THE POSTURAL EFFECT OF DIFFERENT TYPES OF LOAD CARRIAGE IN ERGONOMIC DURING WALKING GAIT

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THE POSTURAL EFFECT OF DIFFERENT TYPES OF LOAD CARRIAGE IN ERGONOMIC DURING WALKING GAIT

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Biomedical Engineering with Honours

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Sept 2023

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

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ABSTRACT

This study investigates the impact of different backpack types and varying loads on the postural dynamics of young female adults during walking gait. The objectives were to analyze spatiotemporal, kinematic, and kinetic parameters in traditional and ergonomic backpacks with different loads and to compare their effects on posture. Data were collected from twenty female subjects (22 ± 1 years, 161 ± 6 cm, and 52 ± 6 kg), and analyses were conducted on parameters including cadence, step length, stride length, trunk flexion angle, ankle and knee range of motion (RoM), pelvic RoM (tilt, obliquity, rotation), as well as vertical ground reaction forces (VGRF). The results revealed that load variations did not significantly affect lower limb parameters, while heavier loads did impact VGRF, trunk flexion angle, and pelvic obliquity RoM ($p < 0.05$). Notably, there was no significant difference in VGRF between ergonomic and traditional backpacks, challenging marketing claims of substantial weight reductions. However, ergonomic backpacks did reduce trunk flexion angle ($p < 0.05$). These findings emphasize the importance of selecting backpacks that prioritize comfort and proper weight distribution to mitigate musculoskeletal stress and injury risk during daily activities.

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LIST OF SYMBOLS / ABBREVIATIONS

VGRF	Vertical Ground Reaction Force, N
$\hat{F}_{VGRF}$	Normalized Vertical Ground Reaction Force
$\hat{l}$	Normalized Step Length and Stride Length
$\hat{c}$	Normalized Cadence
m_o	Body Mass, kg
g	Acceleration of Gravity, 9.81 m/s^2
l_o	Leg Length, m
α	Angle Between Thigh Segment and Shank Segment
β	Angle Between Shank Segment and Foot from Lateral Malleolus to MTP5
PSIS	Posterior Superior Iliac Spine
MTP5	Fifth Metatarsophalangeal Joint Calcaneus
RoM	Range of Motion
SD	Standard Deviation

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Load carriage is a common phenomenon in daily life, with individuals often carrying various loads while performing daily activities such as walking. Most young adults at university are carrying their bag and walking to and from get out of class every day, and they also often walk a long distance to shops and restaurants. They like to carry more stylish and trendy bag types include messenger bags, tote bags, and hand carry bags, while backpacks are a common choice among the young adults due to their convenience and ability to distribute weight evenly across the back and shoulders.

However, the impact of different type of load carriage on posture and gait patterns is an area of concern, especially in the case of young female adults who are often required to carry heavy bags containing textbooks, laptops, cosmetics and other study materials. This has led to growing interest in the impact of different types of load carriage on posture and gait patterns, particularly with regards to ergonomic walking gait. Research showed that carrying different weights of loads and type of load carriage can shift the centre of body gravity, resulting in compensatory postural changes (Singh and Koh, 2009; Dahl et al., 2016). The postural changes can lead to discomfort, pain, and even injuries over time, which increased risk of tripping or falling due to shorter strides.

In recent market trends, a new type of backpack has emerged known as the ergonomic backpack, featuring an elastic shoulder straps system. These backpacks are unique because they claim to reduce the weight load while walking, potentially by up to 45% (*Aoking*, 2020). Additionally, they offer thicker cushioning on the back and shoulder straps to enhance shock absorption and reduce the risk of spinal injuries (Hadid et al., 2018). Despite the increasing popularity of ergonomic backpacks in the marketplace, there is limited research to date that has investigated the impact of these backpacks on injuries, as well as their effects on spatiotemporal, kinetic and kinematic.

Understanding the impacts of different types of load carriage on posture and gait patterns during walking gait can contribute to the development of ergonomic guidelines for load carriage and potentially reduce the incidence of musculoskeletal disorders associated with heavy load carriage.

1.2 Importance of the Study

Research on studying the postural implications of a simultaneous varying load with a varying type of load carriage impact on walking mechanics has been conducted widely (Bettany-Saltikov and Cole, 2012). Previous studies more focus on the effects on posture and lower-extremity either caused by the asymmetric and symmetric load carrying with different loading (Crosbie, Flynn and Rutter, 1994; Smith et al., 2006; Bettany-Saltikov and Cole, 2012; Corrigan, 2012; Silder, Delp and Besier, 2013). Another study examined the postural change in children when they carried varied loads in their backpacks (Hong and Brueggemann, 2000; Hong and Cheung, 2003; Singh and Koh, 2009; Li and Hong, 2010; SHASMIN et al., 2011; Ahmad and Barbosa, 2019). However, there is still limited knowledge on the postural effect of different types of backpacks on young female adults, specifically the features such as elastic straps that able to provide ergonomic support. Therefore, in this study, the postural effects of different types of backpacks with varying load during walking will be determined with the use of the forced plate treadmill and G-walk.

1.3 Problem Statement

Young female adults are often required to carry heavy bags with laptop in university. However, poor posture and gait mechanics can lead to musculoskeletal pain and injuries. The issue of load carriage and its impact on postural stability and gait mechanics has been widely studied, but there is a lack of research on examining the postural effects of different types of backpacks on young female adults, specifically laptop backpack and elastic straps backpack. Thus, analysis of the kinetic and kinematic in the human gait should be conducted to further investigate the impact of different type of backpack with varying load on posture. This study aims to provide valuable insights into the effect of ergonomic design backpack on posture and lower extremity in young female adults. This study is significant as it may aid in the design of ergonomic load carriage that may reduce the risk of musculoskeletal disorders among university students.

1.4 Aim and Objectives

This study aims to analyse the postural effect of carrying different types of backpacks, which includes traditional laptop backpack and ergonomic backpack during walking gait.

(i) To analyse the spatiotemporal, kinematic and kinetic parameters between traditional backpack and ergonomic backpack with different load during walking gait on young female adult.

(ii) To compare the postural effect between traditional backpack and ergonomic backpack with different load on young female adult.

1.5 Scope and Limitation of the Study

The targeted subjects are limited to undergraduate female students aged 18 to 24 years old. There is a potential for human error in the manual analysis of video clips, which can lead to measurement errors and biases. Besides, subjects walked with the backpack prepared for this study instead of using their own backpack. The gait characteristics may have been changed as the subjects may not feel comfortable when carrying the prepared backpack. Thus, subjects were given sufficient time to familiar with the backpack provided prior to data collection. This step aimed to reduce any discomfort or unfamiliarity that might have otherwise impacted the results.

1.6 Contribution of the Study

The study's contribution lies in its investigation of the impact of ergonomic backpacks with elastic shoulder strap systems on various factors related to load-bearing, kinetics, and kinematics during walking. While these backpacks claim to reduce load weight by up to 45% and offer improved shock attenuation, their actual effects had not been extensively researched prior to this study. By conducting a comprehensive analysis, this research sheds light on the practical implications of ergonomic backpack usage, providing valuable insights for individuals seeking to minimize the risk of spine-related injuries and enhance their overall backpacking experience.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

Load carriage is a common daily activity that involves carrying load of varying weights and types, such as backpacks, messenger bags and briefcases. However, it can have negative impacts on the posture leading to instability (Smith et al., 2006) or musculoskeletal system leading to discomfort, pain and injury (Birrell and Haslam, 2010).

2.2 Spatiotemporal Analysis

Spatiotemporal analysis involves to the measurement and analysis of movement patterns in terms of time and space. In the context of load carriage research, spatiotemporal analysis is commonly used to investigate the effects of carrying loads on gait patterns, including, cadence, step length, stride length and walking speed. These parameters serve as important indicators of overall gait efficiency and can be used to identify alterations in gait that may lead to discomfort, fatigue, or injury.

2.2.1 Gait Pattern

The gait cycle refers to the series of events that occur during one complete stride, from the initial contact of a foot with the ground to the next contact of the similar foot. The gait cycle can be divided into five main stages which are initial contact, loading response, mid-stance, terminal stance and pre-swing as shown in Figure 2.1.

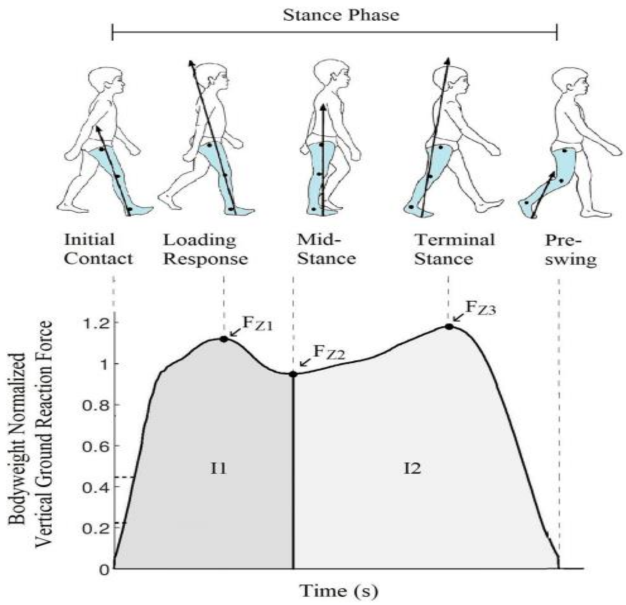

Figure 2.1: Walking Gait Pattern (das Neves et al., 2021).

The beginning of the gait cycle is known as the initial contact, during which the heel of the foot comes into contact with the ground. At this stage, the foot is in a slightly dorsiflexed position and the ankle joint is in a neutral position. Next is the loading response, showing a rapid increase in the vertical ground reaction force (VGRF) due to the transfer of body weight onto the supporting leg. The following phase is the midstance. At this stage, the body is supported on a single limb, and the VGRF is at its maximum as VGRF is directed through the supporting limb and is equal in magnitude to the body weight. Terminal stance begins when the heel of the supporting foot lifts off the ground, cause the VGRF decreases as the body weight is shifted forward onto the toe. Finally, pre-swing stage occurs when the supporting foot leaves the ground, and the swing leg is about to begin its forward motion. The vertical GRF is at its minimum, as the body weight is no longer supported by the foot on the ground.

2.2.2 Cadence, Step Length and Stride Length

Cadence, step length, and stride length are important spatiotemporal parameters that can provide insight into gait patterns during load carriage. Cadence refers to the number of steps taken per minute, where step length refers to the measurement of distance between the heel strike of a foot and the heel strike of the opposite foot, and stride length is the measurement of the distance between two consecutive initial contacts of the similar foot. It is determined by the combination of step length and cadence.

Regarding load carriage, a study investigated the effects of wearing a military backpack on gait parameters and found that step length and stride length decreased with increasing backpack weight, while cadence remained relatively constant (Birrell and Haslam, 2010). Another study found that when carrying weight bilaterally, there is a tendency for cadence to increase, while stride length tends to decrease as the weight increases (Corrigan, 2012). These changes in spatiotemporal parameters may be the body is adapting to the increased load and maintaining stability during walking. In contrast, a study in children shown no significant differences in cadence, stride length, single and double support time between unload and load of 20% body weight (Hong and Cheung, 2003).

Additionally, there is limited research available on the effects of ergonomic backpacks on spatiotemporal parameters. It has been found that there was no significant difference in cadence, step length, and stride length between elastic straps backpack and traditional backpack (Huang, Sui and He, 2020), and between unilateral and bilateral backpack (Corrigan, 2012) with load of 10% body weight.

2.2.3 Walking Speed

Several studies on load carriage have allowed subjects to self-select their preferred walking speed (Smith et al., 2006; Corrigan, 2012; Huang, Sui and He, 2020). Waking with self-selected speed is more natural and may better reflect their normal daily activities. The demands of walking speed may influence the movement patterns of the body, especially in pelvic angle (Smith et al., 2006).

2.3 Kinetic Analysis

Kinetic analysis is a method used to study the forces and movements involved in human motion (Menychtas et al., 2020). The analysis is conducted by measuring the forces acting on the body or a specific body part during movement.

2.3.1 Vertical Ground Reaction Force (VGRF)

VGRF is the force that the ground exerts on a body in contact with it during locomotion. It can be obtained through force-plates embedded in the treadmill, which is a critical instrument for determining the impact of various conditions on gait, such as load carriage and injury. Previous studies have shown that the maximum VGRF without any load is lower than with a load, regardless of load carriage type (Zhang, Ye and Wang, 2010; Dahl et al., 2016). The VGRF increased nearly three-fold as loads reached up to 20% of body weight compared to 10% of body weight, which indicating a significant difference in VGRF at a load of 20% of body weight (Shasman et al., 2011). The VGRF increase with increasing load.

A study shown a reduction in VGRF of elastic straps backpack in children when compared to traditional backpack during walking gait, as the first vertical force peak is reduced due to the loss of energy caused by the elastics (Barbosa et al., 2022). However, there is a little different of VGRF between the type of backpacks. Dahl et al. (2016) found out there is higher VGRF for carrying BackTpack, which is an ergonomic backpack, when compared with traditional backpack.

2.4 Kinematic Analysis

Kinematic analysis refers to the study of motion without considering the forces that cause the motion (Molotnikov & Molotnikova, 2023). In the case of load carriage, kinematic analysis can provide insights into the changes in body position, joint angles, and movement patterns that occur when carrying a load, including trunk, hip, knee and ankle flexion angle, as well as pelvic tilt, obliquity and rotation angle.

2.4.1 Trunk Flexion Angle

In a study by Al-Khabbaz, Shimada and Hasegawa (2008), the authors used motion capture to analyse the movement of the trunk in all three planes (sagittal, transverse, and frontal) with carrying of different loads when standing, ranging from unloaded to 20% body weight. The study found no significant differences in the frontal or transverse planes with increasing load but observed significant differences in forward trunk flexion (Al-Khabbaz, Shimada and Hasegawa, 2008). Another study by Birrell and Haslam (2010) used a similar approach to analyse the kinematics of soldiers carrying different loads. The authors found that carrying a heavy load caused an increase in trunk flexion, which may increase forward lean and the risk of injury in spine. These findings suggest that the impact of symmetrical load on the trunk mainly affects the sagittal plane.

According to Ramadan and Al-Tayyar (2020), carrying an ergonomic backpack while carrying loads greater than 10% body weight able to minimize trunk flexion as compared to traditional backpack. Additionally, a study found that carrying BackTpack backpack showed a significant reduction in forward trunk flexion in comparison to using a traditional backpack, indicating that the load distribution system in ergonomic backpack could serve to lower the chance of back pain and spinal deformities brought by the forward tilt of trunk (Dahl et al., 2016).

2.4.2 Hip, Knee and Ankle Flexion Angle

According to Physiopedia contributors (2022), the normal reading of maximal range of motion (RoM) for knee flexion measures 60 degrees, whereas ankle flexion demonstrates a RoM of 25 degrees throughout the walking gait cycle. The effect of load carriage on joint kinematics is analysed (Kinoshita, 1985; Birrell and Haslam, 2010; Wang et al., 2013). The authors found that carrying a load caused changes in knee and ankle flexion, which may affect stability and increase the risk of injuries (Kinoshita, 1985). However, a study found that between 0 kg and 30 kg loads, increasing loads resulted in decreased range of motion in knee flexion and increased range of motion in ankle flexion. Another study by Birrel and Haslam (2010), indicate no difference in knee flexion in sagittal plane while carrying load until the load is greater than 24 kg, indicating an increased flexion angle. However, not all studies have found a significant effect of load on joint kinematics. A result showed that due to the limitation of soldiers wearing military boots, increasing loads had no effect on ankle flexion and no effect on hip flexion in the sagittal plane, there was only changing in the frontal and transverse planes (Chow et al., 2007; Birrell and Haslam, 2010). In contract, the results in some studies did not observe any significant changes in ankle or knee joint kinematics (Tilbury-Davis and Hooper, 1999; Chow et al., 2007; Silder, Delp and Besier, 2013). The authors suggest that the primary mechanism for load-related changes in gait may be alterations in muscle activation patterns rather than changes in joint kinematics (Tilbury-Davis and Hooper, 1999).

One study carried by (Dahl et al., 2016) found that the use of traditional backpack significantly increased hip and knee joint angle during walking compared to BackTpack due to larger forward trunk to reduce stress on joint. In contrast, another study by Huang, Sui and He (2020) found there was no significant difference in hip, knee and ankle flexion or extension in both elastic straps backpack and traditional backpack with load of 10% body weight.

2.4.3 Pelvic Tilt, Obliquity and Rotation Angle

One research by Smith et al. (2006) studied the pelvic tilt angle in sagittal plane of female college students remained unchanged as load increased regardless type of load carriage, while the pelvic obliquity angle in frontal plane and pelvic rotation angle in transverse plane decreased during walking. Similarity, a study reported that increasing backpack load did not significantly affect pelvic tilt for adolescent girls but did lead to an increase in pelvic obliquity and rotation during walking, which able to minimize the impact of moment of inertia of backpack (Chow et al., 2007). However, other studies found the increasing backpack load resulted in increased pelvic tilt during walking in college students (Crosbie, Flynn and Rutter, 1994; Wang et al., 2013). There is limited research available on the effects of ergonomic backpacks on pelvic kinematics. A study done by Huang, Sui and He (2020) found there was no significant difference in pelvic angle of 3 planes in both elastic straps backpack and traditional backpack with load of 0% and 10% body weight.

2.5 Placement of Marker

Placement of markers is an essential aspect of kinematics analysis in gait analysis. Proper placement of markers on anatomical landmarks is necessary to obtain accurate measurements of joint angles and segmental motion. A study has focused on the effects of marker placement on knee joint and have found that small changes in marker placement can have a significant impact on the measured angle (Szczerbik and Kalinowska, 2011). According to the study of Kutilek, Socha and Hana (2014), standardized markers were fixed on the lower extremity: fifth metatarsophalangeal joint, lateral malleolus, lateral epicondyle of femur and greater trochanter of femur as shown in Figure 2.2. The C7 in cervical vertebrae and S1 in sacrum bone are often used as reference points for measuring trunk angle in gait analysis (Alessa and Ning, 2018). However, there is the limitation due to blocked view of backpack at S1, posterior superior iliac spine (PSIS) can also be used as a reference point to measure trunk angles during standing (Brouwer et al., 2021).

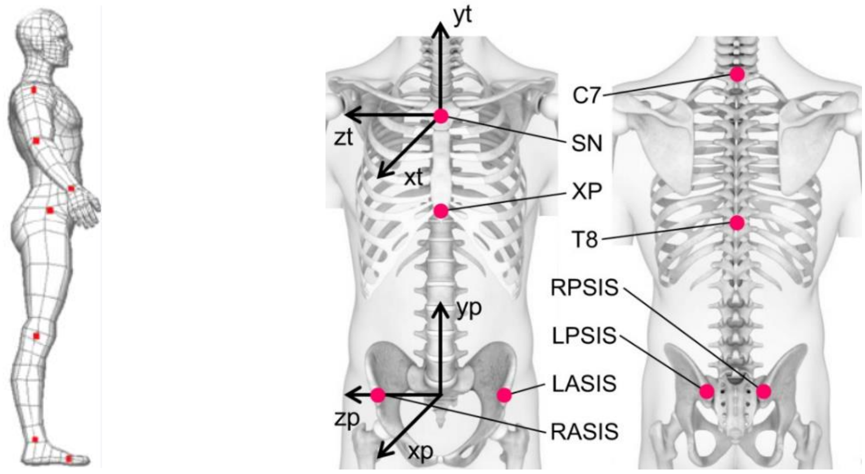

Figure 2.2: The Placement of Markers for Kinematics Analysis (Kutilek, Socha and Hana, 2014; Brouwer et al., 2021).

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

The methodology of this project is composed of six distinct phases, each building upon the previous phase to ensure a rigorous and systematic approach to the research. The first phase is the planning of experimental protocol, which involves the identification of the variables and selection of appropriate research methods. The second phase is pilot test of the protocol to identify any potential issues or problems that need to be addressed before the main study begins. If the pilot test is not accepted, the experimental protocol should be amended. After, the ethical approval will be proceeded. The fourth phase is subject recruitment, where participants who meet the inclusion criteria are identified and invited to participate in the study. The fifth and final phase is data collection and analysis, where the data is collected using appropriate measurement tools and analysed using statistical software to draw conclusions about the postural effect of different types of load carriage in ergonomic backpacks during walking gait. Figure 3.1 shows the flow chart process flow of the study. The application for ethical clearance for this study was approved by the UTAR Scientific and Ethical Review Committee (U/SERC/187/2023), as detailed in Appendix A.

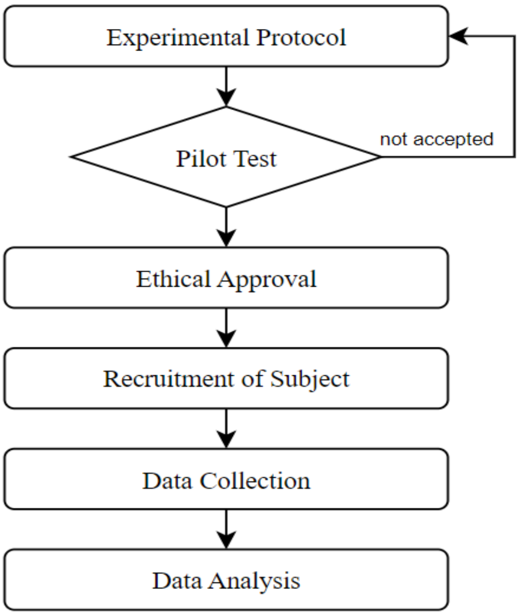

Figure 3.1: Flowchart of Methodology.

3.2 Planning

The planning of this project involved the backpack selection, weight of load, trial duration and walking speed.

3.2.1 Backpack Selection

Backpack selection is a critical factor in load carriage research, as it can significantly affect the load distribution and the biomechanics of the body during walking. In this study, two types of backpacks were selected: traditional backpack and ergonomic backpack, which aimed to compare the different in spatiotemporal, kinetic and kinematic analysis. For the traditional backpack, a standard laptop backpack commonly used by university students was chosen. It had a simple design with a single large compartment and a smaller front pocket. For the ergonomic backpack, the Aoking 4th generation backpack was selected. This backpack had an elastic strap system, which mentioned able to reduce the load to 45%. The force suspension weight reduction system makes the backpack no longer follow the movement of the shoulder through the energy storage and release of elastic potential energy, so as to achieve the effect of weight reduction and effectively protect the spine. Figure 3.2 shows the type of backpacks used in this study and Table 3.1 shows the comparison of the characteristics between both type of backpack.

Figure 3.2: Type of Backpack: Traditional (left), Ergonomic (right).

Table 3.1: Comparison of Characteristic between Traditional and Ergonomic Backpack

Characteristic	Traditional Backpack	Ergonomic Backpack
Shoulder Strap	Fixed non-elastic	High elastic
Support	No	Provide spine support
Padding	Thin padding on shoulder strap and back	Thick padding on shoulder strap and back
Back Ventilation	No	Yes

3.2.2 Weight of load

The survey of backpack load weight carried by young female students was conducted using digital luggage scale. This process was repeated twice to obtain an average weight measurement and minimize potential measurement errors. Prior to each measurement session, the scale was calibrated to ensure its precision and reliability.

Two different loads with a weight of 4 kg and 8 kg were selected for testing in the experiment based on the survey as they are commonly carried by university young female adults in their backpacks. There were 10 and 4 of out 18 students carry 4 kg and 8 kg load in their backpack respectively. Table 3.1

shows the common objects carried by university female students within 4 kg and 8 kg.

Table 3.2: The Common Objects Carried by University Female Students within 4 kg and 8 kg.

4 kg	8 kg
1. Laptop with charger 2. Tablet	1. Laptop with charger 2. Tablet 3. Stationary 4. 30000 mAh power bank 5. Notebook 6. Cosmetics

3.2.3 Trial Duration

The trial duration in this study refers to the amount of time allocated for each condition during data collection. In this study, five conditions were performed on each subject: unload, traditional backpack with 4 kg load, traditional backpack with 8 kg load, ergonomic backpack with 4 kg load and ergonomic backpack with 8 kg load. For each condition, 2 trials will be performed, and each trial will have 15 seconds of data collection. Break will be provided with every trials.

3.2.4 Walking Speed

Preferred speed is commonly used in gait analysis studies as it allows subjects to walk in a manner that is most comfortable and natural for them (Smith et al., 2006; Corrigan, 2012; Huang, Sui and He, 2020). When subjects are asked to walk at a fixed speed, it can alter their gait pattern, making it difficult to obtain accurate results (Smith et al., 2006). Additionally, it also helps to better mimic real-world situations where individuals are not typically asked to walk at a specific speed.

3.2.5 Placement of Markers

Placement of markers is a crucial step in motion analysis as it determines the accuracy of the collected data. In this study, six markers were placed on the body of subject as shown in Figure 3.3. The markers were placed on the C7 of cervical vertebrae, posterior superior iliac spine (PSIS), greater trochanter of femur, lateral epicondyle of femur, lateral malleolus, and fifth metatarsophalangeal joint calcaneus (MTP5) to measure the motion of the joint angle during the gait cycle.

Figure 3.3: Placement of Marker on Trunk and Lower Limb.

3.3 Pre-test of Protocol

In the pre-test for this study, 1 healthy volunteer is recruited for walking for 15 seconds on a treadmill while carrying a backpack filled with weight. Both traditional and an ergonomic backpack with weight of 5kg and 10 kg were used in the pre-test. The volunteer indicates that the weights is appropriate. The postural angles of volunteer were recorded using a phone camera. The optimal placement for markers for evaluating postural angles during the main experiment were chosen using the information gathered from the pre-test. Before beginning the main experiment, the data gathered from the pre-test was also analysed to determine the change.

3.4 Recruitment of Subjects

In the recruitment phase of the study, a total of 20 healthy female subjects were recruited to participate. The inclusion criteria for the subjects:

i. The subject between the ages of 18 and 24 years old.
ii. The subject is having a body mass index (BMI) of 18.5-24.9 kg/m^2.
iii. The subject is having no history of musculoskeletal or neurological disorders.
iv. The subject is not suffered from pain in neck, back and leg.
v. The subject is having no history of heart disease and serious surgery.
vi. Light postural deformities are accepted: scoliosis, bow legged, flat foot, high arch.

3.5 Data Collection

3.5.1 Equipment and Instrument

The equipment and instruments used in this study included H/P Cosmos Instrumented Treadmill (Model: TLA10004681) embedded with force plate, BTS G-Walk, Kistler Gaitway Software, BTS-G-Studio and Kinovea.

The H/P Cosmos Instrumented Treadmill is a device for measuring VGRF and spatiotemporal parameters during gait analysis. Continuous data can be gathered on the instrumented treadmill, allowing for a more thorough gait study. While a computer programme called Kistler Gaitway Software is utilised to analyse motion and gait analysis data obtained from the instrumented treadmills. Besides, G-Walk is a wearable device attached to S1 of sacrum vertebrae which able to measure the range of motion of pelvic during gait analysis. The sensors connect wirelessly with a computer programme known as BTS-G-Studio, which analyses the data and generates reports for study. Additionally, Kinovea is a video analysis software designed to track the postural angle during kinematic analysis.

3.5.2 Experiment Protocol

A flow chart of the experiment protocol explained every step involved in the experiment as shown in Figure 3.4. It helps to provide a clear understanding of the sequence of events and the overall planning of the experiment for subjects.

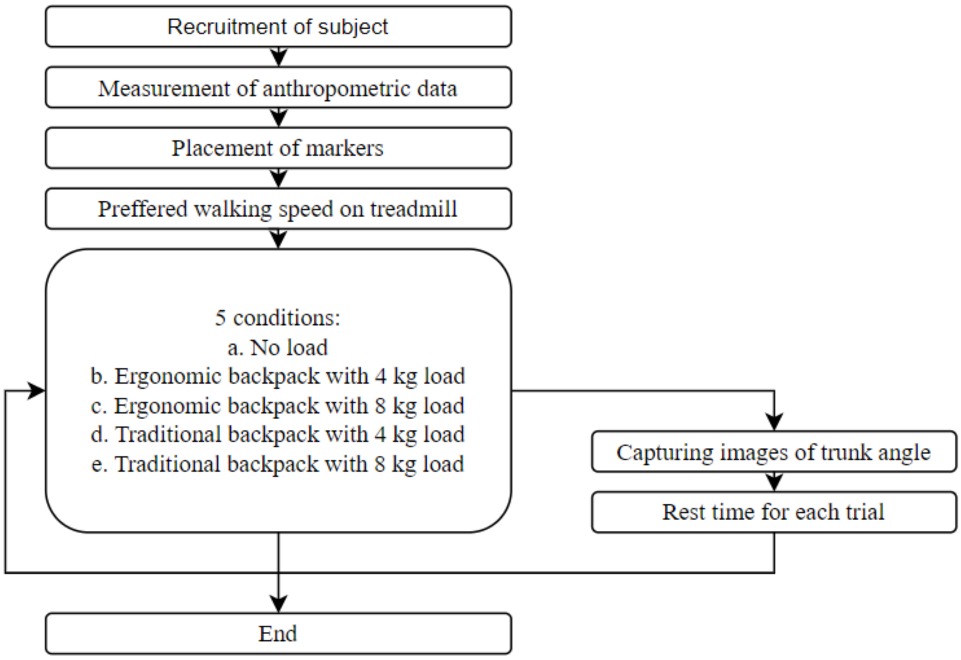

Figure 3.4: Flow Chart of Experiment Protocol.

Based on Table 3.2, the anthropometric data of each subject are measured and recorded by using measuring tape and weighting scale. After the placement of G-walk and markers, the subject can choose own preferred walking speed on treadmill. Leg length will be measure from greater trochanter of femur to lateral malleolus. Besides, 5 conditions will be performed with 2 trials each, and each trial will last 15 seconds.

Table 3.3: Anthropometric Parameters.

Name:	Data
Age:	
Body Height (m):	
Body Weight (kg):	
Walking Speed (km/h):	
Leg length (cm):	

3.6 Data Analysis

In this study, the joints flexion angle including trunk, knee and ankle were collected from one volunteer by placing the angle to the joint to track the change during standing and walking in Kinovea Software. Figure 3.5 and Figure 3.6 show the angle obtained from the Kinovea.

Parameters:

α = angle between thigh segment and shank segment

β = angle between shank segment and foot from lateral malleolus to MTP5

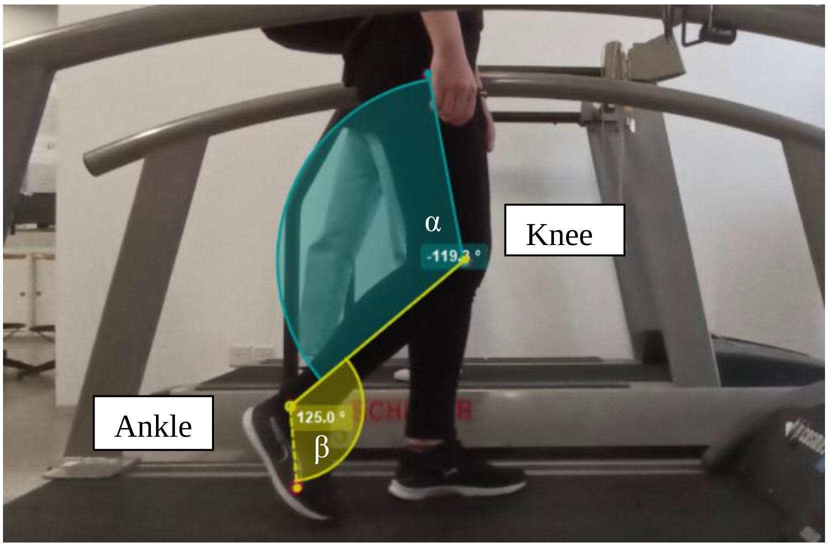

Figure 3.5: Collection of Knee and Ankle Flexion Angle.

Figure 3.6: Collection of Trunk Flexion Angle.

3.6.1 Data Normalization

In data analysis, it is important to ensure that the data being compared are comparable across different subjects. One way to achieve this is through data normalization, which involves scaling the values of the data to have a standard range. This is particularly important in analysis of kinematic and kinetic data, as individuals may have different body dimensions or perform tasks differently, which can lead to differences in the raw data values. Normalizing the data allows for a more accurate comparison between subjects and reduces the variability between individuals. Table 3.3 shown the normalization formula for different parameters based on research done by Hof (2018).

Table 3.4: Dimensionless Numbers Related to Movement Analysis (Hof, 2018).

Parameters	Dimensionless Number
Vertical Ground Reaction Force, F_{VGRF}	$\hat{F}_{VGRF} = \frac{F_{VGRF}}{m_o g}$ (3.1)
Step Length and Stride Length, l	$\hat{l} = \frac{l}{l_o}$ (3.2)
Cadence, c	$\hat{c} = \frac{c}{60\sqrt{g/l_o}}$ (3.3)

$\hat{F}_{VGRF}$ = Normalized Vertical Ground Reaction Force, $\hat{l}$ = Normalized Step Length and Stride Length, $\hat{c}$ = Normalized Cadence, m_o = Body Mass, g = Acceleration of Gravity ($g = 9.81\ m/s^2$), l_o = Leg Length.

3.6.2 Sample Calculation

Sample calculation of kinematic and kinetic normalization data obtained from a subject is demonstrated below. The example provides a step-by-step guide on the ways to process and analyse the data. After the data has been normalized, it can be analysed and compared across different subjects or trials. This is important for identifying patterns or differences in the study. The calculations were performed only on the data obtained from the left leg of the subject.

Maximum vertical ground reaction force, $F_{VGRF} = 573.92\ N$

Body mass, $m_o = 53.5\ kg$

Acceleration of gravity, $g = 9.81\ m/s^2$

Leg length, $l_o = 0.875\ m$

Step Length, $l = 0.4371\ m$

Stride Length, $l = 1.01\ m$

Cadence, $c = 94.49\ steps/min$

Vertical Ground Reaction Force

$$\text{Normalized Max VGRF, } \hat{F}_{VGRF} = \frac{F_{VGRF}}{m_o g}$$

$$= \frac{573.92\ N}{(53.5\ kg)(9.81\ m/s^2)}$$

$$= 1.094$$

Step Length and Stride Length

$$\text{Normalized Step Length, } \hat{l} = \frac{l}{l_o}$$

$$= \frac{0.4371\ m}{0.875\ m}$$

$$= 0.500$$

$$\text{Normalized Stride Length, } \hat{l} = \frac{l}{l_o}$$

$$= \frac{1.01\ m}{0.875\ m}$$

$$= 1.154$$

Cadence

$$\text{Normalized Cadence, } \hat{c} = \frac{c}{60\sqrt{g/l_o}}$$

$$= \frac{94.49\ steps/min}{60\sqrt{\frac{9.81\ m/s^2}{0.875\ m}}}$$

$$= 0.470$$

3.6.3 Statistical Analysis

In the post-data collection phase, the output data obtained from the spatiotemporal, kinetic and kinematic analyses were utilized for further analysis. The peak values of each parameter for each subject were calculated using equations 3.6 and 3.7 to determine the mean and standard deviation.

$$\bar{x} = \frac{\Sigma x}{N} \tag{3.4}$$

$$\sigma = \sqrt{\frac{\Sigma(x - \bar{x})}{N}} \tag{3.5}$$

Where,

$\bar{x}$ = mean

x = value of data

N = number of data

σ = standard deviation

The analyses were performed utilizing the Statistical Package for the Social Sciences (SPSS), version 27. One-way repeated measure analysis of variance (ANOVA) was implemented to compare the mean among three or more conditions within the same group of subjects. Bonferroni Test from post hoc analysis was conducted to determine the significant differences in the means. The statistical significance was set at $p < 0.05$.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Introduction

Chapter 4 will delve into the analysis of spatio-temporal, kinetics and kinematics movement while walking on a treadmill with various types of backpacks. This study recruited a total of 20 healthy female subjects, aged between 19 and 23 years old, with an average age of 21.9±0.89 years. Table 4.1 provides an overview of the physical characteristics of these subjects.

Table 4.1: Anthropometric of the 20 Female Subjects.

Characteristic	Mean±S.D.
Age (years)	21.9±0.89
Height (m)	1.61±0.06
Body Mass (kg)	51.75±6.39

S.D. = Standard Deviation.

4.2 Spatiotemporal Analysis

Table 4.2 shows the mean and standard deviation of spatiotemporal parameters, including normalized cadence, step length and stride length with different type of backpack and load when walking.

Table 4.2: Normalized Spatiotemporal Parameters across Different Conditions.

Conditions	Cadence (N=20)	Step Length (N=20)	Stride Length (N=20)
	Mean±S.D.	Mean±S.D.	Mean±S.D.
U	4.691±0.416	0.599±0.075	1.193±0.150
E4	4.582±0.409	0.611±0.072	1.196±0.141
E8	4.501±0.432	0.610±0.071	1.205±0.144
T4	4.703±0.380	0.598±0.055	1.199±0.114
T8	4.619±0.361	0.602±0.069	1.211±0.136

S.D. = Standard Deviation.

U = Unload, E4 = Ergonomic backpack with 4 kg load, E8 = Ergonomic backpack with 8 kg load, T4 = Traditional backpack with 4 kg load, T8 = Traditional backpack with 8 kg load.

4.2.1 Increment of Load

Table 4.3 below shows the mean difference values of normalized cadence, step length and stride length as the load increased for both ergonomic and traditional backpack. The relationships between these spatiotemporal parameters and varying loads are illustrated in Figure 4.1, Figure 4.2 and Figure 4.3.

Table 4.3: Comparison of Spatiotemporal Parameters with Increment of Load.

Parameter	Conditions	Mean Difference (N=20)
Cadence	U & E4	0.109
	U & E8	0.189
	E4 & E8	0.080
	U & T4	-0.013
	U & T8	0.071
	T4 & T8	0.084
Step Length	U & E4	-0.012
	U & E8	-0.011
	E4 & E8	0.001
	U & T4	0.000
	U & T8	-0.003
	T4 & T8	-0.004
Stride Length	U & E4	-0.003
	U & E8	-0.012
	E4 & E8	-0.009
	U & T4	-0.005
	U & T8	-0.018
	T4 & T8	-0.012

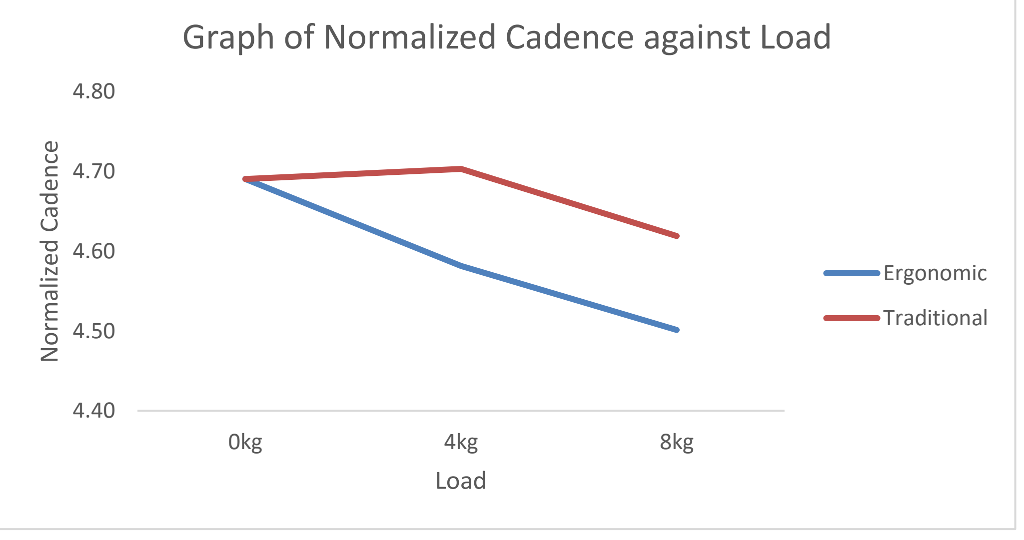

Figure 4.1: Graph of Normalized Cadence against Load during Walking.

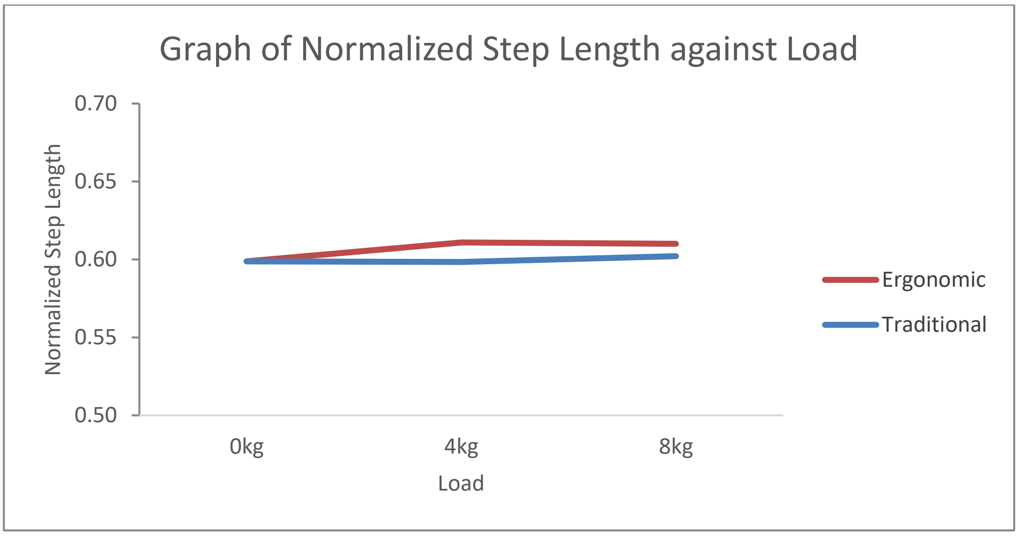

Figure 4.2: Graph of Normalized Step Length against Load during Walking.

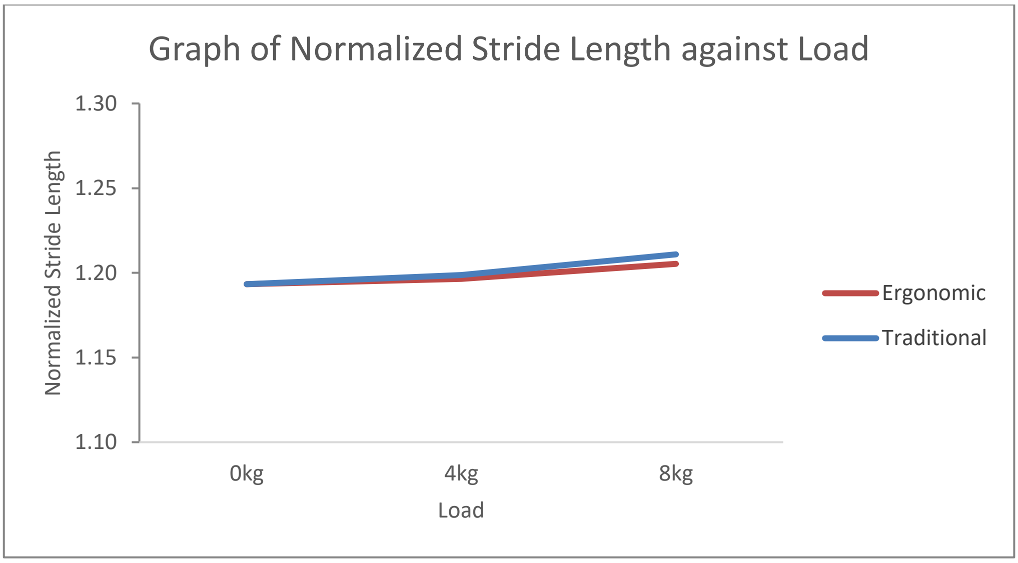

Figure 4.3: Graph of Normalized Stride Length against Load during Walking.

Figure 4.1 illustrates that normalized cadence slightly decreases with increasing load, irrespective of the backpack type, although the change is not statistically significant ($p > 0.05$). The results could potentially signify a compensatory mechanism intended to reduce either induced gait instability or the strain on the musculoskeletal system, which may involve reducing the impact of higher lower limb joint moments (Singh and Koh, 2009). Besides, normalized step length and stride length remained relatively constant with increasing backpack weight as illustrated in Figure 4.8. Based on Table 4.3, statistical analysis shown that there were no significant differences observed in these parameters ($p > 0.05$). The results are consistent with previous study by Hong and Cheung (2003), indicating no significant differences in cadence and stride length between unload and load of 20% body weight to optimize energy expenditure and maintain walking efficiency.

4.2.2 Type of Backpack

Table 4.4 below shows the mean difference values of normalized cadence, step length and stride length between ergonomic and traditional backpacks at 4 kg and 8 kg loads. The relationships between these spatiotemporal parameters and type of backpack are illustrated in Figure 4.4, Figure 4.5 and Figure 4.6.

Table 4.4: Comparison of Spatiotemporal Parameters with Type of Backpack.

Parameter	Conditions	Mean Difference (N=20)
Cadence	E4 & T4	-0.121
	E8 & T8	-0.118
Step Length	E4 & T4	0.012
	E8 & T8	0.008
Stride Length	E4 & T4	-0.002
	E8 & T8	-0.006

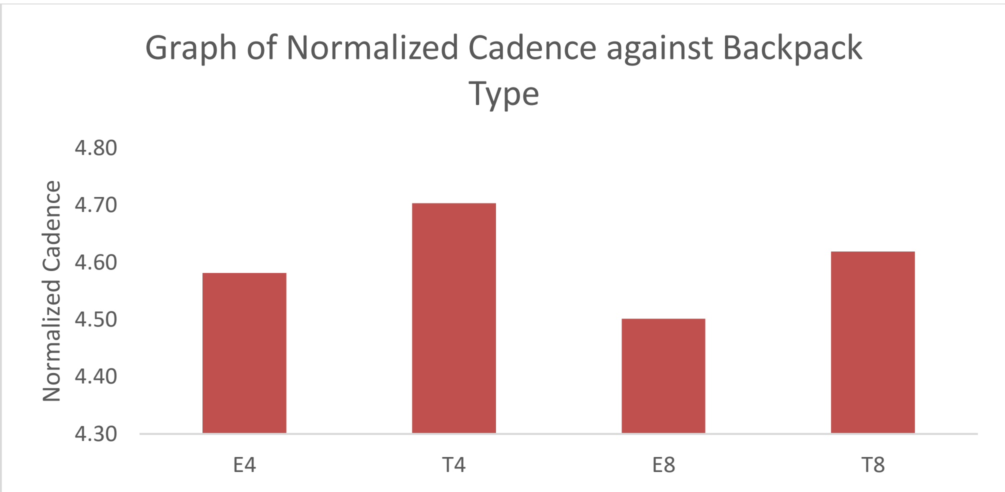

Figure 4.4: Graph of Normalized Cadence against Backpack Type at 4kg and 8kg.

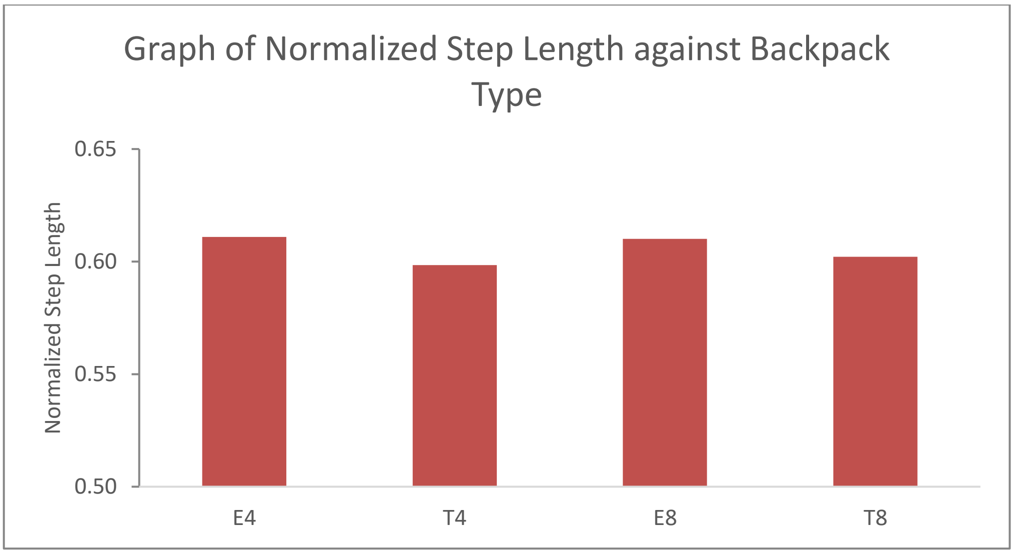

Figure 4.5: Graph of Normalized Step Length against Backpack at 4kg and 8kg.

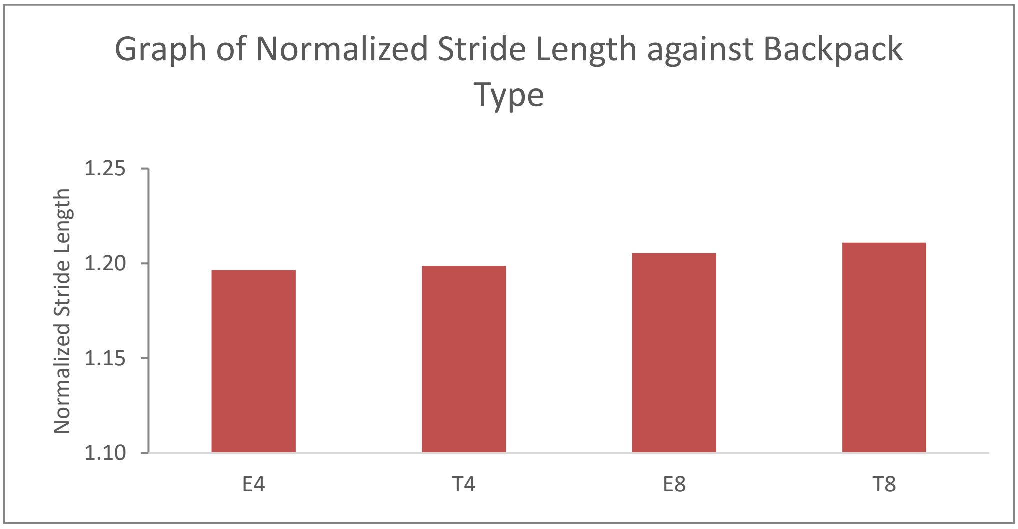

Figure 4.6: Graph of Normalized Stride Length against Backpack Type at 4kg and 8kg.

In the comparison between ergonomic and traditional backpacks, it was observed that the ergonomic backpack exhibited a lower normalized cadence in comparison to the traditional backpack at both loaded conditions, although the change is not statistically significant ($p > 0.05$). Lower cadence helps to reduce the risk of musculoskeletal discomfort or fatigue associated with walking with a heavy backpack (Castro et al., 2015). This observation implies that ergonomic backpacks may have ergonomic benefits, potentially offering greater comfort and minimizing the stress on the musculoskeletal system. However, there was no significant difference in step length stride length observed between different types of backpacks ($p > 0.05$), which is also consistent with previous studies (Corrigan, 2012; Huang, Sui and He, 2020). The consistent step and stride lengths indicate that subjects adapt their walking patterns to maintain a relatively consistent pace regardless of the backpack type used.

4.3 Kinetic Analysis

An analysis of kinetic parameters, specifically VGRF in various conditions was conducted. The data had been normalized before conducting the statistical analysis. Table 4.5 presents the mean and standard deviation of the maximum VGRF under 5 different conditions which is unload, ergonomic backpack with 4 kg and 8 kg loads, and traditional backpack with 4 kg and 8 kg loads.

Table 4.5: Normalized Maximum VGRF in Different Loads and Backpack Conditions.

Conditions	**Maximum VGRF (N=20)**
	Mean±S.D.
U	1.093±0.046
E4	1.173±0.052
E8	1.233±0.058
T4	1.164±0.049
T8	1.217±0.049

S.D. = Standard Deviation.

U = Unload, E4 = Ergonomic backpack with 4 kg load, E8 = Ergonomic backpack with 8 kg load, T4 = Traditional backpack with 4 kg load, T8 = Traditional backpack with 8 kg load.

4.3.1 Increment of Load

Table 4.6 below shows the mean difference values of normalized maximum VGRF as the load increased for both ergonomic and traditional backpack. The relationships between the VGRF and varying loads are illustrated in Figure 4.7.

Table 4.6: Comparison of Kinetic Parameters with Increment of Load.

Parameter	Conditions	Mean Difference (N=20)
Max VGRF	U & E4	**-0.080***
	U & E8	**-0.140***
	E4 & E8	**-0.060***
	U & T4	**-0.070***
	U & T8	**-0.123***
	T4 & T8	**-0.053***

* = significant at p <.05.

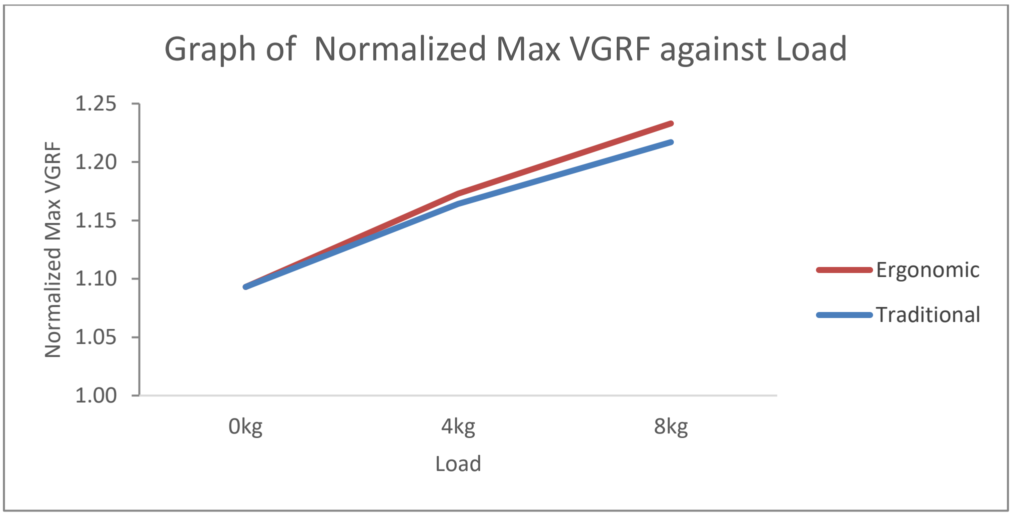

Figure 4.7: Graph of Normalized Maximum VGRF against Load during Walking.

The graph patterns between both the ergonomic backpack and traditional backpack groups were similar as shown in Figure 4.7. Based on Table 4.6, carrying ergonomic or traditional backpacks with 4 kg and 8 kg loads resulted in higher maximum VGRF compared to walking without a backpack with mean difference of -0.080 and -0.140 respectively (P <0.05). Regardless of the backpack type, there was a statistically significant consistent increase in maximum VGRF with increasing load, while carrying 8 kg load had the highest VGRF. The results were consistent with previous studies, which have shown that walking without a load resulted in the lowest maximum VGRF compared to walking with a load (Zhang, Ye and Wang, 2010; Shasman et al., 2011; Dahl et al., 2016). Excessively high VGRF values indicated higher lower limb loading due to shock propagation through the skeleton, which eventually raised the risk of injury over time (Bates et al., 2013). Therefore, it is advisable to minimize the carriage of heavy loads, and one practical approach is to avoid carrying unnecessary items, such as cosmetics, in university. This measure aligns with the goal of reducing musculoskeletal stress during daily activities and promoting overall well-being.

4.3.2 Type of Backpack

Table 4.7 below shows the mean difference values of normalized maximum VGRF between ergonomic and traditional backpack at 4 kg and 8 kg loads. The relationship between the VGRF and type of backpack is illustrated in Figure 4.8.

Table 4.7: Comparison of Kinetic Parameters with Type of Backpack.

Parameter	Conditions	Mean Difference (N=20)
Max VGRF	E4 & T4	0.009
	E8 & T8	0.016

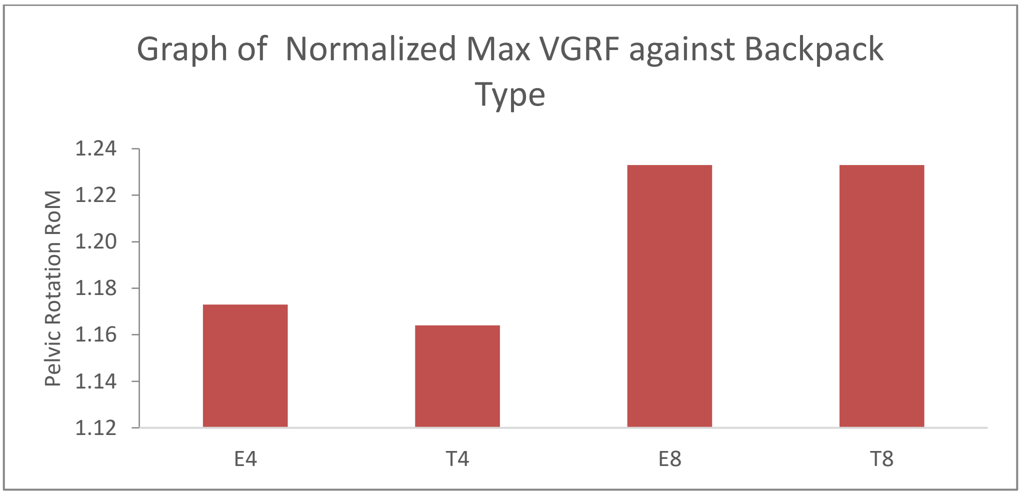

Figure 4.8: Graph of Normalized Maximum VGRF against Backpack Type at 4kg and 8kg.

The analysis of maximum VGRF data indicated that there was no statistically significant difference between the two types of backpacks ($p > 0.05$), as both types of backpacks provided almost similar levels of load distribution and support as shown in Figure 4.8. However, it is noteworthy that the ergonomic backpack exhibited slightly higher maximum VGRF values compared to the traditional backpack, although this difference did not reach statistical significance. It can be observed that the results obtained in this study are consistent with the findings of previous research, which is the higher VGRF for carrying BackTpack when compared with traditional backpack (Dahl et al., 2016). The finding was contrary to the market, which claimed that weight reductions of up to 45% can be achieved by using an ergonomic backpack. The slightly higher VGRF values observed for the ergonomic backpack may be attributed to its design features, especially the elastic shoulder straps, which may affect the biomechanics of load transport. Elastic shoulder straps can potentially create a bouncing or oscillating motion of the backpack when walking (Yang et al., 2020). This dynamic movement can lead to variations in the distribution of forces, resulting in transient increases in VGRF as the backpack moves with each step.

4.4 Kinematic Analysis

In this study, the analysis of 6 kinematic parameters in various conditions was conducted, which included trunk fexion angle, knee and ankle range of motion (RoM), and the RoM of the pelvic region, including tilt, obliquity, and rotation.

4.4.1 Joint Angle in Sagittal

Table 4.8 shows the mean and standard deviation of trunk flexion angle, knee RoM and ankle RoM in sagittal plane under 5 different conditions which is unload, ergonomic backpack with 4 kg and 8 kg loads, and traditional backpack with 4 kg and 8 kg loads.

Table 4.8: Trunk Flexion Angle, Knee RoM and Ankle RoM across Different Conditions.

Conditions	**Trunk Flexion Angle (°) (N=20)**	**Knee RoM (°) (N=20)**	**Ankle RoM (°) (N=20)**
	Mean±S.D.	**Mean±S.D.**	**Mean±S.D.**
U	0.855±1.934	57.335±2.583	31.345±4.714
E4	3.235±2.140	55.795±3.038	33.315±5.768
E8	4.495±1.565	54.855±3.591	33.490±5.735
T4	4.055±2.761	55.340±3.718	33.035±5.364
T8	5.895±2.306	55.105±2.861	33.465±6.026

S.D. = Standard Deviation.

U = Unload, E4 = Ergonomic backpack with 4 kg load, E8 = Ergonomic backpack with 8 kg load, T4 = Traditional backpack with 4 kg load, T8 = Traditional backpack with 8 kg load.

4.4.1.1 Increment of Load

Table 4.9 below shows the mean difference values of trunk flexion angle, knee flexion RoM and ankle flexion RoM as the load increased for both ergonomic and traditional backpack. The relationships between these kinematic parameters and varying loads are illustrated in Figure 4.9, Figure 4.10 and Figure 4.11.

Table 4.9: Comparison of Joint Angle Parameters with Increment of Load.

Parameter	Conditions	Mean Difference (N=20)
Trunk Flexion Angle	U & E4	**-2.380***
	U & E8	**-3.640***
	E4 & E8	**-1.260***
	U & T4	**-3.200***
	U & T8	**-5.050***
	T4 & T8	**-1.850***
Knee RoM	U & E4	1.540
	U & E8	**2.480***
	E4 & E8	0.940
	U & T4	1.995
	U & T8	**2.230***
	T4 & T8	0.235
Ankle RoM	U & E4	-1.970
	U & E8	-2.145
	E4 & E8	-0.175
	U & T4	-1.690
	U & T8	-2.120
	T4 & T8	-0.430

* = significant at p <.05.

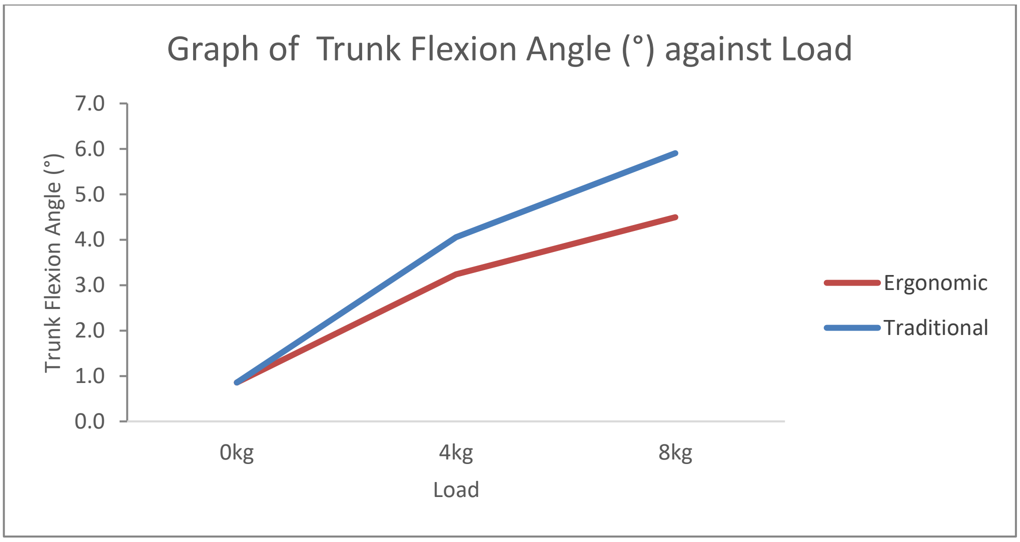

Figure 4.9: Graph of Trunk Flexion Angle against Load during Standing.

Based on Figure 4.9, the analysis of trunk flexion angle revealed significant differences across various load conditions. When comparing the unload condition to the loaded conditions (4 kg and 8 kg) for both ergonomic and traditional backpacks, highly significant differences were observed ($p < 0.05$). Additionally, the significant mean difference of -1.260 ($p < 0.05$) and -1.850 ($p < 0.05$) were observed when comparing the E4 & E8 and T4 & T8 respectively, highlighting differences in trunk flexion angles between these two loaded states. Within the loaded conditions, the 8 kg load condition resulted in the highest trunk flexion angle. This observation aligns with the previous study, where trunk flexion angle increased with greater load carriage (Al-Khabbaz, Shimada and Hasegawa, 2008). This indicates that the heavier load led to a compensatory mechanism of leaning forward by shifting centre of gravity posteriorly towards to the boundary of the base of support (Singh and Koh, 2009). This adjustment helps ensure that the line of gravity remains comfortably within the base of Support, which able to maintain balance and stability (Singh and Koh, 2009). As the load increase, the additional load led to excessive stress on spinal discs and vertebrae, which may increase the risk of spines injury (Birrell and Haslam, 2010).

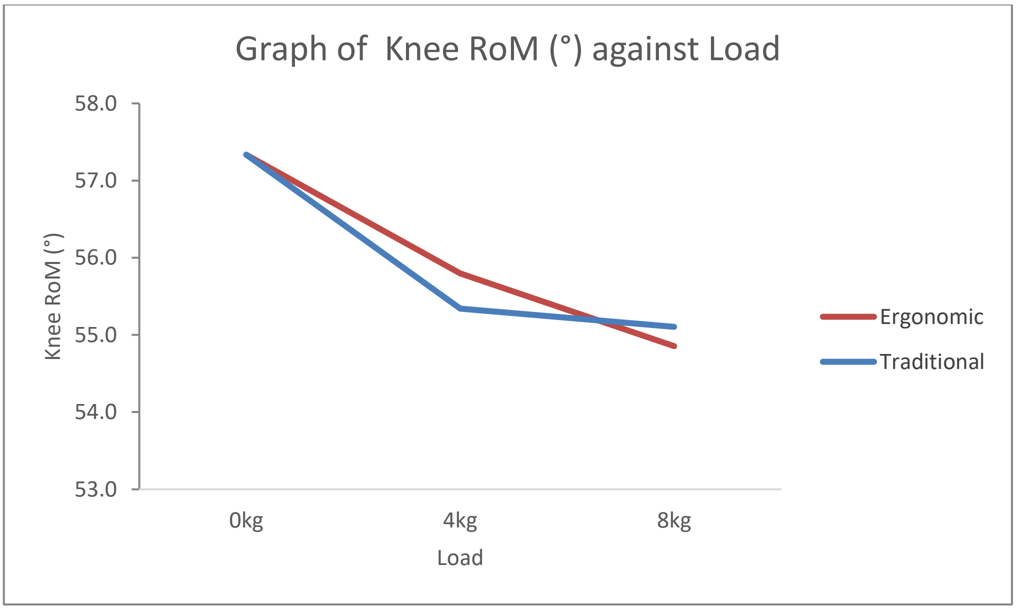

Figure 4.10: Graph of Knee Flexion RoM against Load during Walking.

Based on Figure 4.4, it was observed that both the 4 kg and 8 kg load conditions shown a lower range of motion of the knee compared to the unload condition, irrespective of the backpack type. Specifically, the 8 kg load condition resulted in the lowest knee RoM among all the tested conditions. When comparing the knee RoM of U & E8 and U & T8, there were a significant mean difference of 2.480 and 2.230 ($p < 0.05$) respectively. However, the comparison between 4 kg and 8 kg loads within both ergonomic (E4 & E8) and traditional (T4 & T8) backpacks did not yield significant differences in knee RoM ($p > 0.05$). This suggested that the effect may constant beyond a certain load threshold. The knee RoM decrease with increasing load across the various load conditions due to the center of body gravity shifts, and the muscles around the knee joint may need to work harder to maintain balance and stability (Nishino et al., 2015). Additionally, this increased load led to greater muscular effort and fatigue, thereby restricting the knee's ability to flex and extend fully. The observed findings align with the results reported in a previous study, suggesting the consistency of the impact of increasing load carriage led to lower Knee RoM (Polcyn et al., 2002; Han and Wang, 2011).

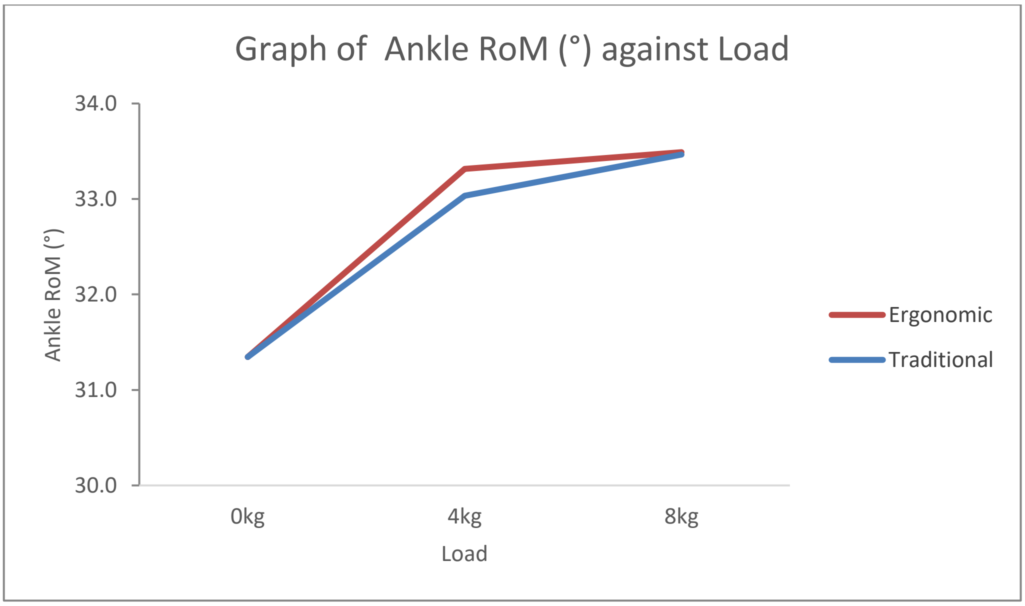

Figure 4.11: Graph of Ankle Flexion RoM against Load during Walking.

It was observed that both the 4 kg and 8 kg load conditions induced greater ankle RoM compared to the unload condition, although there is not significant ($p > 0.05$). Notably, the 8 kg load condition exhibited the highest ankle RoM, while the difference between the 8 kg and 4 kg load conditions was relatively small. This suggests that while increasing load tends to increase ankle RoM, the effect may constant beyond a certain load threshold. The observed increase in ankle RoM could be attributed to potential muscle fatigue in the ankle region, which may impact the ankle muscles responsible for maintaining proper ankle alignment through eccentric contractions (Simpson, Munro and Steele, 2012). The result aligns with findings from previous studies, indicating a consistent response of higher ankle RoM with increasing load carriage (Singh and Koh, 2009; Han and Wang, 2011). Therefore, it is advisable that young female adults should decrease the loads of backpack in their daily life to avoid excessive stress on ankle.

4.4.1.2 Type of Backpack

Table 4.10 below shows the mean difference values of trunk flexion angle, knee flexion RoM and ankle flexion RoM between ergonomic and traditional backpacks at 4 kg and 8 kg loads. The relationships between these kinematic parameters and varying loads are illustrated in Figure 4.12, Figure 4.13 and Figure 4.14.

Table 4.10: Comparison of Joint Angle Parameters with Type of Backpack.

Parameter	Conditions	Mean Difference (N=20)
Trunk Flexion Angle	E4 & T4	-0.820
	E8 & T8	**-1.410***
Knee RoM	E4 & T4	0.455
	E8 & T8	-0.250
Ankle RoM	E4 & T4	0.280
	E8 & T8	0.025

* = significant at p <.05.

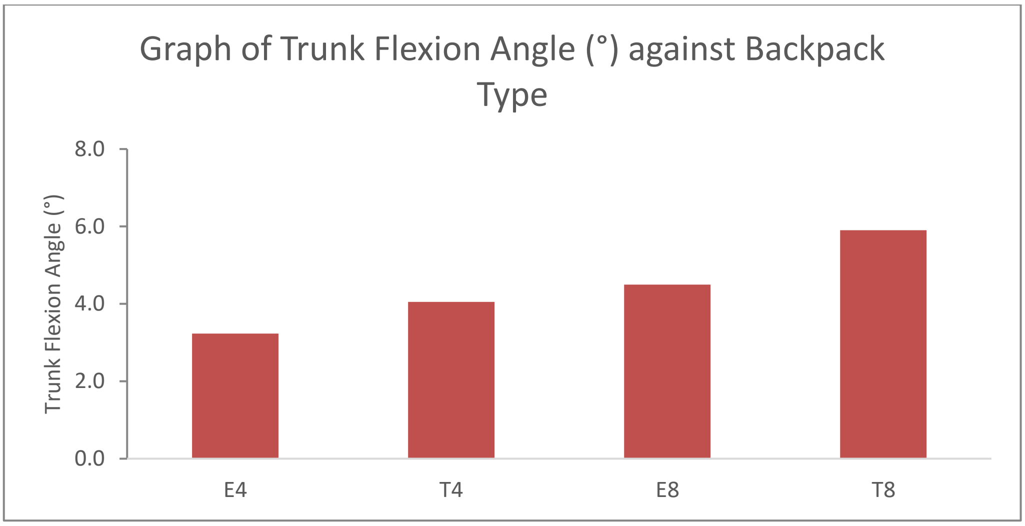

Figure 4.12: Graph of Trunk Flexion Angle against Backpack Type at 4kg and 8kg.

At the 4 kg load level, ergonomic backpack was only having slightly lower trunk flexion angle compared to traditional backpack, which is not significant ($p > 0.05$). However, a statistically significant difference was found between E8 and T8 with mean difference of -2.430 ($p < 0.05$). In this case, the ergonomic backpack induced lower trunk flexion compared to the traditional backpack. The result indicated the type of backpack had an influence on trunk flexion angle, particularly with heavier loads. The result is consistent with the previous study, carrying ergonomic backpack able to minimize trunk flexion as compared to traditional at certain weight (Dahl et al., 2016). This finding showed that the design of the traditional backpack may not provide adequate support to the spine and may result in a greater demand for trunk flexion to maintain balance, while the load distribution system in ergonomic backpack could serve to lower the chance of back pain and spinal deformities brought by the forward tilt of trunk (Dahl et al., 2016). This also suggested that the ergonomic backpack design effectively promotes a more upright posture and reduced trunk flexion, potentially offering benefits in terms of reduced musculoskeletal strain and improved postural alignment during load carriage.

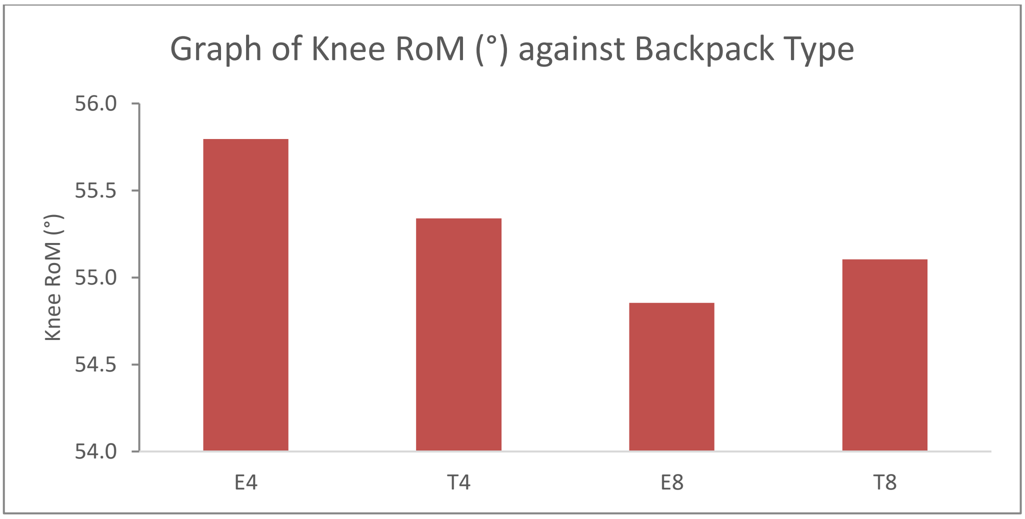

Figure 4.13: Graph of Knee Flexion RoM against Backpack Type at 4kg and 8kg.

The analysis of Knee RoM showed there was no significant difference when comparing the two backpack types at the 4 kg and 8kg load conditions ($p > 0.05$). These findings suggest that there is no clear advantage of one backpack type over the other within the scope of this study. In the study of Huang, Sui and He (2020) also found there was no significant difference in knee flexion or extension in both elastic straps backpack and traditional backpack when loaded with 10% of body weight.

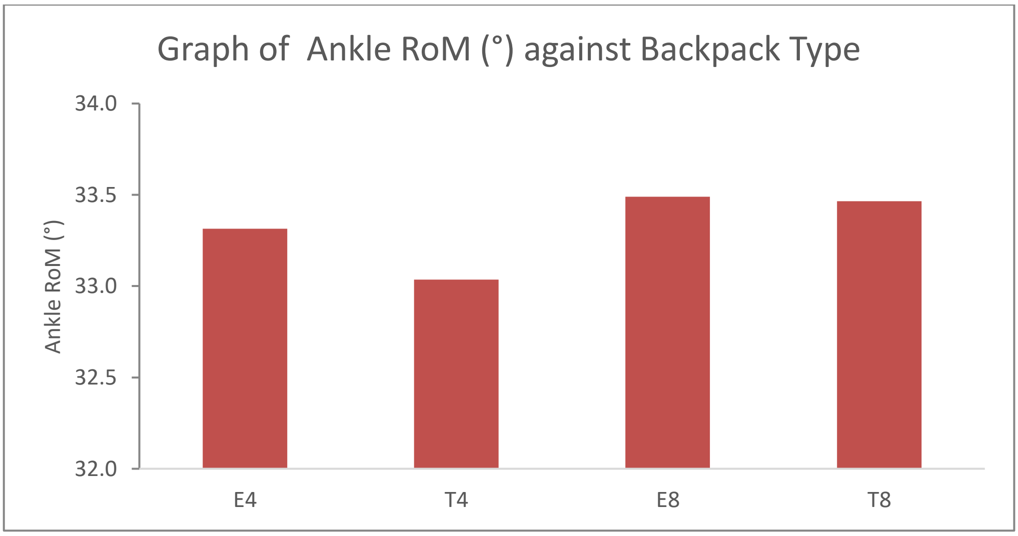

Figure 4.14: Graph of Ankle Flexion RoM against Backpack Type at 4kg and 8kg.

There was no statistically significant distinction in ankle RoM observed between the two backpack types at either load condition ($p > 0.05$). However, it is important to mention that the ergonomic backpack consistently exhibited slightly higher ankle RoM values compared to the traditional backpack, although this difference did not attain statistical significance. Similarly, a study by Huang, Sui and He (2020) found that there was no significant difference in ankle flexion angle between elastic straps backpack and traditional backpack when loaded with 10% of body weight, which indicated that both can be regarded as equally accommodating in terms of ankle flexibility. The result suggested that changes in backpack did not significantly impact lower limb in this study.

4.4.2 Pelvic RoM

Table 4.11 shows the mean and standard deviation of pelvic RoM parameters, including pelvic tilt, obliquity and rotation with different type of backpack and load when walking.

Table 4.11: Pelvic RoM of Tilt, Obliquity and Rotation across Different Conditions.

Conditions	**Pelvic Tilt RoM (°) (N=20)**	**Pelvic Obliquity RoM (°) (N=20)**	**Pelvic Rotation RoM (°) (N=20)**
	Mean±S.D.	**Mean±S.D.**	**Mean±S.D.**
U	4.220±1.580	7.285±2.002	6.385±2.408
E4	4.310±0.965	5.210±1.693	8.700±2.748
E8	4.085±1.028	4.570±1.681	8.080±3.369
T4	4.985±1.173	4.940±1.901	10.080±3.000
T8	4.860±0.797	5.120±2.160	9.680±2.624

S.D. = Standard Deviation.

U = Unload, E4 = Ergonomic backpack with 4 kg load, E8 = Ergonomic backpack with 8 kg load, T4 = Traditional backpack with 4 kg load, T8 = Traditional backpack with 8 kg load.

4.4.2.1 Increment of Load

Table 4.12 below shows the mean difference values of RoM of pelvic tilt, pelvic obliquity and pelvic rotation as the load increased for both ergonomic and traditional backpack. The relationships between these pelvic RoM and varying loads are illustrated in Figure 4.15, Figure 4.16 and Figure 4.17.

Table 4.12: Comparison of Pelvic RoM with Increment of Load.

Parameter	Conditions	Mean Difference (N=20)
Pelvic Tilt RoM	U & E4	-0.090
	U & E8	0.135
	E4 & E8	0.225
	U & T4	-0.765
	U & T8	-0.640
	T4 & T8	0.125
Pelvic Obliquity RoM	U & E4	**2.075***
	U & E8	**2.715***
	E4 & E8	**2.345***
	U & T4	**2.345***
	U & T8	**2.165***
	T4 & T8	-0.180
Pelvic Rotation RoM	U & E4	-2.315
	U & E8	-1.695
	E4 & E8	0.620
	U & T4	**-3.695***
	U & T8	**-3.295***
	T4 & T8	0.400

* = significant at p <.05.

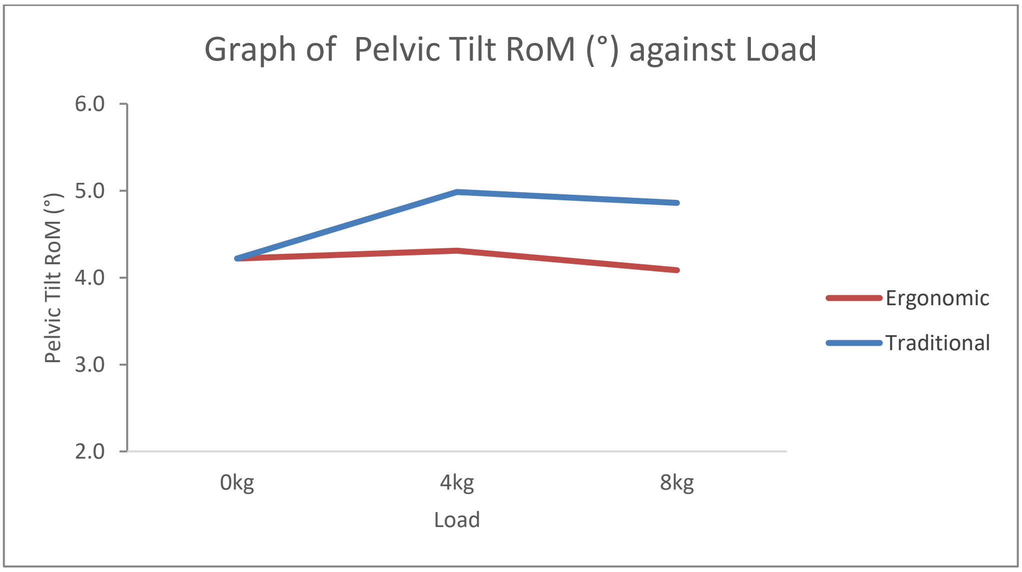

Figure 4.15: Graph of Pelvic Tilt RoM against Load during Walking.

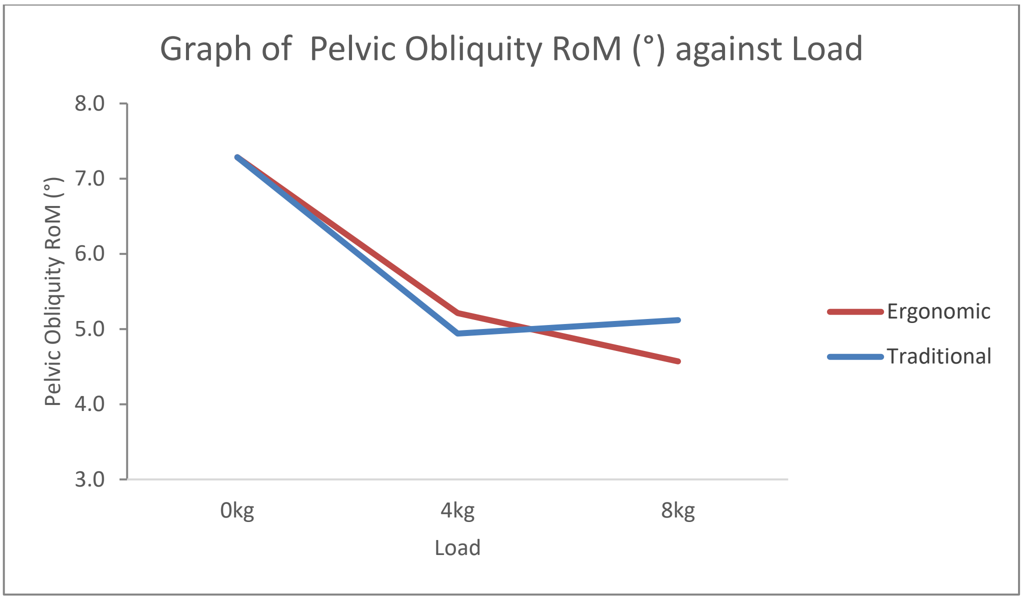

Figure 4.16: Graph of Pelvic Obliquity RoM against Load during Walking.

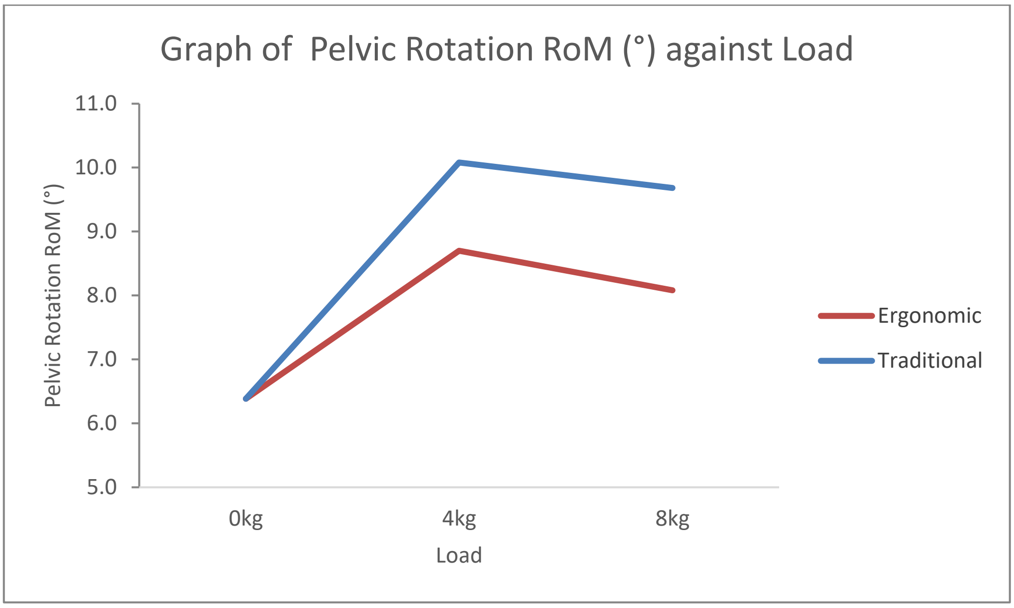

Figure 4.17: Graph of Pelvic Rotation RoM against Load during Walking.

For the pelvic kinematics, the analysis of pelvic tilt RoM across different conditions revealed no significant differences in any of the comparisons ($p > 0.05$). Both ergonomic and traditional backpacks displayed a consistent and uniform pelvic tilt RoM across different load conditions. Besides, statistically significant differences were observed in pelvic obliquity RoM when compare U to E4 and E8, as well as U to T4 and T8 ($p < 0.05$). It was observed that both the 4 kg and 8 kg load conditions induced a significantly lesser pelvic obliquity RoM compared to the unload condition, irrespective of the backpack type. However, there is no significant difference in pelvic obliquity RoM between T4 and T8 ($p > 0.05$). The result showed that the pelvic obliquity RoM decreased with increasing load. For pelvic rotation RoM, significant differences were observed in the comparisons between U & T4 and U & T8, with the mean differences of -3.695 and -3.295 respectively ($p < 0.05$). It was observed that both the 4 kg and 8 kg load conditions induced a larger pelvic rotation RoM compared to the unload condition. Interestingly, it was found that the 8 kg load condition exhibited slightly smaller pelvic rotation RoM than the 4 kg load level for both backpack conditions, although there were only slight differences when transitioning from the 4 kg to the 8 kg load condition.

The analysis of pelvic RoM in this study is in accordance with prior research by Chow et al. (2007), which found that increasing backpack load did not significantly impact pelvic tilt but did lead to an increase in pelvic rotation during walking, as a compensatory mechanism to minimize the effect of the backpack's moment of inertia. Similarly, Smith et al. (2006) observed a significant decrease in pelvic obliquity ROM under loaded conditions compared to walking without a backpack, while pelvic tilt RoM remained unchanged. The pelvic pattern could be explained by the body's adaptive response to maintain balance and stability. Initially, as load is added, the pelvic obliquity and rotation may increase to accommodate the change in the center of gravity. However, as the load further increases to 8 kg, the body may adjust its movement strategy to maintain stability by restricting lateral pelvic movement and minimize excessive rotation (Hyung, Lee and Kwon, 2016).

4.4.2.2 Type of Backpack

Table 4.13 below shows the mean difference values of RoM of pelvic tilt, pelvic obliquity and pelvic rotation between ergonomic and traditional backpacks at 4 kg and 8 kg loads. The relationships between these pelvic RoM and type of backpack are illustrated in Figure 4.18, Figure 4.19 and Figure 4.20.

Table 4.13: Comparison of Pelvic RoM with Type of Backpack.

Parameter	Conditions	Mean Difference (N=20)
Pelvic Tilt RoM	E4 & T4 E8 & T8	-0.675 -0.775
Pelvic Obliquity RoM	E4 & T4 E8 & T8	0.270 -0.550
Pelvic Rotation RoM	E4 & T4 E8 & T8	-1.380 -1.600

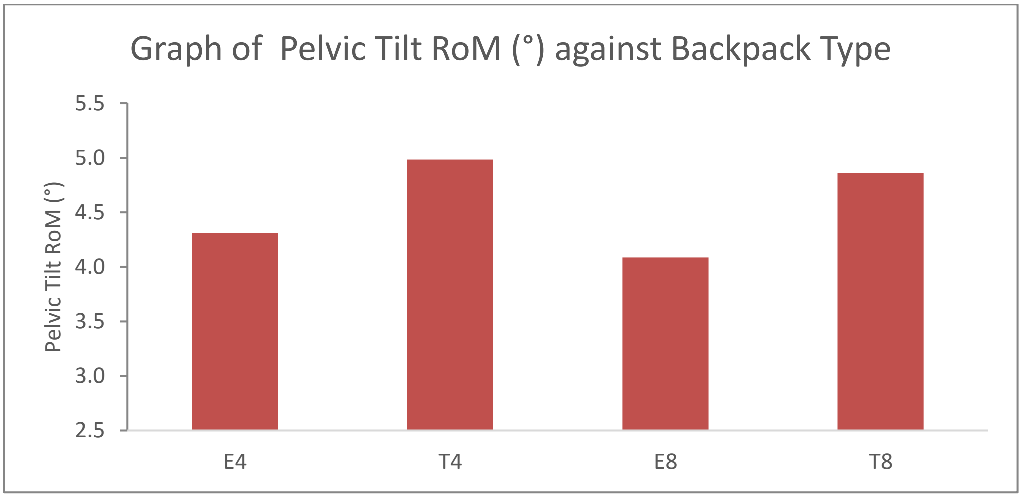

Figure 4.18: Graph of Pelvic Tilt RoM against Backpack Type at 4kg and 8kg.

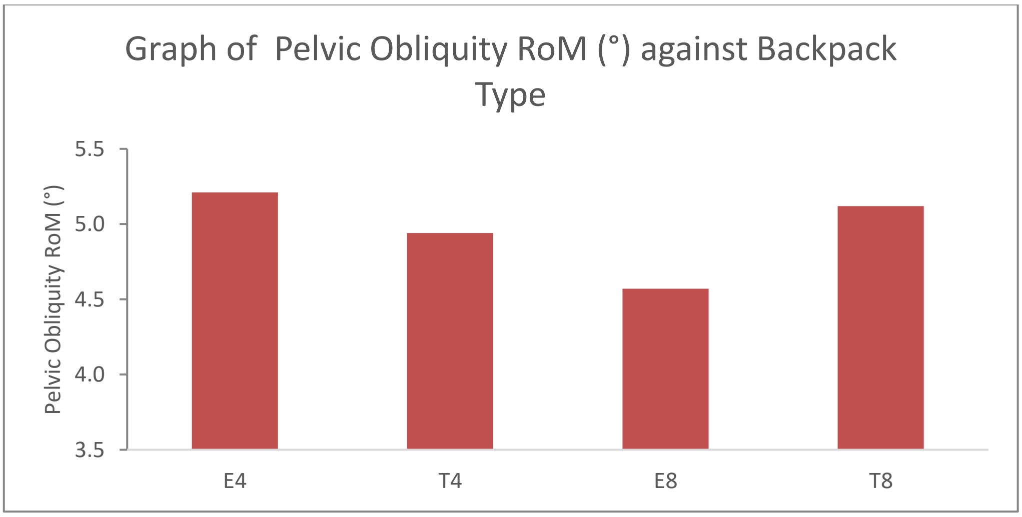

Figure 4.19: Graph of Pelvic Obliquity RoM against Backpack Type at 4kg and 8kg.

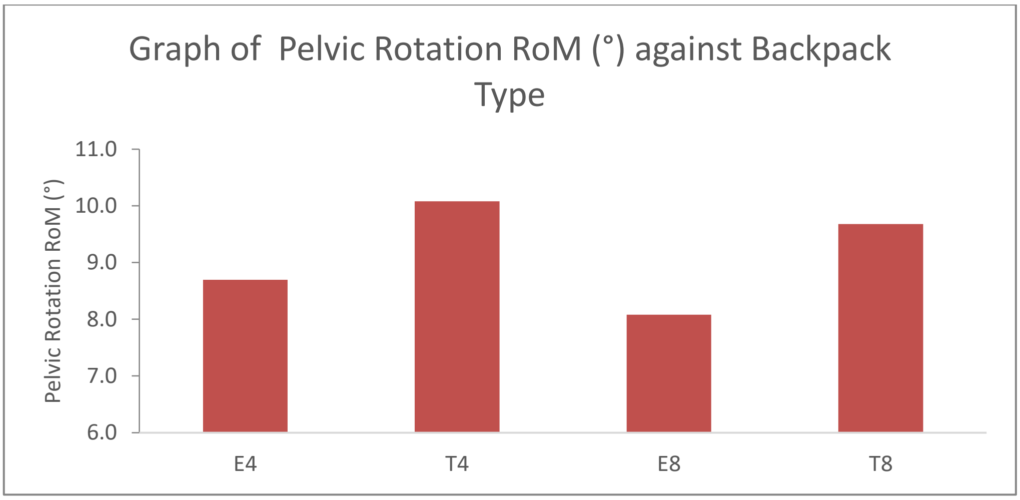

Figure 4.20: Graph of Pelvic Rotation RoM against Backpack Type at 4kg and 8kg.

In comparing the pelvic RoM between ergonomic and traditional backpacks, it was found that there was no significant difference in all three directions ($p > 0.05$). The obtained results align closely with a prior investigation conducted by Huang, Sui, and He (2020), where it was similarly observed that there existed no statistically significant difference in the pelvic angle across three planes between elastic straps backpacks and traditional backpacks under load conditions of 0% and 10% of body weight. However, it can be observed that ergonomic backpack exhibited slightly lower RoM in pelvic tilt and rotation compared to the traditional backpack for both loaded conditions. These findings suggest that the ergonomic design may have a slight advantage in reducing pelvic tilt and rotation during walking gait, potentially contributing to improved postural stability.

CHAPTER 5

PROBLEMS AND RECOMMENDED SOLUTIONS

5.1 Conclusions

In conclusion, this comprehensive study on the impact of different backpack types and loads on walking biomechanics provides valuable insights into the factors influencing musculoskeletal health and gait stability on university young female adults. The study resulted that change in load did not have significant impact on lower limb, including cadence, step length, stride length, and ankle flexion RoM. However, carrying heavier load provide a significant impact on VGRF, trunk flexion angle, knee flexion RoM, pelvic obliquity RoM and pelvic obliquity RoM. Besides, no significant impact was found in knee flexion RoM, ankle flexion RoM, pelvic RoM (tilt, obliquity and rotation), as well as spatiotemporal parameters (cadence, step length and stride length). The study also found no significant difference in VGRF between ergonomic and traditional backpacks, which contrary to marketing claims of substantial weight reductions with elastic shoulder straps designs. However, an ergonomic backpack has a significant impact on reducing trunk flexion angle. These findings underscore the importance of choosing a backpack that prioritizes comfort, load distribution, and proper weight management to minimize the risk of musculoskeletal stress and injury during daily activities.

5.2 Recommendations for Future Work

Present study had been focused on young female adult. Expanding the subject pool to include both males and females in future studies can provide a more comprehensive understanding of how ergonomic and traditional backpacks affect gait mechanics, ensuring the results are applicable to a broader population. Additionally, it is advisable standardized sole thickness in sport shoes. This standardization can help eliminate or at least minimize the effects of varying sole thicknesses on the measurements of variables such as ground reaction forces, gait patterns, and overall biomechanics.

Furthermore, the study encountered technical issue with the H/P Cosmos Instrumented Treadmill, primarily attributed to the treadmill's age and wear. The malfunction included the failure to detect the subject's foot strike, necessitating repeated trial attempts by the subjects. It is imperative for future studies to consider investing in updated and well-maintained treadmill equipment to avoid time wastage when collecting data.

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APPENDICES

Appendix A: Figure

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Re: U/SERC/187/2023

27 July 2023

Ir Dr Goh Choon Hian
Head, Department of Mechatronics and BioMedical Engineering
Lee Kong Chian Faculty of Engineering and Science
Universiti Tunku Abdul Rahman
Jalan Sungai Long
Bandar Sungai Long
43000 Kajang, Selangor

Dear Ir Dr Goh,

Ethical Approval For Research Project/Protocol

We refer to your application for ethical approval for your students' research project from Bachelor of Engineering (Honours) Biomedical Engineering programme enrolled in course UEGE4118. We are pleased to inform you that the application has been approved under Expedited Review.

The details of the research projects are as follows:

No.	Research Title	Student's Name	Supervisor's Name	Approval Validity
1.	Impact of Carrying School Backpacks on Students: Quantitative Biomechanical Approach	Wong Keqi	Ms Tan Yin Qing Dr Chan Siow Cheng	27 July 2023 – 26 July 2024
2.	The Postural Effect of Different Types of Load Carriage in Ergonomic During Walking Gait	Ng Xiao Jing		
3.	Shoe Wear Influence on Kinematic Parameters in Timed Up and Go (TUG) Test	Chua Yew Chuen		

The conduct of this research is subject to the following:

(1) The participants' informed consent be obtained prior to the commencement of the research;

(2) Confidentiality of participants' personal data must be maintained; and

(3) Compliance with procedures set out in related policies of UTAR such as the UTAR Research Ethics and Code of Conduct, Code of Practice for Research Involving Humans and other related policies/guidelines.

(4) Written consent be obtained from the institution(s)/company(ies) in which the physical or/and online survey will be carried out, prior to the commencement of the research.

Kampar Campus : Jalan Universiti, Bandar Barat, 31900 Kampar, Perak Darul Ridzuan, Malaysia
Tel: (605) 468 8888 Fax: (605) 466 1313
Sungai Long Campus : Jalan Sungai Long, Bandar Sungai Long, Cheras, 43000 Kajang, Selangor Darul Ehsan, Malaysia
Tel: (603) 9086 0288 Fax: (603) 9019 8868
Website: www.utar.edu.my

FigureA-1a: Ethical Approval.

Should the students collect personal data of participants in their studies, please have the participants sign the attached Personal Data Protection Statement for records.

Thank you.

Yours sincerely,

Professor Ts Dr Faidz bin Abd Rahman
Chairman
UTAR Scientific and Ethical Review Committee

c.c Dean, Lee Kong Chian Faculty of Engineering and Science
Director, Institute of Postgraduate Studies and Research

Kampar Campus : Jalan Universiti, Bandar Barat, 31900 Kampar, Perak Darul Ridzuan, Malaysia
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Tel: (603) 9086 0288 Fax: (603) 9019 8868
Website: www.utar.edu.my

FigureA-1b: Ethical Approval.

(PARTICIPATION IN THIS RESEARCH IS VOLUNTARY)

1. Student Name	:	Ng Xiao Jing	**Faculty**	:	LKC FES

FYP Title : The postural effect of different types of load carriage in ergonomic during walking gait.

Purpose of study : To analyse the kinematic and kinetic parameters between traditional backpack and ergonomic backpack with different load during walking gait on young female adult.

Procedure : BTS G-Walk and forced plate treadmill will measure the parameters of the subjects during walking with load carriage.

Risk and Discomfort : Subjects may experience fatigue which is often accompanied by muscle soreness due to the side effect of carrying heavy load during walking.

Benefit : Subjects would be able to evaluate and compare the effect to their body due to carrying different load with traditional backpack and ergonomic backpack.
Subjects could learn the most appropriate backpack that is best for their body which will help to minimize the discomfort of carrying heavy bags.

Payment : -

Note: All volunteers involved in this study will not be covered by insurance

2. Particulars of Volunteer (Volunteer Identifier/Label)
(Please use separate form if more than one volunteer)

Full Name :

Chinese character *(if applicable)* :

New Identity Card/ Passport No. : Gender :

Contact No. :

Email :

FigureA-2a: Consent Form.

3. Medical History
A brief medical history will be taken as detailed in **Appendix A**

4. Voluntary participation
You understand your participation in this study is voluntary and that if you decide not to participate, you will experience no penalty or loss of benefits to which you would otherwise be entitled. If you decide to participate, you may subsequently change your mind about your being in the study, and may stop you from participating at any time. You understand that you must inform the principal investigator of your decision immediately.

5. Available Medical Treatment
If you are injured during his/her participation or in the course of the study or whether or not as a direct result of this study, UTAR will not be liable for any loss or damage or compensation or absorb the costs of medical treatment. However, assistance will be provided to you in obtaining emergency medical treatment.

6. Confidentiality
All information, samples and specimens you have supplied will be kept confidential by the principal investigator and the research team and will not be made available to the public unless disclosure is required by law.

7. Disclosure
Data, samples and specimens obtained from this study will not identify you individually. The data, samples and specimens may be given to the sponsor and/or regulatory authorities and may be published or be reused for research purposes not detailed within this consent form. However, your identity will not be disclosed. The original records will be reviewed by the principal investigator and the research team, the UTAR Scientific and Ethical Review Committee, the sponsor and regulatory authorities for the purpose of verifying research procedures and/or data.

By signing this consent form, you authorize the record review, publication and re-utilisation of data, information and sample storage and data transfer as described above

8. Declaration

I have read or have the information above read to me, in the language understandable to me. The above content has been fully explained to me.

I have asked all questions that I need to know about the study and this form. All my questions have been answered. I have read, or have had read to me, all pages of this consent form and the risks described. I voluntarily consent and offer to allow me to take part in this study. By signing this consent form, I certify that all information I have given, including my medical history, is true and correct to the best of my knowledge. **I will not hold UTAR or the research team responsible for any consequences and/or liability whatsoever arising from my participation in this study.**

FigureA-2b: Consent Form.

9. Declaration

If you wish to participate in this study, please sign below.

____

Name :
IC/Passport No :
Date :

10. Statement of student

I have fully explained to the guardian/parent of the subject taking part in this study what he / she can expect by virtue of his / her participation. The guardian/parent of the participant, who is giving consent to take part in this study

- Understands the language that I have used.
- Reads well enough to understand this form, or is able to hear and understand the contents of the form when read to him or her.
- Is of the age of majority of 18 or above.

To the best of my knowledge, when the guardian/parent of the participant signed this form, he or she understands:

- That taking part in the study is voluntary.
- What the study is about.
- What needs to be done.
- What are the potential benefits.
- What are the known risks.

A copy of this consent form has been given to the guardian/parent of the participant.

____

Name of Student : Ng Xiao Jing
IC/Passport No : 010830-14-1064
Date :

FigureA-2c: Consent Form.

Project Title :	The postural effect of different types of load carriage in ergonomic during walking gait.

Medical History of Volunteer			
Have you ever had any of the following:		**Yes**	**No**
a	a serious illness or accident?	☐	☐
b	an operation/ investigative procedure?	☐	☐
c	yellow jaundice or hepatitis?	☐	☐
d	tuberculosis?	☐	☐
e	malaria?	☐	☐
f	a tattoo?	☐	☐
g	a blood transfusion?	☐	☐
h	contact with any infectious disease?	☐	☐
i	heart disease?	☐	☐
j	high blood pressure (>140/90 mmHg)?	☐	☐
k	asthma?	☐	☐
l	kidney disease?	☐	☐
m	diabetes?	☐	☐
n	a stomach ulcer?	☐	☐
Do you or family have any of the following:			
o	Cancer?	☐	☐
p	Is a HIV carrier?	☐	☐
q	psychiatric disease/ mental problem?	☐	☐

FigureA-3: Medical History.