely around 3 inches hence, this study will make use of 3 inches to compare with the normal heeled shoe (Clark, 2024).

Somatotype Survey Questionnaire: This is organized into three distinct sections to gather comprehensive information about the participants.

Part I focuses on the basic profile of each participant. It includes details such as the participant's name, age, and sex to establish a general demographic background.

Part II explores physical characteristics associated with body type. Participants are asked to reflect on and identify traits such as being lean and thin, having narrow hips, chest, and shoulders, possessing long legs and arms, a higher forehead, and a thinner facial structure.

Part III delves into personality traits commonly linked with specific somatotypes. It includes descriptors such as being socially awkward, self-conscious, introverted, private, artistic, thoughtful, sensitive, anti-social, and intellectual. This section aims to connect physical attributes with personality tendencies to offer a fuller

Omron body composition monitor: An Omron body composition understanding of the individual's somatotype profile.

Composition Monitor is a home-use device that measures body weight and composition metrics like body fat percentage, skeletal muscle mass, visceral fat, BMI, resting metabolism, and body age. It employs Bioelectrical Impedance Analysis (BIA), sending a weak electrical current through the body to measure tissue resistance. Muscles conduct electricity well due to high water content, while fat resists it. Full-body models (e.g., HBF-514C, BCM-500) use hand and foot sensors for improved accuracy. Results depend on user inputs (height, age, gender) and consistent conditions (e.g., morning, pre-meal, hydrated). The Omron body composition monitor has a validity of 60-90% and a reliability of 85-95% (Tingsley et al, 2022).

Pulse Oximeter: A pulse oximeter is a non-invasive medical device used to measure the oxygen saturation level (SpO_2) of the blood and the patient's pulse rate. It typically consists of a probe that clips onto a thin part of the body, such as a fingertip or earlobe. The device uses light-emitting diodes (LEDs) and a photodetector to determine the amount of oxygenated hemoglobin in the blood based on the absorption of red and infrared light (Jubran, 2025).

Digital sphygmomanometer: A digital sphygmomanometer (also called an automatic blood pressure monitor) is a device used to measure arterial blood pressure. Unlike the manual sphygmomanometer that requires a stethoscope, the digital version uses electronic pressure sensors and an oscillometric method to automatically detect blood pressure values. The cuff is wrapped around the patient's upper arm (or wrist), and the device inflates the cuff automatically. The monitor then detects oscillations in the arterial wall and calculates systolic, diastolic, and mean arterial pressure. Results are displayed on an electronic screen, often with pulse rate (Ntousopoulos et al., 2024).

3.3 Methods

3.3.1 Research Designs

The study was a single-blind randomized controlled trial registered with the Pan African Clinical Trial Registry (PACTR202509672126877) Appendix II.

3.3.2 Sampling Techniques/Sample Size Calculation

Consecutive sampling technique was used to recruit participants, participants were selected based on body types from each female halls of residence and was blocked randomized into body types of ectomorph, mesomorph and endomorph. Block randomization was varied between 4 and 8. block sizes of 4, 5, 6, 7, and 8, respectively, created using computer generated codes consisting of group one, two and three labels. The codes were used to allocate the participants into the three the body types that make up the groups in the study. Also participants were unaware of the group of study that they belong to ensure single blinding.

The formula by Chan (2003): $n=c\times\pi1\ (1-\pi1) + \pi2\ (1-\pi2)/\ (\pi1-\pi2)^2$ which assumes a type 1 error and a power of 80% was used. For a two-sided test of 5%, assuming a successful outcome of 25% in one intervention will only be relevant if we observe a 40% effect size of absolute improvement in the other intervention. Therefore: n= sample size, $\pi1=0.25$, $\pi2=0.65$, c= the power of the sample (c= 7.9 for the power of 80%). n= 7.9 × 0.25 (1- 0.25) + 0.65 (1- 0.65)/ (0.25-0.65) ^2= 21. For the three groups of participants, n=3×21=63. Assuming 20% drop out, n = 63× 0.20= 75.6.

Hence, 75 participants were recruited such that there were 25 participants for each group:, group one (ectomorph) was 25, group two (mesomorph) was 25, and group three (endomorph) was 25.

3.3.3 Research Procedure/Procedure for Data Collection

Ethical approval was obtained from the ethics committee of the University of Benin and informed consent was obtained from the participants. Participants were sourced from the halls of residence within the university to ensure representation across somatotypes. The researcher screened the participants using the somatotypes survey questionnaire, participants were blocked randomized into three groups (ectomorph, mesomorph and endomorph). The participants were made to wear the flat shoe and all measurements of biomechanical parameters (LF, QA, LLD, QL, and GL) were taken. Also, they wore the 3-inch high-heeled shoe and biomechanical parameters (LF, QA, LLD, QL, and GL) were taken. Participants then undertook the 6min walk test with their flat shoe immediately after which aerobic parameters (TLC, SPO_2, SBP, DBP, and PR) were taken. Thereafter, they rested for 15 minutes, and underwent the 6min walk test on the 3-inch high-heeled shoe and the aerobic parameters (TLC, SPO_2, SBP, DBP, and PR) were retaken. All scores measured was duly recorded. The following method was used to assess the biomechanical parameters (LF, QA, LLD, QL, and GL) and anthropometric parameters (height, weight, body mass index, percentage body fat).

Measurement of heights: Participants' heights was measured with a height meter to the nearest 0.1m. Participants were instructed to stand erect by the wall with their backs against the wall and feet together. Then the researcher placed a meter rule on the participants' vertex and takes a reading from the height meter (WHO, 2008).

Measurement of weight: Participants' weights was measured with a standard weighing scale to the nearest 0.1Kg. The participants were asked to be on light shorts and stand on the weighing scale with head erect. Then the researchers read the weights from the scale and record it (WHO, 2008).

Calculation of Body mass index: The BMI of each participant was calculated as the ratio of their weight to the square of their heights in Kg/m2 (WHO, 2008).

Measurement of Percentage body fat: Percentage body fat is measured using the Omron body composition monitor which uses Bioelectrical Impedance Analysis (BIA) method, which sends a weak electrical current through the body to measure resistance (Micheal et al., 2011).

Measurement of Quadriceps angle: Participants' Q-angle for the right knee was measured with the circle universal manual goniometer (Baseline® 360 Degree Economy Plastic) using the procedure described by Weiss et al. Participants lay supine on a plinth with knees extended, and the researcher beside the plinth. The hips, knees and feet of the participant were placed in a neutral position. The researcher then identified and labels the anterior superior iliac spine, mid-point of the patella and the tibia tubercle. A line was thereafter drawn from anterior superior iliac spine to the midpoint of patella and then from the midpoint of the patella to the tibia tubercle. The angle formed by the crossing of the two lines was measured and recorded as the Q-angle (Figure 7). Surface goniometry for the measurement of Q-angle is reported to be reliable (Weiss et al., 2013).

Figure 7: Measurement Quadriceps angle with a universal circle goniometer

Measurement of lumbar flexibility: The modified Schober's procedure described by Meritt et al was used to measure lumbar flexibility. Participants will be asked to stand upright on bare feet with their trunk exposed. The researcher marked a spot at the spinous process of the L4 vertebral, indicated by a horizontal line connecting the participants' posterior superior iliac spine. Another spot will be marked at 5 cm below the first spot. A third spot will be marked at 10cm above the first spot (Figure 8). The participants will be instructed to bend forward to touch their toes . The researcher re-measures the distance between the third and second spots with the participants fully flexed, and subtracts 15cm from it to obtain the values for participants' lumbar flexibility. The obtained values of lumbar flexibility will be recorded to the nearest 0.1m.

Figure 8: Measurement of lumbar flexibility

3.3.4 Ethical Considerations

Ethical approval (CMS/REC/2024/829) was sought and obtained from the Research and Health Ethics Committee, University of Benin. Informed consent was obtained from the participants.

3.3.5 Data Analysis

Data was analyzed using the Statistical Package for the Social Sciences (IBM) version 26 (M Corp., USA). Kolmogorov-Smirnov test was used to determine the normality of the data. Data was found not to be normally distributed for (QA, QL, SPO_2) hence, inferential statistics for Wilcoxon, Kruskal-Wallis, Mann Whitney U test, however, data was found to be normally distributed for (PR, TLAP) hence, inferential statistics for Paired Samples T-Test and analysis of variance .Descriptive statistics of mean and standard deviation was used to summarize participant's age, height, weight, body mass index, percentage body fat, quadriceps muscle length, lumbar flexibility, quadriceps angle. A one-way analysis ANOVA was used to compare outcomes across somatotypes and shoe height with post-hoc Bonferroni tests for significant interactions. The level of significance was set at $p < 0.05$.

CHAPTER FOUR

RESULTS

4.1 Preamble

The primary aim of this study was to determine the effect of high-heeled shoes on selected biomechanical parameters (lumbar flexibility, quadriceps angle, limb length discrepancy, quadriceps muscle length and gastrocnemius muscle length) and aerobic capacity in female undergraduate's body somatotype in the University of Benin.

4.1.2 One-sample Kolmogorov-Smirnov Test of Normality for Participants' Baseline data

A One-Sample Kolmogorov-Smirnov test was performed to determine if the baseline data were normally distributed. As shown in Table 4.2, the distributions for several variables deviated significantly from a normal distribution. These variables include: Age (D(75) = 0.157, p < .001), Height (D(75) = 0.133, p = .002), Weight (D(75) = 0.107, p = .032), Body mass index (D(75) = 0.154, p < .001), Limb length discrepancy (D(75) = 0.114, p = .017), Quadriceps (D(75) = 0.161, p < .001), Quadriceps length (D(75) = 0.145, p < .001), Systolic blood pressure (D(75) = 0.128, p = .004), Diastolic blood pressure (D(75) = 0.111, p = .022), Oxygen saturation (D(75) = 0.163, p < .001), Laps (D(75) = 0.128, p = .004), Lumbar flexibility (D(75) = 0.08, p = .007), Gastrocnemius length (D(75) = 0.100, p = .006), and Partial Lap (D(75) = 0.123, p = .007).

Conversely, the test was non-significant for some variables, indicating that their distributions can be assumed to be normal. These variables are: Body fat % (D(75) = 0.077, p = .200), Pulse rate (D(75) = 0.099, p = .064) and Total lap (D(75) = 0.071, p = .200).

Table 4.2: One-sample Kolmogorov-Smirnov Test of Normality for Participants' Baseline data

Variables	**N**	**Most Extreme Differences**			**Test Statistics**	**p**
		Absolute	**Positive**	**Negative**		
Age	75	0.157	0.146	-0.157	0.157	0.000***
Height	75	0.133	0.133	-0.103	0.133	0.002***
Weight	75	0.107	0.107	-0.070	0.107	0.032***
Body mass index	75	0.154	0.154	-0.081	0.154	0.000***
Body fat %	75	0.077	0.053	-0.077	0.077	0.200
Lumbar flexibility	75	0.098	0.098	-0.078	0.098	0.007***
Limb length discrepancy	75	0.114	0.114	-0.078	0.114	0.017***
Quadriceps angle	75	0.161	0.133	-0.161	0.161	0.000***
Quadriceps length	75	0.145	0.145	-0.093	0.145	0.000***
Gastrocnemius length	75	0.100	0.100	-0.095	0.100	0.006***
Systolic blood pressure	75	0.128	0.128	-0.082	0.128	0.004***
Diastolic blood pressure	75	0.111	0.111	-0.079	0.111	0.022***
Oxygen saturation	75	0.163	0.163	-0.135	0.163	0.000***
Pulse rate	75	0.099	0.091	-0.099	0.099	0.064
Total Laps Covered	75	0.128	0.090	-0.128	0.128	0.200

*** = p is significant at $p < 0.05$

4.1.3 Anthropometric Characteristics of the Endomorph Somatotype

The anthropometric characteristics for the endomorph group are presented in Table 4.3. This group, with a mean age of 21.40 ± 1.61 years, was characterized by the highest mean weight (92.56 ± 10.51 kg), Body Mass Index (34.00 ± 4.15 kg/m^2), and Body Fat percentage (44.46 ± 3.46%) among the three somatotypes. Table 4.3

4.1.4 Anthropometric Characteristics of the Mesomorph Somatotype

The anthropometric characteristics for the mesomorph group are provided in Table 4.4. This group had a mean age of 19.96 ± 4.15 years, with a mean weight of 66.14 ± 7.76 kg and a Body Mass Index of 23.83 ± 2.40 kg/m^2. Table 4.4

4.1.5 Anthropometric Characteristics of the Ectomorph Somatotype

The anthropometric characteristics of the ectomorph group are summarized in Table 4.5. This group, with a mean age of 20.00 ± 1.89 years, recorded the lowest mean weight (51.06 ± 6.16 kg) and BMI (18.61 ± 1.77 kg/m^2) of the three somatotypes. Table 4.5

Table 4.3: Anthropometric Characteristics of the Endomorph Somatotype (N=25)

Variable	Mean ± SD	Minimum	25%	75%	Maximum	CV (%)
Age (years)	21.40 ± 1.61	19.00	20.00	22.00	25.00	7.5
Height (m)	1.65 ± 0.07	1.55	1.59	1.72	1.78	4.2
Weight (Kg)	92.56 ± 10.51	75.00	84.00	99.75	111.00	11.4
BMI (Kg/m²)	34.00 ± 4.15	27.70	30.81	37.85	41.40	12.2
Body Fat (%)	44.46 ± 3.46	38.00	41.70	47.65	49.80	7.8

Table 4.4: Anthropometric Characteristics of the Mesomorph Somatotype (N=25)

Variable	Mean ± SD	Minimum	25%	75%	Maximum	CV (%)
Age (years)	19.96 ± 4.15	2.00	19.50	22.00	24.00	20.8
Height (m)	1.65 ± 0.07	1.55	1.59	1.72	1.81	4.4
Weight (Kg)	66.14 ± 7.76	54.00	60.50	70.25	86.00	11.7
BMI (Kg/m²)	23.83 ± 2.40	19.94	22.19	25.00	29.70	10.1
Body Fat (%)	34.11 ± 4.01	25.00	30.90	36.30	40.60	11.7

Table 4.5: Anthropometric Characteristics of the Ectomorph Somatotype (N=25)

Variable	Mean ± SD	Minimum	25%	75%	Maximum	CV (%)
Age (years)	20.00 ± 1.89	17.00	18.00	22.00	24.00	9.5
Height (m)	1.69 ± 0.07	1.54	1.61	1.72	1.78	4.2
Weight (Kg)	51.06 ± 6.16	40.00	46.50	55.00	63.00	12.1
BMI (Kg/m²)	18.61 ± 1.77	15.60	17.45	19.95	21.30	9.5
Body Fat (%)	23.58 ± 5.83	13.60	17.30	29.00	32.30	24.7

4.1.6 Biomechanical Parameters of the Endomorph Somatotype

The biomechanical parameters for the endomorph group are detailed in Table 4.6. At baseline, the mean lumbar flexibility was 7.62 ± 1.66 cm, which decreased to 6.31 ± 1.74 cm post-intervention. Similarly, the quadriceps angle reduced from a baseline mean of 15.24 ± 1.20° to a post-intervention mean of 13.14 ± 1.42°. A general decrease was observed across all other biomechanical measures. Table 4.6

4.7 Biomechanical Parameters of the Mesomorph Somatotype

Table 4.7 details the biomechanical parameters for the mesomorph group. Lumbar flexibility decreased from a baseline mean of 8.01 ± 1.16 cm to 6.68 ± 1.42 cm post-intervention. The quadriceps angle also showed a decrease, from a baseline of 15.28 ± 1.21° to 12.83 ± 1.13° after the intervention. Table 4.7

4.8 Biomechanical Parameters of the Ectomorph Somatotype

Table 4.8 shows the biomechanical data for the ectomorph group. This group showed a trend of post-intervention decrease across biomechanical measures. The most substantial mean decrease was in quadriceps angle, which went from a baseline of 14.68 ± 1.65° to 11.89 ± 1.15° post-intervention. Table 4.8

Table 4.6: Biomechanical Parameters for the Endomorph Somatotype (N=25)

Variable	Time	Mean ± SD	Minimum	25%	75%	Maximum	CV (%)
Lumbar Flexibility (cm)	Baseline	7.62 ± 1.66	5.00	6.00	8.65	11.50	21.8
	Post-Intervention	6.31 ± 1.74	4.00	5.00	7.75	11.00	27.6
Limb Length Discrepancy (cm)	Baseline	92.92 ± 6.19	82.00	87.00	97.25	104.00	6.7
	Post-Intervention	91.15 ± 6.08	81.00	85.50	95.00	102.00	6.7
Quadriceps Angle (°)	Baseline	15.24 ± 1.20	13.00	14.00	16.00	17.00	7.9
	Post-Intervention	13.14 ± 1.42	11.00	12.00	14.00	15.00	10.8
Quadriceps Muscle Length (cm)	Baseline	17.62 ± 1.24	15.60	16.65	18.95	20.10	7.0
	Post-Intervention	16.56 ± 1.10	15.00	15.85	17.55	19.00	6.7
Gastrocnemius Muscle Length (cm)	Baseline	17.10 ± 1.49	14.90	16.05	18.00	21.00	8.7
	Post-Intervention	15.31 ± 1.36	13.00	14.25	16.10	18.20	8.9

Key: CV= Coefficient of Variation, SD=Standard deviation

Table 4.7: Biomechanical Parameters for the Mesomorph Somatotype (N=25)

Variable	Time	Mean ± SD	Minimum	25%	75%	Maximum	CV (%)
Lumbar Flexibility (cm)	Baseline	8.01 ± 1.16	6.00	7.00	8.85	10.50	14.5
	Post-Intervention	6.68 ± 1.42	5.00	5.50	7.75	10.00	21.2
Limb Length Discrepancy (cm)	Baseline	93.04 ± 5.91	85.00	88.50	100.00	104.00	6.4
	Post-Intervention	91.12 ± 5.99	83.50	86.00	98.00	102.00	6.6
Quadriceps Angle (°)	Baseline	15.28 ± 1.21	12.00	15.00	16.00	17.00	7.9
	Post-Intervention	12.83 ± 1.13	10.00	12.00	14.00	14.10	8.8
Quadriceps Muscle Length (cm)	Baseline	18.12 ± 1.68	16.00	16.95	19.75	21.70	9.3
	Post-Intervention	16.79 ± 1.75	14.00	15.70	18.75	20.10	10.4
Gastrocnemius Muscle Length (cm)	Baseline	17.16 ± 1.20	15.20	16.15	17.95	20.00	7.0
	Post-Intervention	15.49 ± 1.17	13.40	14.80	16.30	18.40	7.6

Table 4.8: Biomechanical Parameters for the Ectomorph Somatotype (N=25)

Variable	Time	Mean ± SD	Minimum	25%	75%	Maximum	CV (%)
Lumbar Flexibility (cm)	Baseline	7.49 ± 1.22	5.50	6.35	8.50	9.50	16.3
	Post-Intervention	6.70 ± 1.09	4.50	6.00	7.50	9.00	16.3
Limb Length Discrepancy (cm)	Baseline	91.78 ± 5.00	79.00	88.00	95.00	104.00	5.5
	Post-Intervention	89.32 ± 5.22	77.00	86.00	92.50	102.00	5.8
Quadriceps Angle (°)	Baseline	14.68 ± 1.65	11.00	14.00	15.50	18.00	11.2
	Post-Intervention	11.89 ± 1.15	10.00	11.00	13.00	14.00	9.7
Quadriceps Muscle Length (cm)	Baseline	18.18 ± 1.39	15.60	17.60	19.70	20.00	7.6
	Post-Intervention	17.38 ± 1.29	15.00	16.65	18.80	19.20	7.4
Gastrocnemius Muscle Length (cm)	Baseline	17.33 ± 1.40	14.90	16.20	18.50	20.00	8.1
	Post-Intervention	15.72 ± 1.33	13.10	14.90	17.00	18.40	8.5

4.1.9 Aerobic Parameters for the Endomorph Somatotype

As shown in Table 4.9, the endomorph group experienced an increase in blood pressure post-intervention. Systolic blood pressure increased from a baseline mean of 121.96 ± 13.18 mmHg to 128.64 ± 13.05 mmHg, while diastolic blood pressure rose from 77.68 ± 15.28 mmHg to 80.64 ± 13.99 mmHg. Conversely, their aerobic capacity, measured by the total distance covered, decreased from a baseline of 469.28 ± 56.49 m to 389.96 ± 34.70 m post-intervention.

4.1.10 Aerobic Parameters for the Mesomorph Somatotype

The aerobic data for the mesomorph group are in Table 4.10. Post-intervention, systolic blood pressure increased from a baseline of 115.40 ± 10.55 mmHg to 124.60 ± 9.97 mmHg, and diastolic blood pressure rose from a baseline of 70.32 ± 9.05 mmHg to 78.44 ± 8.76 mmHg. Aerobic capacity, measured by total laps covered, decreased from 521.80 ± 42.41 m at baseline to 427.92 ± 33.62 m post-intervention.

4.11 Aerobic Parameters for the Ectomorph Somatotype

The aerobic parameters for the ectomorph group are in Table 4.11. This group experienced an increase in blood pressure post-intervention. Notably, the ectomorph group also showed the greatest reduction in aerobic capacity; the total distance covered decreased from a baseline mean of 573.40 ± 53.04 m to 476.40 ± 50.37 m post-intervention.

Table 4.9: Aerobic Parameters for the Endomorph Somatotype (N=25)

Variable	Time	Mean ± SD	Minimum	25%	75%	Maximum	CV (%)
Systolic BP (mmHg)	Baseline	121.96 ± 13.18	95.00	115.50	130.50	157.00	10.8
	Post-Intervention	128.64 ± 13.05	109.00	119.00	133.50	159.00	10.1
Diastolic BP (mmHg)	Baseline	77.68 ± 15.28	55.00	67.00	85.50	111.00	19.7
	Post-Intervention	80.64 ± 13.99	57.00	71.00	91.50	113.00	17.4
Oxygen Saturation (%)	Baseline	96.60 ± 1.71	94.00	95.00	98.00	99.00	1.8
	Post-Intervention	98.00 ± 1.00	96.00	97.50	99.00	99.00	1.0
Pulse Rate (bpm)	Baseline	84.60 ± 9.10	72.00	75.50	93.50	99.00	10.8
	Post-Intervention	87.12 ± 8.49	74.00	81.00	94.00	102.00	9.7
Total Lap Covered (m)	Baseline	469.28 ± 56.49	363.00	421.50	507.00	593.00	12.0
	Post-Intervention	389.96 ± 34.70	324.00	352.00	416.50	444.00	8.9

Table 4.10: Aerobic Parameters for the Mesomorph Somatotype (N=25)

Variable	Time	Mean ± SD	Minimum	25%	75%	Maximum	CV (%)
Systolic BP (mmHg)	Baseline	115.40 ± 10.55	97.00	109.50	120.50	135.00	9.1
	Post-Intervention	124.60 ± 9.97	105.00	118.50	133.00	142.00	8.0
Diastolic BP (mmHg)	Baseline	70.32 ± 9.05	51.00	65.00	76.50	87.00	12.9
	Post-Intervention	78.44 ± 8.76	59.00	72.00	85.50	92.00	11.2
Oxygen Saturation (%)	Baseline	96.64 ± 1.73	94.00	95.00	98.50	99.00	1.8
	Post-Intervention	98.12 ± 0.93	95.00	98.00	99.00	99.00	0.9
Pulse Rate (bpm)	Baseline	85.76 ± 7.52	70.00	82.00	89.00	101.00	8.8
	Post-Intervention	94.64 ± 9.80	79.00	88.00	100.50	114.00	10.4
Total Lap Covered (m)	Baseline	521.80 ± 42.41	444.00	481.50	552.00	596.00	8.1
	Post-Intervention	427.92 ± 33.62	372.00	403.00	461.00	507.00	7.9

Table 4.11: Aerobic Parameters for the Ectomorph Somatotype

Variable	Time	Mean ± SD	Minimum	25%	75%	Maximum	CV (%)
Systolic BP (mmHg)	Baseline	113.92 ± 9.47	90.00	109.00	120.00	133.00	8.3
	Post-Intervention	123.76 ± 10.94	104.00	117.00	128.50	149.00	8.8
Diastolic BP (mmHg)	Baseline	69.36 ± 8.90	51.00	65.00	75.50	89.00	12.8
	Post-Intervention	70.76 ± 9.49	51.00	65.50	78.00	91.00	13.4
Oxygen Saturation (%)	Baseline	96.76 ± 1.88	93.00	95.00	98.50	99.00	1.9
	Post-Intervention	97.80 ± 1.12	96.00	97.00	99.00	99.00	1.1
Pulse Rate (bpm)	Baseline	87.12 ± 6.29	74.00	84.00	92.00	100.00	7.2
	Post-Intervention	90.44 ± 10.60	55.00	84.00	96.50	113.00	11.7
Total Lap Covered (m)	Baseline	573.40 ± 53.04	468.00	539.50	624.00	652.00	9.3
	Post-Intervention	476.40 ± 50.37	376.00	431.50	512.50	573.00	10.6

4.1.12 Within-Group Analysis of Biomechanical Parameters

A Wilcoxon Signed Ranks Test was conducted to determine the statistical significance of the changes in biomechanical parameters from baseline to post-intervention for each somatotype. The results show that the intervention had a statistically significant effect on all measured biomechanical variables ($p < 0.05$). Table 4.12

4.1.13 Within-Group Analysis of Cardiovascular Parameters

The Wilcoxon Signed Ranks Test was also used to assess the statistical significance of changes in cardiovascular parameters from baseline to post-intervention. There was a statistically significant increase in systolic blood pressure for all three somatotype groups ($p \leq 0.001$). For diastolic blood pressure, a statistically significant increase was observed only in the mesomorph group ($p < 0.001$), while the changes for the endomorph ($p = 0.146$) and ectomorph ($p = 0.367$) groups were not statistically significant. Oxygen saturation showed a statistically significant increase for all three groups after the intervention. Table 4.13

4.1.14 Within-Group Analysis of Aerobic Capacity Parameters

A Paired Samples T-Test was conducted to evaluate the changes in pulse rate and total lap covered from baseline to post-intervention. The decrease in total lap covered was found to be statistically significant across all three somatotypes ($p < 0.001$ for all groups), indicating a reduction in aerobic capacity. Post-intervention pulse rate increased significantly for endomorphs ($p = 0.003$) and mesomorphs ($p < 0.001$). However, for the ectomorph group, the observed increase in pulse rate was not statistically significant ($p = 0.069$). Table 4.14

Table 4.12: Wilcoxon Signed Ranks Test for Biomechanical Parameters within Each Somatotype

Variable	Somatotype	Baseline Mean ± SD	Post-Intervention Mean ± SD	Z	p
Lumbar Flexibility	Endomorph	7.62 ± 1.66	6.31 ± 1.74	-4.303	<0.001
	Mesomorph	8.01 ± 1.16	6.68 ± 1.42	-3.991	<0.001
	Ectomorph	7.49 ± 1.22	6.70 ± 1.09	-3.346	0.001
Limb Length Discrepancy	Endomorph	92.92 ± 6.19	91.15 ± 6.08	-4.449	<0.001
	Mesomorph	93.04 ± 5.91	91.12 ± 5.99	-4.419	<0.001
	Ectomorph	91.78 ± 5.00	89.32 ± 5.22	-4.418	<0.001
Quadriceps Angle	Endomorph	15.24 ± 1.20	13.14 ± 1.42	-4.434	<0.001
	Mesomorph	15.28 ± 1.21	12.83 ± 1.13	-4.455	<0.001
	Ectomorph	14.68 ± 1.65	11.89 ± 1.15	-4.411	<0.001
Quadriceps Muscle Length	Endomorph	17.62 ± 1.24	16.56 ± 1.10	-4.378	<0.001
	Mesomorph	18.12 ± 1.68	16.79 ± 1.75	-4.377	<0.001
	Ectomorph	18.18 ± 1.39	17.38 ± 1.29	-4.389	<0.001
Gastrocnemius Muscle Length	Endomorph	17.10 ± 1.49	15.31 ± 1.36	-4.384	<0.001
	Mesomorph	17.16 ± 1.20	15.49 ± 1.17	-4.377	<0.001
	Ectomorph	17.33 ± 1.40	15.72 ± 1.33	-4.378	<0.001

Table 4.13: Wilcoxon Signed Ranks Test for Cardiovascular Parameters within Each Somatotype

Variable	Somatotype	Baseline Mean ± SD	Post-Intervention Mean ± SD	Z	p
Systolic Blood Pressure	Endomorph	121.96 ± 13.18	128.64 ± 13.05	-3.175	0.001
	Mesomorph	115.40 ± 10.55	124.60 ± 9.97	-3.743	<0.001
	Ectomorph	113.92 ± 9.47	123.76 ± 10.94	-3.933	<0.001
Diastolic Blood Pressure	Endomorph	77.68 ± 15.28	80.64 ± 13.99	-1.455	0.146
	Mesomorph	70.32 ± 9.05	78.44 ± 8.76	-3.909	<0.001
	Ectomorph	69.36 ± 8.90	70.76 ± 9.49	-0.902	0.367
Oxygen Saturation	Endomorph	96.60 ± 1.71	98.00 ± 1.00	-3.593	<0.001
	Mesomorph	96.64 ± 1.73	98.12 ± 0.93	-3.447	0.001
	Ectomorph	96.76 ± 1.88	97.80 ± 1.12	-2.298	0.022

Table 4.14: Paired Samples T-Test for Aerobic Capacity Parameters within Each Somatotype

Variable	Somatotype	Baseline Mean ± SD	Post-Intervention Mean ± SD	t	p
Pulse Rate	Endomorph	84.60 ± 9.10	87.12 ± 8.49	-3.308	0.003
	Mesomorph	85.76 ± 7.52	94.64 ± 9.80	-6.869	<0.001
	Ectomorph	87.12 ± 6.29	90.44 ± 10.60	-1.904	0.069
Total Lap Covered	Endomorph	469.28 ± 56.49	389.96 ± 34.70	14.436	<0.001
	Mesomorph	521.80 ± 42.41	427.92 ± 33.62	19.199	<0.001
	Ectomorph	573.40 ± 53.04	476.40 ± 50.37	18.135	<0.001

4.1.15 Between-Group Comparison of Respondents' Biomechanical and Aerobic Capacity Parameters

A Kruskal-Wallis H test was conducted to evaluate for differences among the three somatotypes (Ectomorph, Mesomorph, and Endomorph) on the change in biomechanical and aerobic capacity parameters from baseline to post-intervention. The results, as presented in Table 4.14, indicated a statistically significant difference in quadriceps angle difference ($H(2) = 10.24$, $p = 0.006$), quadriceps length difference ($H(2) = 16.45$, $p < 0.001$), and diastolic blood pressure difference ($H(2) = 8.33$, $p = 0.016$). However, the test revealed no statistically significant differences among the groups for lumbar flexibility difference, limb length discrepancy difference, gastrocnemius muscle length difference, systolic blood pressure difference, or oxygen saturation difference.

Table 4.15: Kruskal-Wallis Test for Between-Group Comparison of Biomechanical and Aerobic Capacity Parameters (N=75)

Variables	**Ectomorph (n=25)**	**Mesomorph (n=25)**	**Endomorph (n=25)**	**H**	**df**	**Asymptotic Sig.**
	Mean Rank	Mean Rank	Mean Rank			
Biomechanical Parameters						
LFD	31.78	40.32	41.90	3.18	2	0.204
LLDD	41.36	36.84	35.80	1.08	2	0.582
QD	48.06	36.58	29.36	10.24	2	0.006***
QLD	25.32	50.20	38.48	16.45	2	<0.001***
GD	35.48	35.56	42.96	1.96	2	0.376
Aerobic Capacity						
SBPD	40.82	41.06	32.12	2.74	2	0.254
DBPD	31.04	48.00	34.96	8.33	2	0.016***
SPO2D	35.28	39.76	38.96	0.62	2	0.734

Key: LFD= Lumbar Flexibility Difference; LLDD= Limb Length Discrepancy Difference; QD= Quadriceps Angle Difference; QLD= Quadriceps Length Difference; GD= Gastrocnemius Muscle Length Difference; SBPD= Systolic Blood Pressure Difference; DBPD= Diastolic Blood Pressure Difference; SPO2D= Oxygen Saturation Rate. ***$p \leq 0.05$.

4.1.16 Post-Hoc Analysis for the Between Group Comparison of Respondents' Biomechanical and Aerobic Capacity Parameters

Following the significant Kruskal-Wallis test, post-hoc pairwise comparisons were conducted using the Mann-Whitney U test to identify specific group differences. For quadriceps length difference, a significant difference was found between the ectomorph group (Mean Rank = 16.90) and the mesomorph group (Mean Rank = 34.10), U = 422.50, z = -4.19, $p < 0.001$. A significant difference was also observed between the ectomorph group (Mean Rank = 21.42) and the endomorph group (Mean Rank = 29.58), U = 535.50, z = -1.99, p = 0.046.

For quadriceps angle difference, the ectomorph group (Mean Rank = 29.72) differed significantly from the mesomorph group (Mean Rank = 21.28), U = 743.00, z = -2.19, p = 0.029, and also from the endomorph group (Mean Rank = 19.66), U = 783.50, z = -2.93, p = 0.003.

For diastolic blood pressure difference, a significant difference was found between the ectomorph group (Mean Rank = 19.76) and the mesomorph group (Mean Rank = 31.24), U = 494.00, z = -2.79, p = 0.005, and between the mesomorph group (Mean Rank = 29.76) and the endomorph group (Mean Rank = 21.24), U = 744.00, z = -2.07, p = 0.038. No other group comparisons were statistically significant.

Table 4.16: Mann-Whitney U Test for Pairwise Comparison of Biomechanical and Aerobic Capacity Parameters

Variable	Comparison	MR vs MR	SR vs SR	Z	Asymptotic Sig.
QLD	Ecto vs Meso	16.90 vs 34.10	422.50 vs 852.50	-4.19	<0.001***
	Ecto vs Endo	21.42 vs 29.58	535.50 vs 739.50	-1.99	0.046***
	Meso vs Endo	29.10 vs 21.90	727.50 vs 547.50	-1.75	0.150
QD	Ecto vs Meso	29.72 vs 21.28	743.00 vs 532.00	-2.19	0.029***
	Ecto vs Endo	31.34 vs 19.66	783.50 vs 491.50	-2.93	0.003***
	Meso vs Endo	28.30 vs 22.70	707.50 vs 567.50	-1.44	0.150
DBPD	Ecto vs Meso	19.76 vs 31.24	494.00 vs 781.00	-2.79	0.005***
	Ecto vs Endo	24.28 vs 26.72	607.00 vs 668.00	-0.59	0.553
	Meso vs Endo	29.76 vs 21.24	744.00 vs 531.00	-2.07	0.038***

Key: Ecto=Ectomorph, Meso=Mesomorph, Endo=Endomorph; MR= Mean Rank; SR= Sum of Rank; QLD= Quadriceps Length Difference; QD= Quadriceps Angle Difference; DBPD= Diastolic Blood Pressure Difference. ***$p \leq 0.05$.

4.1.17 Between-Group Comparison of Respondents’ Aerobic Capacity

A one-way analysis of variance (ANOVA) was conducted to compare the effect of wearing high-heeled shoes on aerobic capacity parameters for the different somatotypes. As shown in Table 4.16, there was a statistically significant difference in pulse rate difference between the groups (F(2, 72) = 6.81, p = 0.002). A significant difference was also found in the total lap difference (F(2, 72) = 3.19, p = 0.047), indicating that the change in aerobic capacity was not the same across all somatotypes.

Table 4.17: One-Way ANOVA for Between Group Comparison of Aerobic Capacity

Variables		Sum of Squares	df	Mean Square	F	p
PRD	Between Groups	688.21	2	344.10	6.81	0.002***
	Within Groups	3086.14	72	50.64		
	Total	3774.35	74			
TLAPD	Between Groups	5765.42	2	2882.71	3.19	0.047***
	Within Groups	48207.73	72	902.94		
	Total	53963.15	74			

Key: *PRD= Pulse Rate Difference; TLAPD= Total Lap Difference. ***p ≤ 0.05.

4.1.18 Post-Hoc Analysis for the Between Group Comparison of Respondents' Aerobic Capacity

A Bonferroni post-hoc test was conducted to determine which groups differed in pulse rate difference. The results, presented in Table 4.17, revealed a statistically significant mean difference between the ectomorph and mesomorph groups (MD = -5.56, p = 0.012). Furthermore, a significant difference was found between the mesomorph and endomorph groups (MD = 6.36, p = 0.003). There was no statistically significant difference between the ectomorph and endomorph groups. The post-hoc analysis for total lap difference did not reveal any statistically significant pairwise differences.

Table 4.18: Bonferroni Post-Hoc Test for Pulse Rate and Total Lap Difference

Dependent Variable	(I) Somatotype	(J) Somatotype	Mean Difference (I-J)	p-value
PRD	Ectomorph	Mesomorph	-5.56	0.012***
		Endomorph	0.80	1.000
	Mesomorph	Ectomorph	5.56	0.012***
		Endomorph	6.36	0.003***
	Endomorph	Ectomorph	-0.80	1.000
		Mesomorph	-6.36	0.003***
TLAPD	Ectomorph	Mesomorph	3.12	1.000
		Endomorph	17.56	0.062
	Mesomorph	Ectomorph	-3.12	1.000
		Endomorph	14.44	0.167
	Endomorph	Ectomorph	-17.56	0.062
		Mesomorph	-14.44	0.167

Key: *PRD= Pulse Rate Difference; TLAPD= Total Lap Difference. **$p \leq 0.05$.

4.2 Hypothesis Testing

Hypothesis 1: There would be no significant difference in lumbar flexibility of undergraduate female ectomorphs before and after the application of high-heeled shoes.

Test: Wilcoxon Signed Ranks Test

P-value: 0.05

Observed p-value: 0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

Hypothesis 2: There would be no significant difference in lumbar flexibility of undergraduate female endomorphs before and after the application of high-heeled shoes.

Test: Wilcoxon Signed Ranks Test

P-value: 0.05

Observed p-value: <0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

Hypothesis 3: There would be no significant difference in lumbar flexibility of undergraduate female mesomorphs before and after the application of high-heeled shoes.

Test: Wilcoxon Signed Ranks Test

P-value: 0.05

Observed p-value: <0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

Hypothesis 4: There would be no significant difference in quadriceps angle of undergraduate female ectomorphs before and after the application of high-heeled shoes.

Test: Wilcoxon Signed Ranks Test

P-value: 0.05

Observed p-value: <0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

Hypothesis 5: There would be no significant difference in quadriceps angle of undergraduate female mesomorphs before and after the application of high-heeled shoes.

Test: Wilcoxon Signed Ranks Test

P-value: 0.05

Observed p-value: <0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

Hypothesis 6: There would be no significant difference in quadriceps angle of undergraduate female endomorphs before and after the application of high-heeled shoes.

Test: Wilcoxon Signed Ranks Test

P-value: 0.05

Observed p-value: <0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

Hypothesis 7: There would be no significant difference in limb length discrepancy of undergraduate female ectomorphs before and after the application of high-heeled shoes.

Test: Wilcoxon Signed Ranks Test

P-value: 0.05

Observed p-value: <0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

Hypothesis 8: There would be no significant difference in limb length discrepancy of undergraduate female mesomorphs before and after the application of high-heeled shoes.

Test: Wilcoxon Signed Ranks Test

P-value: 0.05

Observed p-value: <0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

Hypothesis 9: There would be no significant difference in limb length discrepancy of undergraduate female endomorphs before and after the application of high-heeled shoes.

Test: Wilcoxon Signed Ranks Test

P-value: 0.05

Observed p-value: <0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

Hypothesis 10: There would be no significant difference in quadriceps length of undergraduate female ectomorphs before and after the application of high-heeled shoes.

Test: Wilcoxon Signed Ranks Test

P-value: 0.05

Observed p-value: <0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

Hypothesis 11: There would be no significant difference in quadriceps length of undergraduate female mesomorphs before and after the application of high-heeled shoes.

Test: Wilcoxon Signed Ranks Test

P-value: 0.05

Observed p-value: <0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

Hypothesis 12: There would be no significant difference in quadriceps length of undergraduate female endomorphs before and after the application of high-heeled shoes.

Test: Wilcoxon Signed Ranks Test

P-value: 0.05

Observed p-value: <0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

Hypothesis 13: There would be no significant difference in gastrocnemius length of undergraduate female ectomorphs before and after the application of high-heeled shoes.

Test: Wilcoxon Signed Ranks Test

P-value: 0.05

Observed p-value: <0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

Hypothesis 14: There would be no significant difference in gastrocnemius length of undergraduate female mesomorphs before and after the application of high-heeled shoes.

Test: Wilcoxon Signed Ranks Test

P-value: 0.05

Observed p-value: <0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

Hypothesis 15: There would be no significant difference in gastrocnemius length of undergraduate female endomorphs before and after the application of high-heeled shoes.

Test: Wilcoxon Signed Ranks Test

P-value: 0.05

Observed p-value: <0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

Hypothesis 16: There would be no significant difference in the aerobic capacity of undergraduate female ectomorphs before and after the application of high-heeled shoes.

Test: Paired Samples T-Test

P-value: 0.05

Observed p-value: <0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

Hypothesis 17: There would be no significant difference in the aerobic capacity of undergraduate female mesomorphs following the application of high-heeled shoes.

Test: Paired Samples T-Test

P-value: 0.05

Observed p-value: <0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

Hypothesis 18: There would be no significant difference in the aerobic capacity of undergraduate female endomorphs following the application of high-heeled shoes.

Test: Paired Samples T-Test

P-value: 0.05

Observed p-value: <0.001

DECISION: The observed p-value is less than 0.05; the null hypothesis is therefore REJECTED.

CHAPTER FIVE

DISCUSSION, CONCLUSION, RECOMMENDATIONS AND IMPLICATONS

5.1 DISCUSSION

5.1.1 Effects of High Heels on Spinal Flexibility

The results of the present study showed a statistically significant decrease in lumbar flexibility across all three somatotype groups (endomorph, mesomorph, and ectomorph) after the single intervention of walking in high-heeled shoes. This suggests that wearing high heels induces a physiological response that leads to a stiffening of the lumbar region or a reduction in its range of motion. This finding is comparable to the results of a study by Afzal & Manzoor (2017), who found that walking in high heels increase lumbar lordosis and more in its closed packed position thereby limiting lumbar flexibility.

However, contrary to the finding that high heels increase lumbar lordosis, a study by Baaklini et al. (2017) found that walking in high-heeled shoes actually decreased the lumbar curvature angle during gait. Similarly, a study by Weitkunat et al. (2016) found no significant change in lumbar lordosis in standing postures. The observed reduction in lumbar flexibility in the present study may represent a compensatory stabilization strategy where the body might reduce the range of motion in the lumbar spine to maintain balance and control over a less stable base of support. This increased muscular co-contraction and trunk stiffening might have led to the reduced lumbar flexibility found in the present study, and may be a contributing factor to the high incidence of low back pain reported among high-heel users, as reported by Lee et al., (2001) and Wiedemeijer and Otten (2018).

5.1.2 Effects of High Heels on Lower Limb Biomechanics

The finding of the present study showed a significant reduction in the length of the gastrocnemius post-intervention within all somatotype groups. This suggests that high heel use can induce measurable shortening in the gastrocnemius muscle length in the short-term. The present study's finding is in tandem with the results of a study by Kermani et al. (2018) who found increased electromyographic activity in the medial gastrocnemius which reflects the increased demand and altered function of this muscle group. The reduction in gastrocnemius muscle length found in the present study could be due to the fact that high heels force the ankle into a plantarflexed position, causing the calf muscle to operate at a shorter length. Over time, this can lead to structural remodeling, including the shortening of muscle fascicles and a stiffening of the Achilles tendon (Cronin et al., 2012, Cha, 2020 and Beck et al., 2024).

The present study's findings also showed a significant decrease in quadriceps muscle length within all somatotype groups. This finding is comparable to the results of a study by Khanduri & Bhatia (2016) who found heightened electromyography (EMG) activity in the rectus femoris and erector spinae muscles in response to increased heel height, indicating a greater muscular effort to maintain lumbo-pelvic alignment and overall posture. To counteract the forward shift in the body's center of mass caused by the elevated heel, the body must adopt a compensatory strategy involving increased flexion at the knee and hip (Simonsen et al., 2012). This flexed-knee posture places the quadriceps in a shortened state and significantly increases its activation to maintain stability, contributing to greater patellofemoral joint stress and muscle fatigue (Simonsen et al., 2012).

The present study's findings showed a significant decrease in the Quadriceps angle within all somatotype groups. This suggests that altered lower limb biomechanics induced by high heels promote a compensatory knee varus posture. This finding contrasts with the results of a study by Patil et al. (2020) who found that high heels promote valgus knee alignment which moves the patella medially relative to the tibial tuberosity, thereby increasing the measured Quadriceps angle. The reason for this discrepancy may be due to an acute neuromuscular response to instability involving tibial external rotation or external rotation at the hip joint among the present study's participants.

5.1.3 Effects of High Heels on Aerobic Capacity

The present study's findings showed a significant decrease in aerobic capacity, measured by the total distance covered in a 6-mins walk test, for all three somatotype groups after walking in high-heeled shoes. This reduction in performance was accompanied by a statistically significant increase in pulse rate for the endomorph and mesomorph groups. This implies that walking in high heels is a less efficient form of locomotion that demands greater physiological effort.

This finding is in tandem with the results of studies by Ebbeling et al. (1994), Hong et al. (2005), Curran et al. (2010) and Parmar et al. (2021) who found that walking in high heels leads to a higher energy cost, evidenced by increased oxygen consumption (VO_2) and heart rate. The decrease in aerobic capacity found in the present study might be due to the fact that high heels alter natural gait mechanics, reducing stride length and forcing compensatory muscle activation patterns in the lower limbs to maintain forward progression and balance (Di Sipio et al., 2018;

Zeng et al., 2023). This inefficient mechanical pattern increases the metabolic demand of walking. Therefore, for the same walking speed, the body must work harder, resulting in an elevated heart rate and greater energy expenditure.

The observed decrease in distance covered following a 6-min walk test in the present study might have been a direct functional outcome of this inefficiency where participants fatigued more quickly and were thus unable to perform at the same level as when wearing flats.

5.1.4 Effects of High Heels on Aerobic parameters

The present study's findings showed that walking in high-heeled shoes led to a significant increase in systolic blood pressure for all somatotypes. The elevation in blood pressure is a logical physiological response to activity that is more strenuous. Since walking in high heels has been shown to be less economical and requires more muscular work, the cardiovascular system responds by increasing heart rate and blood pressure to supply the working muscles with sufficient oxygenated blood.

The present study's findings showed a statistically significant increase in oxygen saturation for all somatotype groups post-intervention. This finding contrasts with the results of a study by Manselin et al. (2017) who found that a decrease in aerobic efficiency is associated with reduced oxygen saturation. This discrepancy might be due to the fact that an increased respiratory rate to cope with the higher physical demand of walking in high heels might have temporarily led to higher SpO_2 readings.

5.1.5 Influence of Body Somatotype on the Effect of High Heels on Biomechanical, and Aerobic Parameters

Regarding lower limb biomechanics, the ectomorph group demonstrated a significantly greater reduction in quadriceps angle compared to both mesomorph and endomorph groups. Ectomorphs, characterized by lower body fat and muscle mass, may be more susceptible to balance issues (Zeng et al., 2023). Therefore, this pronounced kinematic adjustment at the knee could represent a primary strategy to stabilize the joint and maintain postural control in the absence of sufficient muscle mass to absorb and control forces. Conversely, the change in quadriceps length was significantly more pronounced in mesomorphs and endomorphs compared to ectomorphs. Individuals with higher muscle mass (mesomorphs) or fat mass (endomorphs) possess greater overall body mass. This requires a more substantial postural adjustment and greater quadriceps activation to stabilize the body against the forward shift in the center of mass (Simonsen et al., 2012), plausibly leading to the more significant adaptive muscle shortening observed in these groups.

Somatotype also significantly influenced cardiovascular and aerobic responses. The change in diastolic blood pressure was most pronounced in the mesomorph group, which showed a significantly greater increase than both other groups. While it is often inferred that endomorphs would experience the greatest cardiovascular strain due to higher body mass (Zeng et al., 2023), the acute stress of walking in high heels may elicit a more forceful vascular response in mesomorphs to supply their larger working muscle mass. This is further supported by the pulse rate findings, where the increase in pulse rate was significantly greater in mesomorphs compared to ectomorphs and endomorphs. This suggests a more intense physiological response to the increased energy expenditure required for high-heeled walking (Beck et al., 2024), likely due to greater muscle recruitment to manage the biomechanical challenge. The trend observed, with endomorphs showing the largest decrease in distance covered, aligns with the literature suggesting that their higher fat mass and potentially lower baseline cardiovascular efficiency make them more susceptible to fatigue under increased physical demand (Zeng et al., 2023).

5.2 Conclusion

Wearing high heel shoes leads to a significant decrease in lumbar flexibility, a reduction in the quadriceps angle, and a shortening of both the quadriceps and gastrocnemius muscles among female undergraduate students at the University of Benin regardless of their somatotypes. The magnitude of these changes, however, can be influenced by body type; ectomorphs exhibited a greater reduction in quadriceps angle, while mesomorphs showed the most significant shortening of the quadriceps muscle.

Walking in high heels also significantly impairs aerobic and cardiovascular parameters, demonstrated by a marked reduction in the total distance covered during a 6MWT and an increase in systolic blood pressure across all body types. Somatotype influenced other cardiovascular responses: pulse rate increased more significantly among mesomorphs and endomorphs, and diastolic blood pressure increased significantly only in mesomorphs. These findings show that while high heel shoes impose considerable biomechanical and physiological stress on the body for all somatotypes, certain body types may be more susceptible to specific adverse effects.

Body somatotype is a key determinant of the body's response to high heels. Ectomorphs appear to rely more on kinematic adjustments, whereas mesomorphs exhibit a more robust muscular and cardiovascular reaction. Endomorphs, in turn, appear to be the most vulnerable to a decline in aerobic performance.

5.3 Recommendation

Public Health and Education: Health education campaigns should be initiated to inform women, particularly undergraduates, about the potential long-term musculoskeletal and physiological consequences of habitual use of high heel shoes. This information should be disseminated through university wellness programs and public health channels.

Clinical Practice: Physiotherapists should advise patients on moderating the frequency and duration of high-heeled shoe wear. For individuals who regularly wear them, clinicians should prescribe specific preventative exercises, including targeted stretching for the gastrocnemius, soleus, and quadriceps muscles to mitigate adaptive shortening, alongside core strengthening exercises to improve trunk stability and potentially reduce the need for compensatory lumbar stiffening.

Occupational Health: For professional environments where high-heeled shoes are common, workplace wellness initiatives should encourage the use of more ergonomic footwear. Where formal dress codes exist, employers should consider policies that do not mandate high-heeled shoes, acknowledging the increased physical strain and reduced mobility they cause.

Individual Choice: Individuals should be encouraged to limit high-heeled shoe use to short-duration, low-activity occasions. For daily wear, shoes with a lower heel height (less than 5 cm, as suggested by Ebbeling et al., 1994) and a wider base of support are strongly recommended to reduce biomechanical stress and improve energy efficiency.

5.4 Implications for Further Study

Longitudinal Research: The present study focused on the immediate effects of a high-heel intervention. Longitudinal studies are required to track the chronic progression of the observed changes over several years. This would help to establish a stronger causal link between high-heel wear and the development of pathologies such as knee osteoarthritis, chronic low back pain, and plantar fasciitis.

Multi Centre and Larger Population: Similar studies should be carried out in other universities across Nigeria and among the general population in order to ensure more generalizable results.

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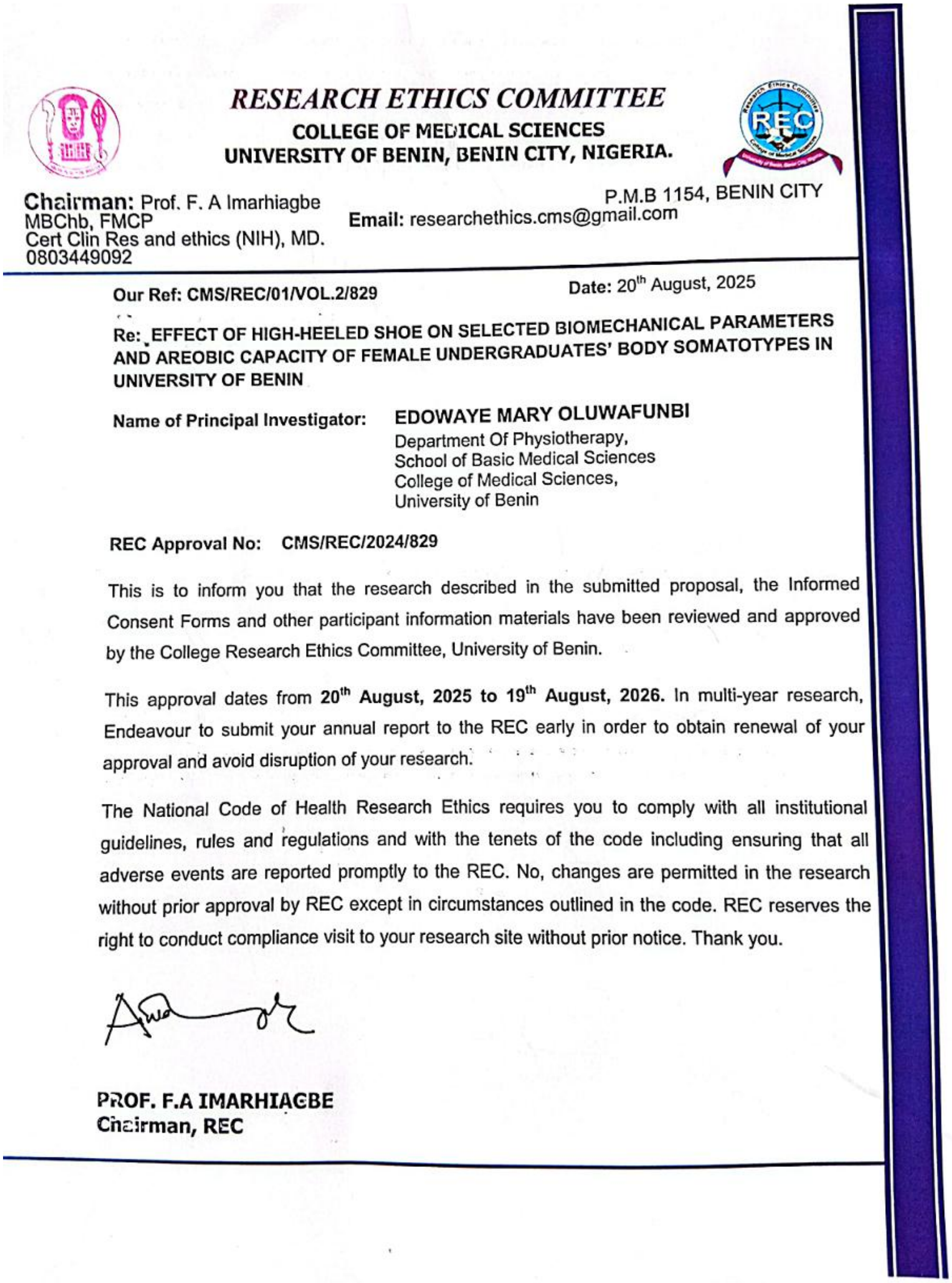
APPENDIX I



RESEARCH ETHICS COMMITTEE
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0803449092

P.M.B 1154, BENIN CITY
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Our Ref: CMS/REC/01/VOL.2/829

Date: 20th August, 2025

Re: EFFECT OF HIGH-HEELED SHOE ON SELECTED BIOMECHANICAL PARAMETERS AND AREOBIC CAPACITY OF FEMALE UNDERGRADUATES' BODY SOMATOTYPES IN UNIVERSITY OF BENIN

Name of Principal Investigator: **EDOWAYE MARY OLUWAFUNBI**
Department Of Physiotherapy,
School of Basic Medical Sciences
College of Medical Sciences,
University of Benin

REC Approval No: **CMS/REC/2024/829**

This is to inform you that the research described in the submitted proposal, the Informed Consent Forms and other participant information materials have been reviewed and approved by the College Research Ethics Committee, University of Benin.

This approval dates from **20th August, 2025 to 19th August, 2026.** In multi-year research, Endeavour to submit your annual report to the REC early in order to obtain renewal of your approval and avoid disruption of your research.

The National Code of Health Research Ethics requires you to comply with all institutional guidelines, rules and regulations and with the tenets of the code including ensuring that all adverse events are reported promptly to the REC. No, changes are permitted in the research without prior approval by REC except in circumstances outlined in the code. REC reserves the right to conduct compliance visit to your research site without prior notice. Thank you.

PROF. F.A IMARHIAGBE
Chairman, REC

APPENDIX II

17 September 2025

To Whom It May Concern:

RE: Effects of high-heeled shoe on selected biomechanical parameters and aerobic capacity of female undergraduates' body somatotypes in University of Benin

As project manager for the Pan African Clinical Trial Registry (pactr.samrc.ac.za) database, it is my pleasure to inform you that your application to our registry has been accepted. Your unique identification number for the registry is **PACTR202509672126877**.

Please be advised that you are responsible for updating your trial, or for informing us of changes to your trial.

Additionally, please provide us with copies of your ethical clearance letters as we must have these on file (via email or post or by uploading online) at your earliest convenience if you have not already done so.

Please do not hesitate to contact us at +27 21 938 0835 or email pactradmin@mrc.ac.za should you have any questions.

Yours faithfully,

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APPENDIX III

INFORMED CONSENT FORM

Title of the study: Effects of 3-inch high-heeled shoes on selected biomechanical parameters and aerobic capacity of female undergraduate's body somatotype of the University of Benin.

Investigator: Edowaye Mary Oluwafunbi

Contact Phone Number: 08132368907

Purpose of the Study: You are invited to take part in a research study aimed at understanding the effects of 3-inch high-heeled shoes on selected biomechanical parameters and aerobic capacity among female undergraduate's body somatotype in the University of Benin.

Participants: Participation is voluntary, you are eligible to participate if you are a female and you are an undergraduate student of the University of Benin.

Procedure: You will be asked to fill out a somatotype survey questionnaire, anthropometric parameters (lumbar flexibility, quadriceps angle, quadriceps muscle length, limb length discrepancy, gastrocnemius muscle length) and aerobic parameters (blood pressure, pulse rate, oxygen saturation rate), including a six-minute walk test will be measured on flat shoe and also on 3-inch high-heeled shoe. This process will take approximately 25-30 minutes and will be conducted in a safe and private setting.

Benefits of Participation: By participating in this study, you will become aware of the effects of 3-inch high-heeled shoes on your biomechanical posture, gait and aerobic capacity and understand how foot wear choices affect balance, walking pattern and physical performance.

Risks of Participation: There are no foreseeable risks associated with participation in this study. All information will be kept confidential, and you may withdraw from the study at any time without any consequences.

Cost/Compensation: There is no cost whatsoever associated with your participation in this study

Contact Information: If you have any questions or concerns about the study, you can contact the named investigator on the stated phone number.

Confidentiality: All responses will be treated as strictly confidential. No names or identifying information will be recorded. Data will be used solely for academic research purposes.

Voluntary Participation: Participation in this study is completely voluntary. You are free to refuse or withdraw at any time without any penalty.

Participant Consent: Now that the study has been clearly explained to me and I fully understand the content and process, I agree to voluntarily take part in this study.

... **...**

Participant's Signature and Date **Witness's signature and**
Date

....

Researcher's Signature and Date

APPENDIX IV

Somatotype Survey Questionnaire

Part I. Profile of the Respondents
Directions: Please fill up the blanks and put check mark (/) in the appropriate boxes that best describes you.

1. Name____
2. Age: 15 – 17 years old ☐ 22 – 24 years old ☐
   18 – 21 years old ☐ 25 years old and above ☐
3. Sex: Male ☐ Female: ☐

Part II. Please put a check (/) mark to the appropriate boxes that best described your characteristics

Ectomorph

Body type:

- ☐ Lean and thin
- ☐ Narrow hips, chest and shoulders
- ☐ Long legs and arms
- ☐ Higher forehead and thinner face

Personalities:

- ☐ Socially-awkward
- ☐ Self-conscious
- ☐ Introverted and Private
- ☐ Artistic
- ☐ Thoughtful
- ☐ Sensitive
- ☐ Anti-social
- ☐ Intellectual
- ☐ Emotionally restrained

Somatotype Survey Questionnaire

Part I. Profile of the Respondents

Directions: Please fill up the blanks and put check mark (/) in the appropriate boxes that best describes you.

1. Name____

2. Age: 15 – 17 years old ☐ 22 – 24 years old ☐
   18 – 21 years old ☐ 25 years old and above ☐

3. Sex: Male ☐ Female: ☐

Part II. Please put a check (/) mark to the appropriate boxes that best described your characteristics

Endomorph

Body type:

- ☐ Larger frame
- ☐ More body fat than most
- ☐ Narrow shoulders and wider hips
- ☐ Slim ankles and wrists

Personalities:

- ☐ Outgoing/ Extrovert
- ☐ Funny
- ☐ Loving
- ☐ Easy-going
- ☐ Attention-seeker
- ☐ Loving personality
- ☐ Tolerant
- ☐ Sociable
- ☐ Comfort-seeking individuals

Somatotype Survey Questionnaire

Part I. Profile of the Respondents
Directions: Please fill up the blanks and put check mark (/) in the appropriate boxes that best describes you.

1. Name____
2. Age: 15 – 17 years old ☐ 22 – 24 years old ☐
   18 – 21 years old ☐ 25 years old and above ☐
3. Sex: Male ☐ Female: ☐

Part II. Please put a check (/) mark to the appropriate boxes that best described your characteristics

Mesomorph

Body type:

- ☐ Naturally muscular
- ☐ Narrow hips and wide shoulders
- ☐ Strong legs and arms
- ☐ Modest amount of body fat

Personalities:

- ☐ Outgoing/ Extrovert
- ☐ Courageous
- ☐ Full of life
- ☐ Competitive
- ☐ Risk taker
- ☐ Adventurous
- ☐ Assertive
- ☐ Active
- ☐ Aggressive
- ☐ Dominant