

**INVESTIGATING THE ASSOCIATION BETWEEN OBJECTIVELY MEASURED
PHYSICAL ACTIVITY, TRUNK ENDURANCE AND LOW BACK PAIN**

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Abstract

The goal of this study was to explore the relationship between physical activity, trunk muscle endurance, and low back pain (LBP) in an undergraduate student population. Using triaxial accelerometers and standardized endurance tests, physical activity and trunk muscle endurance were objectively measured and the results compared between the control and LBP groups.

Findings indicated that while the control group generally showed higher physical activity levels, only two of fifteen variables—maximum METs and percent time in vigorous physical activity—were statistically significant. Trunk muscle endurance was higher in the control group, but a ceiling effect in the trunk endurance tests limited the ability to discover the real differences between participants. The expected correlation between physical activity and trunk muscle endurance could not be confirmed due to these limitations.

This research contributes to improving the understanding of physical activity, trunk endurance, and LBP among undergraduate students. This research not only enriches the current discourse but also lays a foundation for future research to better understand the relationship between these factors.

Acknowledgements

“Not to us, O Lord, not to us, but to your name give glory, for the sake of your steadfast love and your faithfulness!” Psalm 115:1 (ESV)

I would like to thank my Lord and Savior, Jesus Christ, for the immeasurable grace and blessings he has poured out into my life. God’s hand is and has been evident throughout my entire life. I am blessed and thankful for all that the Lord has done for me, with His sacrifice on the cross being the greatest gift possible. Nothing that I have done or achieved in life would have been possible without God, as it is He who gives me life, strength, intelligence, and everything that I need to walk in the works he has prepared for me in advance.

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1. Introduction

Low back pain (LBP) is defined as pain localized between the 12th rib and the inferior gluteal folds, with or without leg pain (Krismer & van Tulder, 2007). Low back pain is one of the leading causes of disability worldwide, affecting people of all ages (Maher et al., 2016; Nunn et al., 2017). Maintaining a physically active lifestyle is recommended in clinical guidelines to help manage LBP (National Guideline Centre, 2016). Some research has found that physical activity which increases aerobic capacity and muscular strength is beneficial for patients with chronic LBP as it facilitates them in completing activities of daily living (Gordon & Bloxham, 2016). Despite the many benefits of physical activity regarding the prevention and rehabilitation of LBP (Darlow et al., 2016; Hashimoto et al., 2018), there have also been many conflicting findings in research, with some systematic reviews suggesting that there is no association between physical activity level and incidence of LBP (Hendrick et al., 2011). There is a scarcity of literature simultaneously looking at trunk endurance, objectively measured physical activity, and the prevalence of LBP in an undergraduate student population.

Physical activity is defined as any bodily movement produced by skeletal muscles that results in energy expenditure (Casperson et al., 1985). Physical activity can be further categorized based on the frequency, duration and intensity of the activity (Miles, 2007). Historically, physical activity research has been conducted using self-reported measures such as questionnaires and diaries. Self-reported measures have been found to be prone to recall bias and overestimation from the participants (Dowd et al., 2018; Zandwijk et al., 2015). Despite the limitations, conclusions deducted using self-reported physical activity measures have been helpful in growing the body of literature and improving the understanding of the impacts of

physical activity. Triaxial accelerometers provide objective measures of physical activity which have been proven to be less variable than self-reported measures (Dowd et al., 2018). Using objective measures of physical activity allows for physical activity measures to be analyzed without the biases that affect self-reported measures.

Low trunk muscle endurance has been identified as a possible risk factor for the development of back pain (Tekin et al., 2009). It has been suggested that due to having a low fatigue threshold, those with poor trunk muscle endurance are most likely to injure the passive and pain-sensitive structures of the low back (Latimer et al., 1999). A study by Dejanovic and colleagues (2013) suggested that torso muscle endurance may be associated with current back disorders, predict future disorders and influence performance. Many tests have been developed to test trunk muscle endurance, two of the most prominent being the Biering-Sørensen and the side plank tests. The Biering-Sørensen test is an isometric trunk extensor muscle endurance test. Research has found that the Biering-Sørensen test produces reliable results when used to assess both participants asymptomatic for non-specific LBP and participants with current or previous non-specific LBP (Keller, 2001). The side plank test was developed to evaluate the endurance of the lateral trunk muscles. The side plank test challenges the quadratus lumborum and the muscles of the abdominal wall (McGill, 1999). The use of the Biering-Sørensen and side plank tests would allow for quantification of the levels of trunk muscle endurance, and subsequent comparison of endurance values between the LBP and control groups.

There are conflating results in the literature regarding the correlation between physical activity and trunk muscle endurance. Different methods have been used to quantify the magnitude of physical activity, such as questionnaires and accelerometry, which could be an

important contributor to the conflating results in the literature. Therefore, this study used an objective measure of physical activity to examine the correlation between physical activity measures and trunk muscle endurance.

2. Objectives & Hypothesis

This study evaluated an undergraduate student population to compare individuals with a history of LBP to those without. Physical activity was quantified with triaxial accelerometers (to obtain an objective and reliable measure), and trunk endurance was measured using both the Biering-Sørensen and side plank tests. Questionnaire data was analyzed to compare the self-reported and objectively measured physical activity. Overall, the aim of this work was to further the understanding of physical activity and trunk muscle endurance as they pertain to LBP in an undergraduate population.

The objectives of this study were three-fold:

1. To assess the association between physical activity and LBP.
2. To assess the association between trunk muscle endurance and LBP.
3. To assess the correlation between physical activity and trunk muscle endurance.

2.1 Hypotheses

The control group was comprised of participants who did not have a previous history of LBP. The LBP group was comprised of participants who had a previous history of LBP. The objectives above were addressed with the following three hypotheses:

1. The control group will have higher levels and amount of physical activity than the LBP group. The control group will have:
 - a. More time spent in moderate and vigorous activity
 - b. Less time in sedentary activity
 - c. More energy expended
2. The control group will have higher trunk muscle endurance in both the Biering-Sørensen and side plank tests compared to the affected groups.
3. There will be at least a moderate correlation (0.3-0.5) between physical activity and trunk endurance measures.

3. Literature Review

Background information in this section provides context for this investigation of trunk muscle endurance, physical activity, and LBP. As such, the literature review includes the following areas: muscles of the vertebral column, abdominal wall, and pelvis; endurance tests; approaches to quantify physical activity; and the relationship between physical activity and LBP.

3.1 Muscles of The Vertebral Column

The muscles of the vertebral column are very complex; they have multiple origins and insertions, lines of action, and they exhibit extensive functional overlap (McKinley et al., 2015).

While this is not an exhaustive summary of the muscles of the vertebral column, the key muscles for supporting and moving the vertebral column will be highlighted. These muscles include the erector spinae group, multifidus, and quadratus lumborum. A muscle that also has

impact on the behaviour of the lumbar spine and control of the vertebral column but is often overlooked is the latissimus dorsi muscle. Each of these muscles are briefly described below.

The erector spinae muscle group primarily functions to maintain posture (McKinley et al., 2015). In addition to maintaining posture, the erector spinae muscle group extends and laterally flexes the trunk, as well as abducts and rotates the vertebral column. Structurally, the erector spinae muscle group is comprised of three muscles: the iliocostalis, the longissimus, and the spinalis. The iliocostalis muscle group is comprised of cervical, thoracic, and lumbar sections and is the most lateral of the erector spinae muscle group. Medial to the iliocostalis muscle group is the longissimus muscle group. The longissimus muscle group is comprised of capitis, cervical, and thoracic sections. The spinalis muscle group is the most medial of the erector spinae muscles and is comprised of a cervical and thoracic section (McKinley et al., 2015).

Functionally, the erector spinae muscles are grouped by region rather than distinct muscles: pars thoracis and pars lumborum. A fiber typing study by Sirca and Kostevc in 1985 found differences in the lumbar and thoracic sections of the erector spinae muscles with the lumbar section being equally mixed and the thoracic sections containing approximately 75% slow-twitch fibers. The pars thoracic components of these muscles have the greatest possible moment arm and therefore produce the greatest amount of extensor moment with a minimal compressive penalty to the spine (McGill, 2007). The line of action of the lumbar components of these muscles (iliocostalis lumborum pars lumborum and longissimus thoracic pars lumborum) are not parallel to the compressive axis of the spine but have a posterior and caudal orientation that causes them to generate posterior shear forces together with an extensor moment on the superior vertebrae (McGill, 2007). These posterior shear forces together support any anterior

reaction shear forces of the upper vertebrae that are produced as the upper body is flexed forward in a typical lifting posture (McGill, 2007). With lumbar flexion, these muscles lose their oblique line of action and reorient to the compressive axis of the spine (McGill, Hughson, and Parks, 2000) resulting in a flexed spine that is unable to resist damaging shear forces (McGill, 2007).

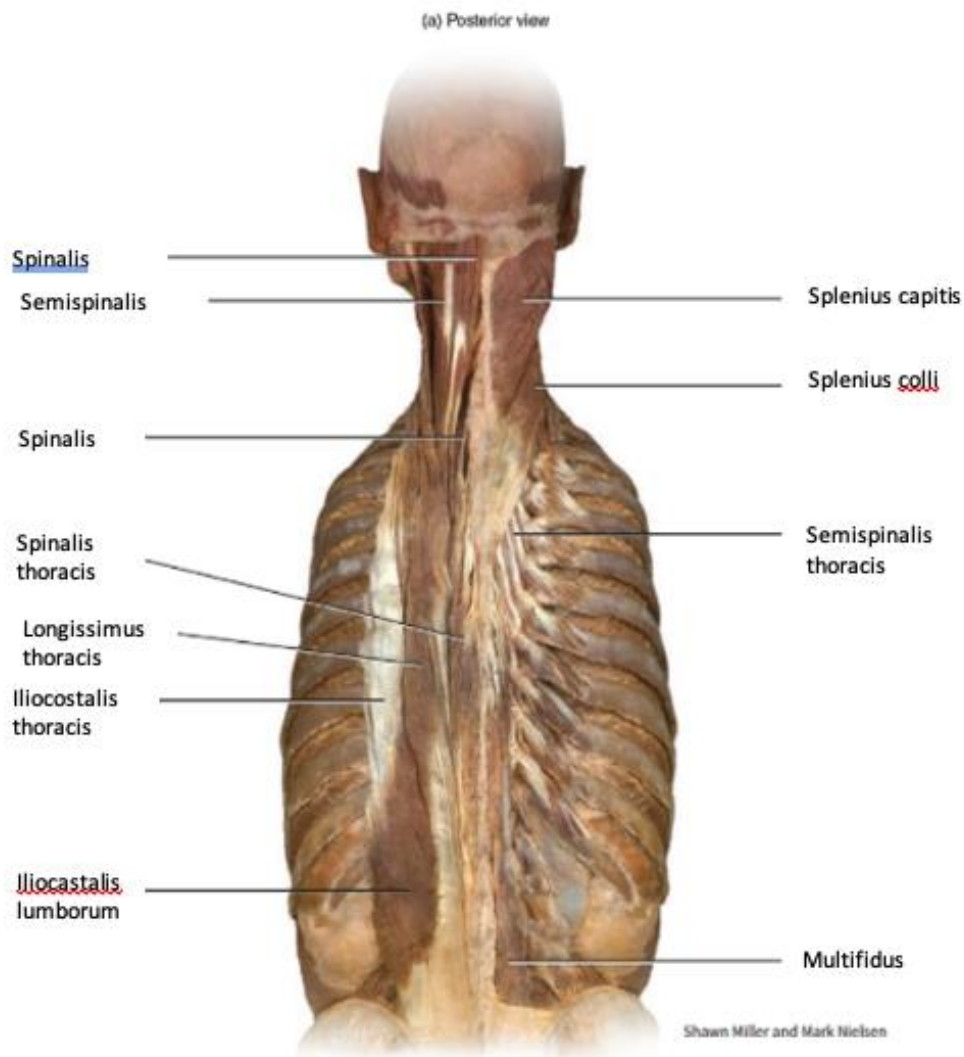


Figure 3.1 Muscles of the back that move the vertebral column. (Modified from Tortora, Gerard, J. and Mark T. Nielsen. (2021). *Principles of Human Anatomy*. Available from: WileyPLUS, (15th Edition). Wiley Global Education US; p.372. Permission for use pending).

The multifidus is a muscle that lies deep to the longissimus thoracis. The multifidus functions to extend the vertebral column and to rotate the vertebral column toward the opposite side (McKinley et al., 2015). The multifidus is a muscle that runs from the sacrum to the level of the second cervical vertebrae. The multifidus is segmented into several sections. In addition to extending the vertebral column, the multifidus maintains the lumbar curve (Tortora & Nielsen, 2021).

The quadratus lumborum is a muscle that is located in the lumbar region of the vertebral column. It originates on the iliac crest of the pelvis (ilium) and inserts on the transverse processes of the lumbar vertebrae and the twelfth rib (3D4Medical.com 2017, Essential Anatomy 5 app). When the quadratus lumborum muscles contract bilaterally, they extend the vertebral column (McKinley et al., 2015). When they contract unilaterally, they laterally flex the vertebral column (McKinley et al., 2015).

The latissimus dorsi is a broad triangular muscle located on the inferior part of the back (McKinley et al., 2015). The latissimus dorsi originates on the spinous processes of T7-T12, ribs 8-12, the iliac crest, and the thoracolumbar fascia and inserts on the intertubercular groove of the humerus (McKinley et al., 2015). As a result of its origin and insertion, the latissimus dorsi can generate a large extensor moment arm and often acts as a major stabilizer (McGill, 2007).

The psoas is a hip flexor. It originates on the transverse processes and bodies of the T12-L5 vertebrae, and it inserts on the lesser trochanter of the femur (McKinley et al., 2015). When activated, the psoas generates a lot of spinal compression and generates some shear stiffness to the lumbar motion segment (McGill, 2007). The psoas can be thought of as a spine stabilizer but only in the presence of significant hip flexor torque (McGill, 2007).

3.2 Muscles of the Abdominal Wall

The abdominal wall is comprised of four pairs of muscles: the external oblique, the internal oblique, the rectus abdominis, and the transversus abdominis. The muscles of the abdominal wall serve several functions, they flex and stabilize the vertebral column, they also laterally flex the vertebral column and compress the abdominal cavity (McKinley et al., 2015). The muscles of the abdominal wall work together but also independently (McGill, 2007). The most superficial of the abdominal muscles is the external oblique, deep to that is the internal oblique, followed by the rectus abdominis, and the deepest of the four muscles is the transversus abdominis.

The rectus abdominis is partitioned into sections and all the sections are activated at similar levels when flexor torque is generated (McGill, 2007). The oblique muscles can contribute to flexion torque, and via differential activation, they can create twisting torque (McGill, 2007). The obliques together with the transversus abdominis, abdominal fascia, and lumbodorsal fascia form a hoop around the spine which assists with spine stability (McGill, 2007).

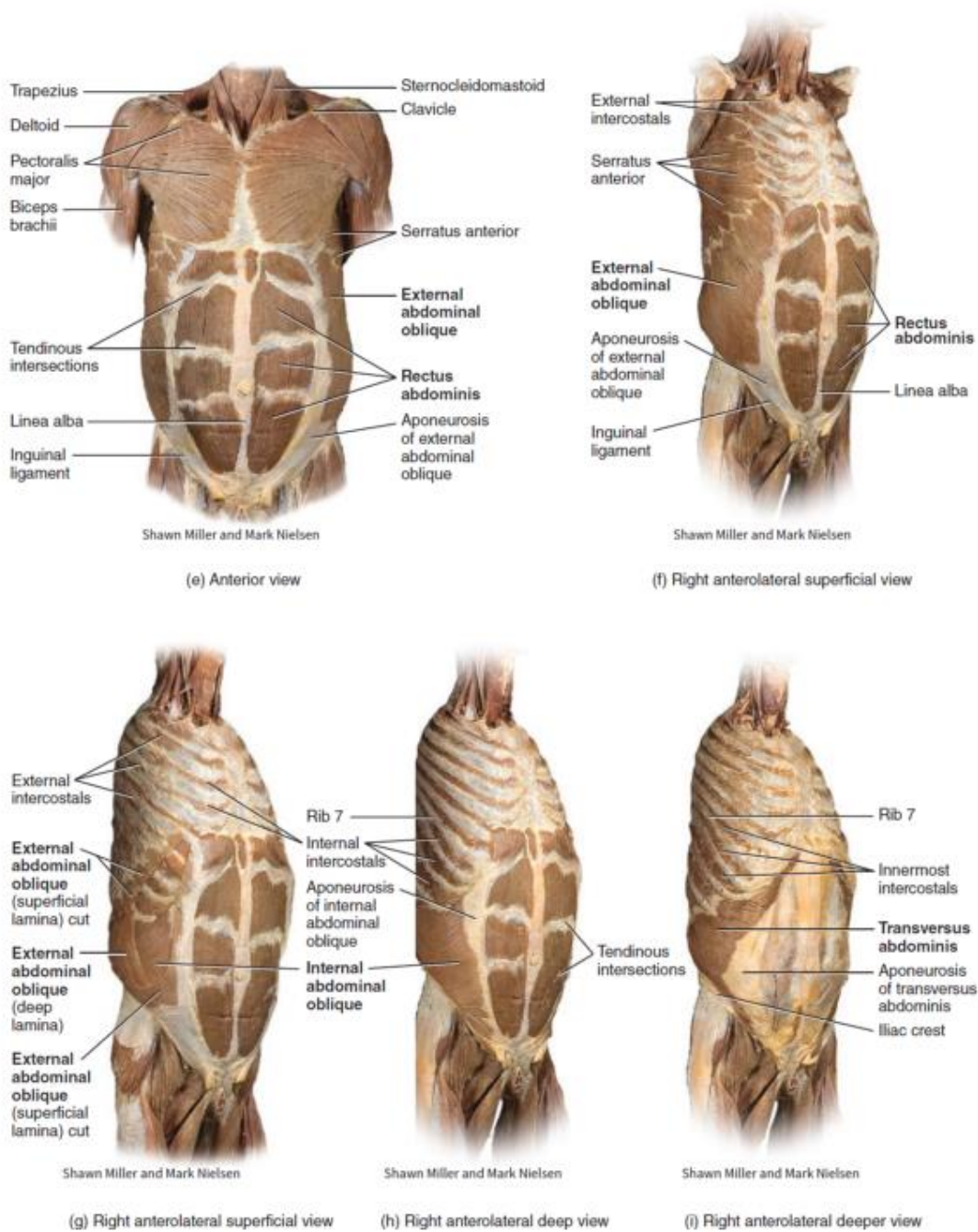


Figure 3.2 Muscles of the abdomen that protect abdominal viscera and move the vertebral column. (Modified from Tortora, Gerard, J. and Mark T. Nielsen. (2021). *Principles of Human Anatomy*. Available from: WileyPLUS, (15th Edition). Wiley Global Education US; p.376).

3.3 Major Muscles Attaching to the Pelvis

The gluteus maximus originates on the iliac crest, sacrum, and coccyx, and inserts on the iliotibial tract. The gluteus maximus is an extensor of the thigh and the torso (Tortora & Nielsen, 2021). The gluteus maximus is a critical muscle for standing and walking as its attachment to the iliotibial tracks helps to stabilize the knee in extension (Tortora & Nielsen, 2021).

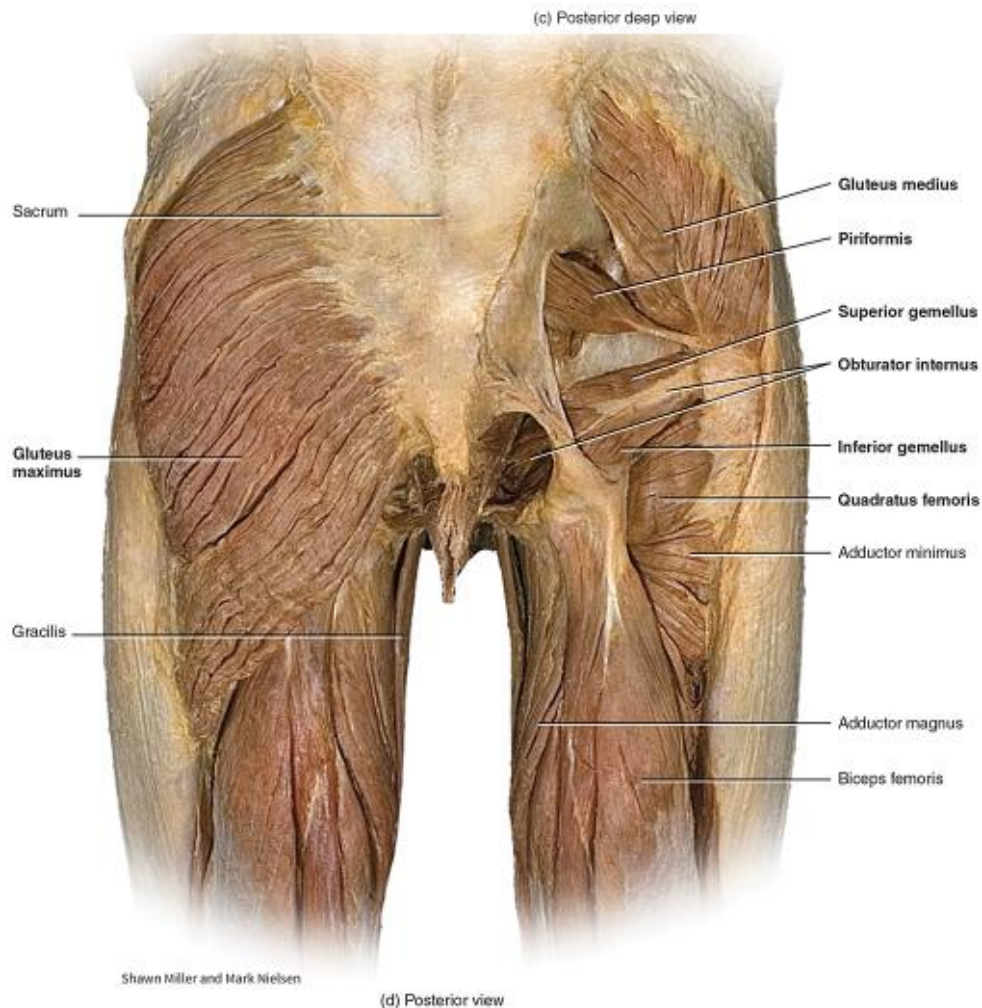


Figure 3.3 Muscles of the gluteal region that move the femur (thigh bone). (Modified from Tortora, Gerard, J. and Mark T. Nielsen. (2021). *Principles of Human Anatomy*. Available from: WileyPLUS, (15th Edition). Wiley Global Education US; p.420).

The hamstring muscle group is comprised of three muscles, the biceps femoris, semimembranosus, and semitendinosus. The hamstring muscles are located on the posterior compartment of the thigh. The biceps femoris is the most lateral of the hamstring muscles, and it is comprised of two heads. Medial to the biceps femoris is the semitendinosus, and medial to that is the semimembranosus. These muscles span both the hip and knee joints, and they function to flex the knee, and extend the hip (Tortora & Nielsen, 2021). The hamstring muscles share a common insertion at the ischial tuberosity of the pelvis.

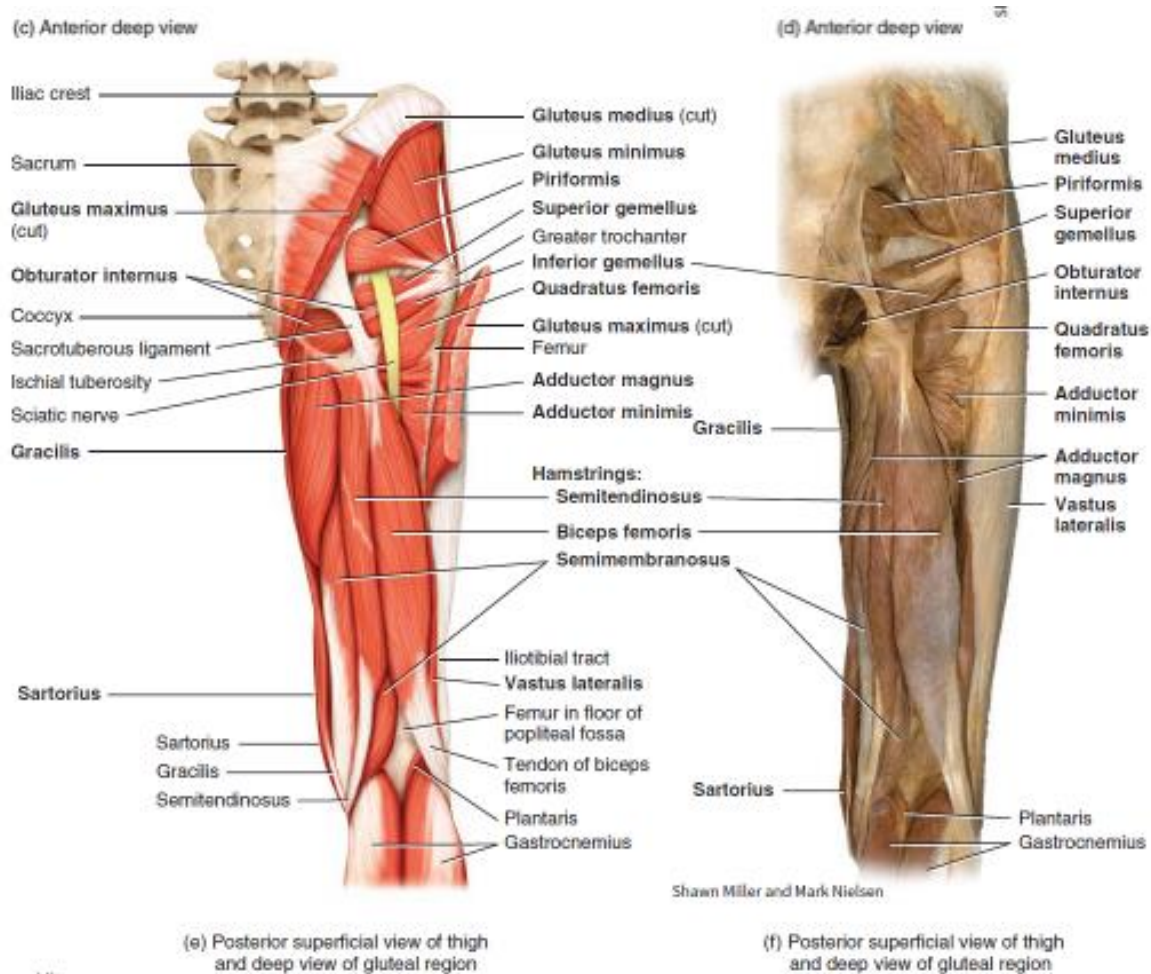


Figure 3.4 Muscles of the thigh that move the femur, tibia, and fibula. (Modified from Tortora, Gerard, J. and Mark T. Nielsen. (2021). *Principles of Human Anatomy*. Available from: WileyPLUS, (15th Edition). Wiley Global Education US; p.425).

3.4 Trunk Endurance: Biering-Sørensen Test

The Biering-Sørensen test is an isometric trunk extensor muscle endurance test. The Biering-Sørensen test is commonly used in research, clinical and athletic settings to assess the muscular endurance performance of the trunk muscles (Demoulin et al., 2016). Biering-Sørensen concluded that a shorter hold time during the test was predictive of the development of LBP within the next year for males (Biering-Sørensen, 1984). Many studies have demonstrated that individuals with a history of LBP had shorter holding times than participants without a history of LBP (Tekin et al., 2009, Keller, 2001). The Biering-Sørensen test has been found to have good predictive and discriminative ability regarding the presence and or development of LBP (Keller, 2001). Research has found that the Biering-Sørensen test produces reliable results when used to test both participants asymptomatic for non-specific LBP and participants with current or previous non-specific LBP (Keller, 2001).

In the Biering-Sørensen test protocol, participants lie prone with their buttocks and legs fixed on a couch or table using three wide canvas straps, arms folded across their chest and their anterior iliac crest positioned at the end of the couch (Biering-Sørensen, 1984). The participants are then asked to isometrically maintain their upper body in a horizontal position for as long as possible. When the participants can no longer hold the trunk in a horizontal position, the test ends and their hold time is recorded. In the original protocol by Biering-Sørensen in 1984, participants were asked to hold their trunk horizontally for up to 240 seconds. However, the participants being asked to hold the trunk horizontally until failure is common in research (Demoulin et al., 2016, Coorevits et al., 2008, Tekin et al., 2009).

Although the Biering-Sørensen test is often referred to as a test of endurance for the spinal extensor muscles, research has found that the hip extensor muscles also contribute to

holding the trunk segment horizontally during the test (Demoulin et al., 2016). Effectively, the test should be referred to as a trunk extensor test (Demoulin et al., 2016). Coorevits and colleagues (2008) used electromyography (EMG) normalized median frequency slopes to assess muscular fatigue of eight back and hip extensor muscles during the Biering-Sørensen test. They found evidence of a decline in normalized median frequency slope of all eight muscles they analyzed, the latissimus dorsi, longissimus thoracis pars thoracis, longissimus thoracis pars lumborum, iliocostalis lumborum pars thoracis, iliocostalis lumborum pars lumborum, multifidus, gluteus maximus, and biceps femoris (Coorevits et al., 2008). A decline in the median frequency indicates muscle fatigue, which further supports that the Biering-Sørensen test challenges trunk extensor muscles, not just spinal extensor muscles.

As a self-regulated test for muscular endurance, the endurance time during the Biering-Sørensen test can be affected by other factors such as motivation, tolerance of the discomfort of fatiguing muscles, pain, and fear of pain (Mannion et al., 2011). Using a regression equation that linked endurance time to EMG activity changes, Mannion and colleagues found that a participant's failure to reach the predicted endurance time was significantly related to a greater level of psychological disturbance and more negative feedback beliefs as determined using questionnaire assessments (Mannion et al., 2011).

3.5 Trunk Endurance: Side Plank Test

The side plank test, also known as the side bridge test, is an isometric trunk exercise commonly used to evaluate trunk muscle endurance. The side plank test is challenging to the lateral trunk muscles such as the quadratus lumborum, the muscles of the abdominal wall, the external abdominal oblique, internal abdominal oblique, transversus abdominis, and rectus abdominis (McGill, 1999). The side plank test is typically conducted with the participant lying

on their side, with the top foot placed in front of the lower foot. The upper body is supported with one elbow, while the hips are lifted off the mat. The free arm is placed on the opposite shoulder to aid in stabilizing. The participants are asked to maintain a straight line from the upper body to the feet, with the test ending when the participant can no longer hold this position (McGill, 1999). The side plank test requires the trunk muscles closest to the floor to be very active, with the other half of the trunk much less active, resulting in a reduced total spine load (McGill, 2009), which increases the spine safety of this test. In 1999, Stuart M. McGill obtained reliability coefficients of 0.99 for the side plank test for both the left and right sides, meaning that the test is highly precise.

Reduced isometric trunk muscle endurance has been found to be a significant predictor for men developing LBP, as well as good isometric endurance of back muscles being preventative of first-time LBP development (Biering-Sørensen, 1984). It has been demonstrated that both male and female patients with reduced trunk endurance were more likely to report non-specific low back pain in the following year than patients with greater trunk endurance (Latimer et al., 1999). Research has found that people with poor trunk muscle endurance may have a low muscle fatigue threshold, which may result in increased loading of the passive low back structures (Durrall et al, 2009).

Standards of side plank endurance times have been established in the literature with various populations. Amongst a university community with a mean age of 23 years, McGill (1999) obtained a mean right side plank time of 94 seconds for males, and 72 seconds for females. As for the left side plank, the males obtained a mean of 97 seconds, and the females obtained a mean of 77 seconds. Amongst a Serbian high school community, Dejanovic and

Colleagues (2013) obtained a mean score of 101.7 seconds and 97.4 seconds for right side plank and left side plank respectively for 18-year-old males. For 18-year-old females they obtained mean scores of 68.8 seconds and 69 seconds for right side plank and left side plank respectively. In a study by Evans and Colleagues (2007), mean core endurance scores were obtained for elite athletes. The athletes had a mean age of 21.3. Male athletes had a mean right-side plank of 126.6 seconds, and a left side plank of 121.2 seconds. Female athletes had a mean score of 91.1 seconds on right side plank and 91.4 seconds on the left side plank. The difference between the scores of isometric core exercise endurance times for athletes and non-athlete populations prompts us to investigate the relationship between physical activity, and isometric core exercise endurance time.

3.6 Quantifying Physical Activity

Self-reported measures such as questionnaires and diaries have been traditionally used to estimate physical activity. However, questionnaires and diaries are prone to adherence problems and recall bias (Zhuo & Macedo, 2021). Self-report measures can also be influenced by social desirability (Zandwijk et al., 2015), which can result in over-reporting of physical activity among participants (Anderson et al., 2019). Accelerometry provides many advantages over self-reported data when there is a need to accurately obtain measures of physical activity. There are several different questionnaires that have been validated for specific populations, and there are many wearable devices capable of detecting and recording measures of physical activity. This section provides pertinent details on the questionnaire and device used to obtain physical activity information in this study.

The Modifiable Activity Questionnaire (MAQ) was developed by Kriska and colleagues (1997) to assess both historical and current physical activity. The MAQ has three main parts that

can be considered individually and completed independently: leisure activity, general, and occupational sections (Gabriel et al., 2010). The questionnaire can be used to quantify the total amount of time in activity as well as the MET-h/week. One MET is defined as the amount of oxygen consumed while sitting at rest, and it can be used to express the energy cost of physical activity as a multiple of the resting metabolic rate (Jetté et al., 1990). As METs are often a calculated output from objectively obtained measures of physical activity, they can be compared to the self-reported METs from the MAQ. The MAQ has been proven to be very reliable and moderately valid in both adult and adolescent populations (Momenan et al., 2012, Delshad et al., 2015). The MAQ was used in this study to obtain self-reported physical activity data for the participants.

Accelerometry is the use of acceleration-sensitive devices that can be used as activity monitors to objectively record human movement or lack thereof. Accelerometry-based activity monitors are typically small, battery-powered instruments that provide quantitative measurements of physical activity for days at a time before needing to be recharged (Mathie et al., 2004). Most modern accelerometers respond to both acceleration due to gravity and acceleration due to body movement in three planes, enabling them to measure postural orientations and body movement (Mathie et al., 2004). Accelerometers provide objective assessments of physical activity regarding intensity, duration, and frequency of activity (Emery et al., 2010).

Modern research grade activity monitors measure acceleration in three planes, vertical, anterior-posterior, and medial-lateral (Emery et al., 2010). These activity monitors are often worn on the hip or the wrist. However, hip-worn accelerometers are most used in research (Ward

et al., 2005), as they are thought to provide a better assessment of center of mass acceleration (Kerr et al., 2017). The typical unit of measurement for activity monitors are counts. Any movement/activity that causes the acceleration signal to exceed a set threshold on the activity monitor is quantified as one count (ActiGraph, 2009). To accurately estimate habitual physical activity amongst adults, at least three to five days of monitoring are required (Ward et al., 2005).

While activity monitors offer an objective means of measuring physical activity, they are not without limitations. These limitations include the inability to provide context for recorded activities, the inability to directly measuring energy expenditure, the potential to miss upper body movements when worn on the waist, and the inability to distinguish between load-bearing and non-load-bearing activities (Emery et al., 2010). Furthermore, the accuracy of the collected data depends on the subject wearing the monitor as instructed. Despite these challenges, activity monitors remain valuable tools for providing an objective estimate of physical activity.

3.7 Physical Activity & LBP

Research has repeatedly linked physical activity to numerous health benefits. Under the Canadian 24-Hour Movement Guidelines for adults aged 18-64 years by the Canadian Society for Exercise Physiology (CSEP), moderate to vigorous aerobic physical activities accumulating to at least 150 minutes per week is recommended, with any progress toward this 150-minute recommendation resulting in some health benefits (CSEP Guidelines, 2020). Physical activity has been found to be preventative of many chronic diseases, including diabetes mellitus, hypertension, bone and joint diseases and depression (Warburton et al., 2006). Maintaining a physically active lifestyle is also recommended in clinical guidelines to help manage LBP (National Guideline Centre, 2016). Physical activity has been shown to increase aerobic capacity and muscular strength which are beneficial for patients with chronic LBP as these facilitate their

ability to complete their activities of daily living (Gordon & Bloxham, 2016). There is also evidence in research suggesting that both the high and low extremes of physical activity are associated with a higher prevalence of LBP (Heneweer et al., 2011).

Despite the many benefits of physical activity regarding the prevention and rehabilitation of LBP (Hashimoto et al., 2018, Darlow et al., 2016), there have been systematic reviews suggesting that there is no association between physical activity level and incidence of LBP (Hendrick et al., 2011). Some of these reviews have utilized self-reported measures such as questionnaires to quantify physical activity. Quantifying physical activity through questionnaires has been documented to be susceptible to recall bias and the under and overestimation of activity due to social desirability (Zhuo & Macedo, 2021, Zandwijk, 2015, Anderson et al., 2019).

A review that included studies that employed objective measurements of habitual physical activity (Overas et al., 2020) found a weak association between physical activity and the development of LBP. The findings from this systematic review conducted by Overas and colleagues were derived from studies that analyzed the difference in physical activity among blue-collared workers. A study employing triaxial accelerometers to investigate physical activity in patients with chronic LBP in comparison with healthy gender and age-matched controls found no difference in the mean level of daily physical activity between the two groups (Verbunt et al., 2001). However, in the study by Verbunt and colleagues, the participants had a mean age of 45 years, and the affected group had a mean duration of 12 years suffering from nonspecific LBP. It was important to investigate whether this finding would be consistent with an undergraduate student population. The studies previously mentioned did not take measures of trunk endurance for the participants. Therefore, in this study, accelerometry will be used to further investigate and

assess the relationship between physical activity, trunk endurance, and LBP in an undergraduate student demographic.

4. Methods

4.1 Overview

The data collection for this study was a part of a larger project that consisted of one, two-hour session in the Drake Biomechanics Lab. Only the methods pertinent to this study are detailed in this thesis, with this section providing an overview of the collection. After participants completed the informed consent form, the age, weight, and height of all participants were collected and recorded. Measures of trunk muscle endurance tests, Biering-Sørensen and the side planks were then completed in a random order. The participants then completed the additional movement assessment tasks for the larger study. Following the collection, participants completed the questionnaires and were given an activity monitor to wear for a seven-day period. Following the seven-day collection period, the activity monitors were returned, and the data from each activity monitor was extracted and processed. This research received ethics review and approval (E2019-240) by the Human Participants Review Sub-Committee, York University's Ethics Review Board and conforms to the standards of the Canadian Tri-Council Research Ethics guidelines. All participants signed an informed consent form prior to their participation in the study.

4.2 Recruitment & Participants

Participants were recruited from the general York University student population, primarily through the Kinesiology Undergraduate Research Experience (KURE) and

Undergraduate Psychology Research Pool (UPRP) groups. Recruitment was limited to current undergraduate students to ensure that the lifestyle of the participants would be as similar as possible. Before COVID shutdowns terminated the larger study, a total of 163 participants were recruited: 59 male and 104 female. Of the 163 participants, only 78 participants met the minimum activity monitor wear time required for analysis. Of these 78 participants, 15 participants were in the LBP group, and 63 in the control group. The LBP group was restricted to participants who had experienced LBP severe enough to require medical attention. Participants over the age of 50 years old were excluded from the analysis. The participants in the LBP group were matched to the participants in the control group by age, height, and weight. After the exclusion criterium mentioned in this section were applied, 13 participants were remaining in the LBP group and the control group.

4.3 Modified Biering-Sørensen Test Procedure

The Biering-Sørensen trunk extensor test was performed with each participant in a prone position with their anterior-superior iliac spine aligned with the edge of the massage table. The participants supported their upper bodies with their hands on a chair placed in front of them, immediately before and after the test. With the investigator holding the participant at the mid-calf level, anchoring the participant, the participants then lifted their upper body to horizontal. With their arms folded across their chest, the participants were then asked to isometrically maintain their upper body in a horizontal position for as long as possible. When the participants could no longer hold the trunk in a horizontal position, the test ended, and their hold time was recorded. The test could also end upon reaching a maximum endurance time of 120 seconds. This fixed duration limit was selected to not unduly fatigue the participants during all the measures of the larger study, and to enable control of the data collection session duration. In this

protocol, the participants were anchored by being held at the mid-calf level by the investigator as opposed to being anchored using three wide canvas straps as in the Biering-Sørensen, 1999 protocol. As a result, this test is referred to as a modified Biering-Sørensen endurance test.



Figure 4.1 The Biering-Sørensen test position used in this study. A chair was placed at a safe location in front of the participant which served to provide them with more support to get in and out of the testing position.

4.4 Side-Plank Test Procedure

The side plank test was conducted with the participants lying on their side, with the top foot placed in front of the lower foot. The upper body was supported with one elbow, while the hips were lifted off the mat. The free arm was placed on the opposite shoulder to aid in stabilizing. The participants were to maintain a straight line from the upper body to the feet, with the test ending when the participant was no longer able to hold this position. The test was also

concluded upon the participants reaching a maximum endurance time of 60 seconds. The side plank test was conducted on both the right and left sides for the participants.



Figure 4.2 Side-plank test position used in this study.

4.5 Questionnaires

Participants completed the leisure activity section of the MAQ and a custom questionnaire that included questions on time spent sitting, standing, stretching habits, and previous injuries (see Appendix). Leisure time physical activity is defined as physical activity performed during exercise, recreation, or any time other than those associated with one's regular occupation, housework, or transportation (Fong, 2021). Effectively, leisure time physical activity is physical activity that an individual performs outside of work, chores, and commuting. The leisure activity section of the MAQ allowed us to obtain a self-reported measure of leisure time physical activity for each participant.

Based on the responses to the previous injury portion of the questionnaire, the participants who had experienced LBP severe enough to require medical attention were classified into the LBP group. The participants with no previous history of LBP requiring medical attention were classified into the control group for the purpose of this study. The MAQ was then analyzed to obtain the self-reported activity measures for the participants.

4.6 Activity Monitor

Activity monitoring devices containing triaxial accelerometers were used to quantify the physical activity levels of participants. The activity monitor used for this study was the ActiGraph GT9X Link (Actigraph™, Pensacola, FL, USA) and is shown in Figure 4.3. This device was selected due to its durability, relatively low cost, and range of information it can provide. The ActiGraph GT9X Link is an integrated inertial measurement unit that contains a gyroscope, a magnetometer, and secondary 3-axis accelerometer sensors, enabling its use for advanced applications (Actigraphcorp.com). The activity monitors were worn on the participant's right hip for seven consecutive days during waking hours.

The device collected raw acceleration data (sampled at 30Hz) which it converted using proprietary algorithms into activity measures including: activity counts, steps, METs, kilocalories (Kcals), physical activity intensity, activity bouts, sedentary bouts, body position, and sleep-related measures (when worn during sleep). Sedentary behavior refers to activities that do not increase energy expenditure substantially above the resting level and includes activities such as sleeping, sitting, and lying down (Pate et al., 2008). The activity monitor calculated both the number, duration, and total percentage of wear-time in a sedentary state.

Physical activity intensities were classified based on the counts per minute (CPM) recorded by the activity monitor. A greater CPM corresponds with an increased intensity of movement and physical activity. These intensities were categorized into four distinct ranges by the ActiLife software (Actigraph, 2020). Sedentary activity was defined as having a CPM range of 0 to 99, light physical activity was identified by a CPM range of 100 to 1951, moderate physical activity fell within the CPM range of 1952 to 5724, and vigorous physical activity was characterized by a CPM range of 5725 to 9498.



Figure 4.3 The ActiGraph GT9X Link (ActiGraph™, Pensacola, FL, USA) was the activity monitoring device that participants were directed to wear on their right hip for seven consecutive days during waking hours.



Figure 4.4 The ActiGraph GT9X Link activity monitors were strapped onto the participant's right hip with an adjustable elastic belt and participants were instructed to wear the activity monitor as such during waking hours for the duration of the seven-day collection period.

4.7 Data Processing and Statistical Analyses

The Biering-Sørensen and the side-plank trunk endurance times were recorded in seconds during the study and required no additional processing. For the MAQ questionnaire, the frequency and duration of various physical activities were recorded based on participants' reports over the past year. Participants listed each activity they engaged in more than ten times annually, noting the monthly frequency and average duration per session. To calculate total physical activity time, the monthly frequency was multiplied by the average duration for each activity. The sum of these products provided an estimate of the participants' self-reported total hours spent in physical activity per week, which is how the MAQ scores were calculated.

ActiLife 6 software (Version 6.13.4, ActiGraph™, Pensacola, FL, USA) was used to calibrate and to process the data from the activity monitors. The algorithm used to process the activity monitor data was the algorithm published by Leena Choi and Colleagues in 2012. A

minimum of three days of wear time was required per participant. Participants who wore the activity monitor for less than three days were omitted from the analysis. Using ActiLife 6, the clinical reports generated by the software were exported for each of the participants, and the calculated estimates of energy expenditure, physical activity intensity and duration, and METs were obtained.

Wilcoxon Ranked Sum Tests were conducted to analyze the difference in the physical activity, and trunk endurance measures between the LBP and control groups. A logistic regression was used to analyze the interaction between the prevalence of LBP with measures of trunk endurance and physical activity. The predictor variables were the duration of the Biering-Sørensen test and the average daily calories recorded. These predictor variables were strategically selected due to the Biering-Sørensen test's robust capability in estimating trunk endurance and the inherent correlation between the recorded average daily caloric expenditure and participants' physical activity levels. Logistic regressions were not run on other physical activity measures due to the smaller range of variation of those values in comparison to the average daily calories recorded, which would result in calculation difficulties. R Studio was used to conduct these analyses

5. Results

The results of this study are presented in this section first by differences between the LBP and control groups for trunk endurance and physical activity (Wilcoxon Ranked Sum Test outcomes), and then as a link between endurance test performance and energy expenditure (logistic regression).

Thirteen participants from the large control group were matched to the 13 LBP participants for sex, age, height, and weight (Table 5.1). There were no potential duplicate control matches for any given LBP participant. See Methods Section titled ‘*Recruitment and Participants*’ for details on how the 13 pairs were identified from the total of 163 participants from the larger study.

Table 5.1 Thirteen participants from each of the control and LBP groups were matched for sex, age, height and weight ($P > 0.670$). Each group had 10F and 3M.

Group	Age	Height	Weight	BMI
LBP	22.2y (7.2)	1.68m (0.09)	67.0kg (17.2)	23.6 (4.2)
Control	22.8y (7.2)	1.69m (0.08)	67.1kg (10.4)	23.5 (2.9)

5.1 Trunk Muscle Endurance

For the modified Biering-Sørensen test, the LBP group had a lower mean (SD) hold time than the control group (* $p=0.037$), indicating that the LBP group had less back extension endurance (Figure 5.2). The LBP group’s average time was 106.23s (± 24.45) with only 69.2% (9/13) of the group attaining the full endurance time of 120s. Whereas, the control group demonstrated greater back extension endurance with an average hold time of 120s (± 0) with 100% (13/13) of the group attaining the full Biering-Sørensen test time.

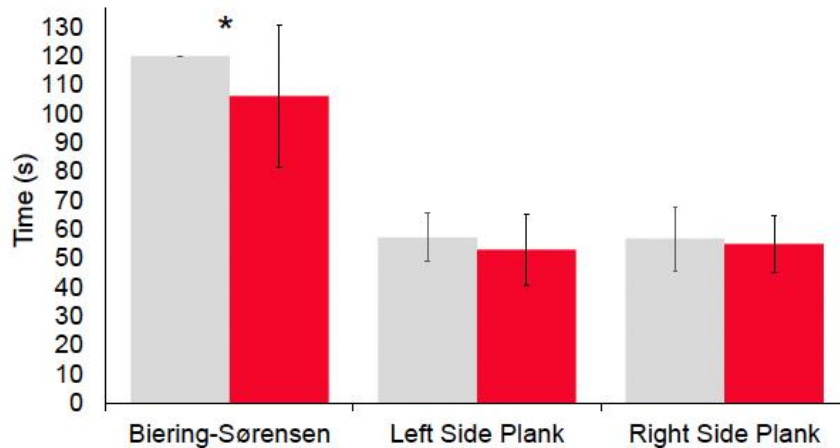


Figure 5.2 LBP group (red) had 12% less trunk extensor muscle endurance (Biering-Sørensen) than the control group (grey; * $p=0.037$). The groups had similar lateral trunk muscle endurance (bilateral side planks; $p>0.367$).

The LBP and control groups performed similarly on the left and right plank tests ($p>0.367$) as shown in Figure 2.0 above. 69.2% (9/13) of the LBP group attained the maximum endurance time of 60s for the left plank test, compared to 84.6% (11/13) of the control group. The mean (SD) endurance time for the left plank test was 53.07 (± 12.39) seconds for the LBP group and 57.31 (± 8.32) seconds for the control group. For the right plank test, 76.92% (10/13) of the participants in the LBP group attained the maximum endurance time compared to 92.3% (12/13) of the control group. The mean (SD) endurance time for the right plank test was 55.07 (± 9.79) seconds for the LBP group and 56.92 (± 11.09) seconds for the control groups.

5.2 Level of Physical Activity: Light, Moderate, Vigorous, and Sedentary

The LBP group spent $0.22 \pm 0.058\%$ of their wear time in light physical activity, while the control group spent $0.24\% \pm 0.057$ (Figure 5.3). The LBP group spent $0.032\% \pm 0.016$ of their wear time in moderate physical activity, in contrast to the control group, which spent $0.042\% \pm 0.018$ in moderate physical activity. When the percent wear time spent in moderate to vigorous

physical activity (MVPA) was analyzed, the control group again attained a higher mean, although the difference was not found to be statistically significant ($p=0.0768$). The LBP group spent 0.032% (± 0.0168) of their wear time in MVPA, compared to 0.045% (± 0.021) for the control group.

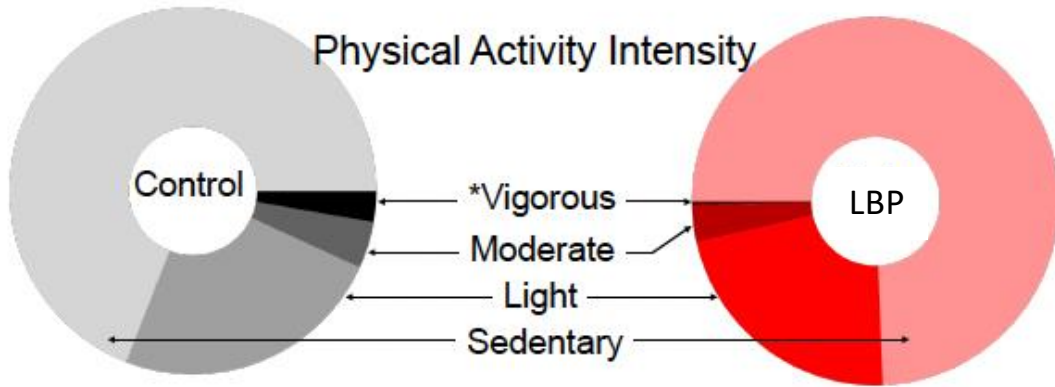


Figure 5.3 LBP group (red) had less percent vigorous activity ($*p=0.036$) than the control group (grey) but were similar for all other intensities (percent sedentary, light, moderate activity; $p > 0.101$).

A statistically significant difference was found when the percent time in vigorous physical activity was analyzed ($*p=0.0361$). The LBP group spent 0.000385% ± 0.00058 of their wear time in vigorous physical activity, whereas the control group spent 0.0028% ± 0.004 of their wear time in vigorous physical activity. The mean (SD) steps per minute counts were 6.69 (± 2.1) and 8.55 (± 3.02) for the LBP group and control group, respectively ($p=0.0684$).

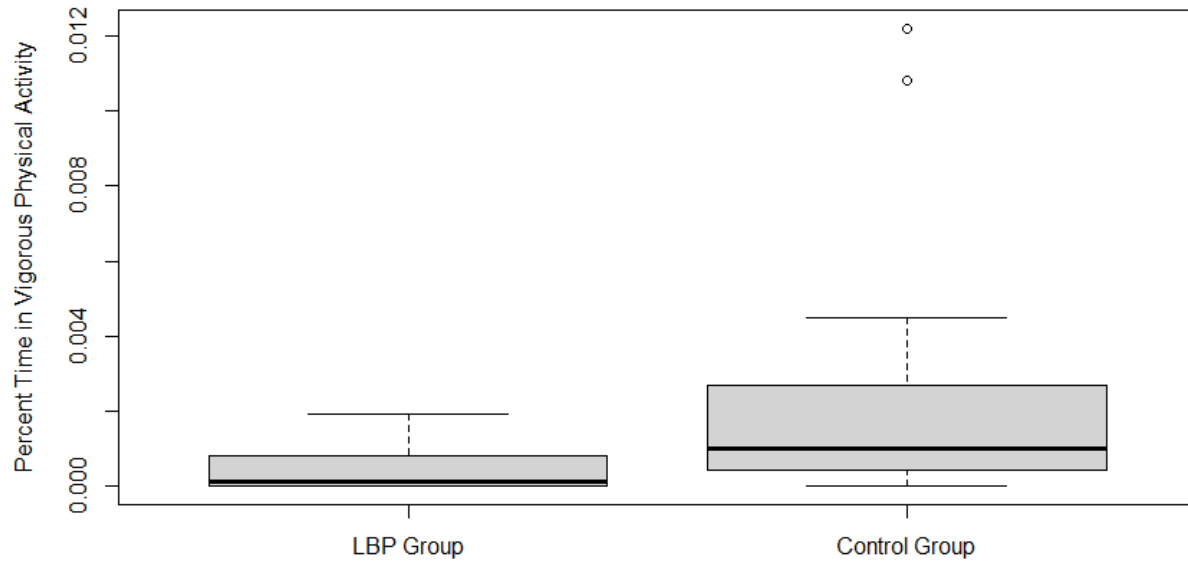


Figure 5.4 Boxplot to compare the percent time in vigorous physical activity recorded by the activity monitors between the LBP and control groups. The mean (SD) for the LBP group was 0.0003(0.0005) and 0.0028(0.0041) for the control group. The control group spent a greater percentage of time in vigorous physical activity than the LBP group (*p=0.036).

The average length of sedentary bouts for the LBP group was 38.3 minutes (± 21.65) and 32.9 minutes (± 21.31) for the control group ($p=0.7194$). The average number of sedentary bouts per day for the LBP group was 557 (± 234.11) and 450.6 (± 218.11) for the control group. This means that 74.6% (± 0.06) of the LBP groups' wear time was spent in a sedentary activity state, compared to 70.8% (± 0.06) for the control group (Figure 5.5).

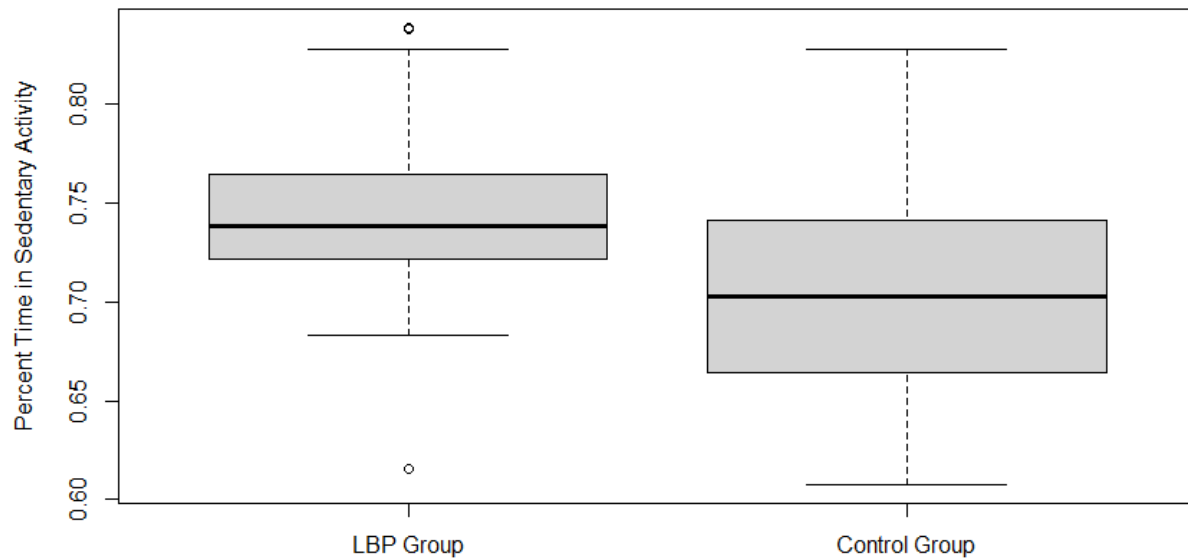


Figure 5.5 Boxplot showing the greater percent time the LBP group spent in sedentary activity compared to the control group. The mean (SD) for the LBP group was 0.746% (0.06) and 0.708% (0.07) for the control group.

5.3 Energy Expenditure

On average, the LBP group expended 346.56 (± 183.93) calories per day, whereas the control group expended 379.66 (± 109.17) calories daily ($p=0.2869$) as shown in Figure 5.6. The average metabolic rate in METs during the wear-time was 1.128 (± 0.085) for the LBP group. The control group had an average metabolic rate of 1.180 (± 0.084) METs during their wear time. The difference in maximum metabolic rate measured in METs was found to be statistically significant between the LBP and control groups ($p=0.03383$) and is shown in Figure 5.7. The maximum recorded METs for the LBP group was 1.348 (± 0.243), whereas the control group was recorded to have a max METs of 1.448 (± 0.120).

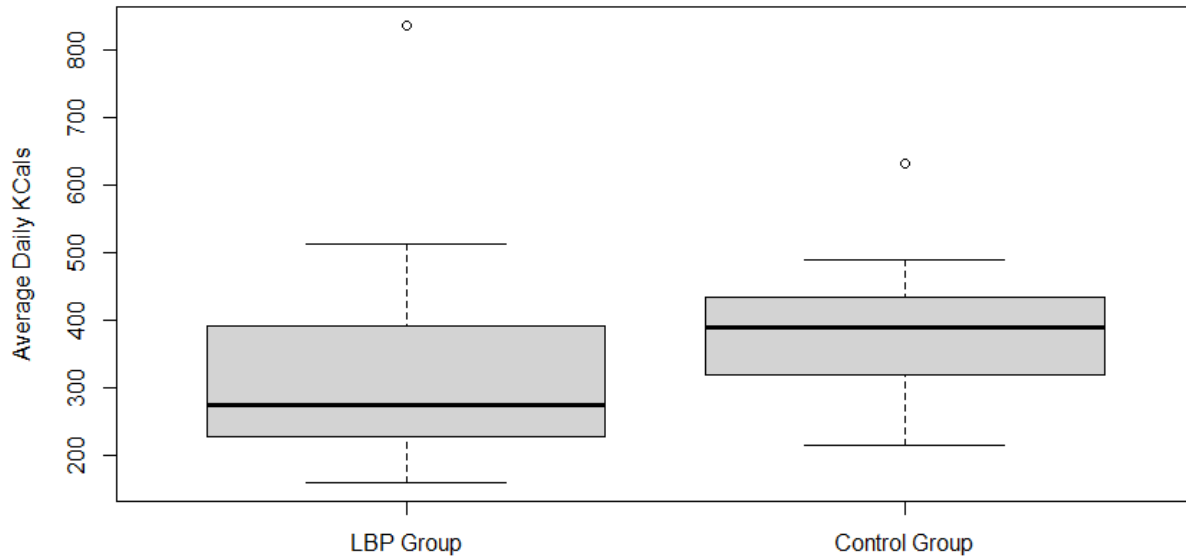


Figure 5.6 Boxplot to compare the average Kcals (calories) recorded per day between the LBP and control groups. The mean (SD) for the LBP group was 347Kcals (183.94), and 380Kcals (109.17) for the control group.

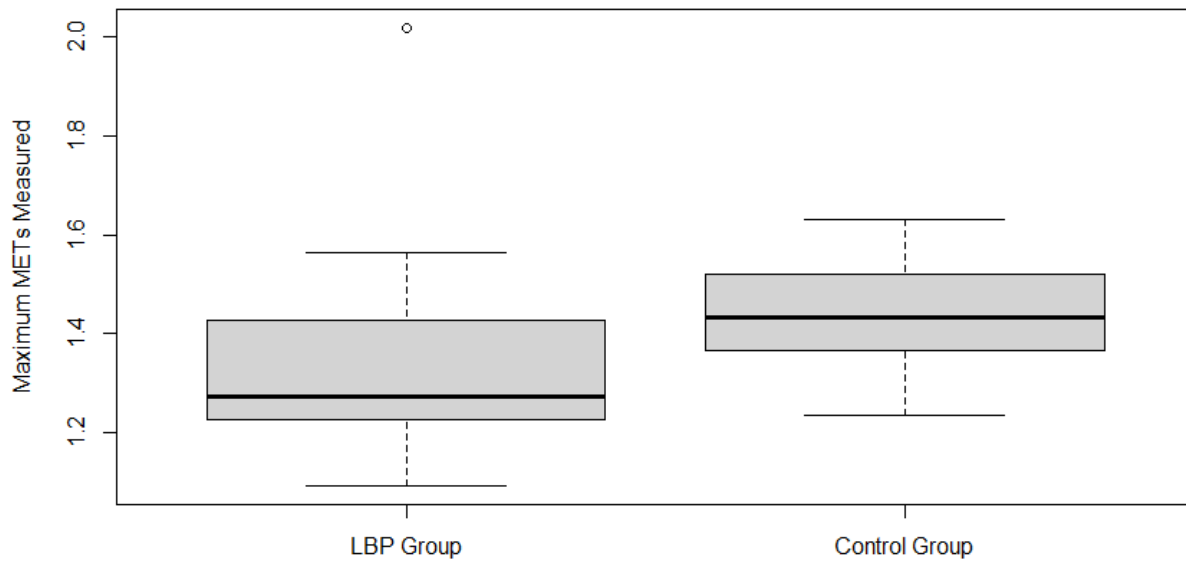


Figure 5.7 Boxplot to compare the maximum METs recorded between the LBP and control groups. The mean (SD) for the LBP group was 1.35(0.24) and 1.45(0.12) for the control group. The control group recorded greater maximum METs than the LBP group (*p=0.03).

5.4 Self-Reported Physical Activity

For the MAQ, one participant in the control group did not complete the MAQ question on the questionnaire. For these analyses, the MAQ scores from 13 participants in the LBP group were compared to the scores of the 12 participants in the control group. Recall, the MAQ was used to estimate the average amount of weekly leisure activity time during the past year. The LBP group reported a mean of 9 hours of leisure activity per week (± 6.5). The control group reported a mean of 7.9 hours of leisure activity per week (± 6.4). This result is not congruent with the rest of the objectively quantified results as all other activity variables were greater for the control group, except the sedentary behaviour variables which were greater for the LBP group (Table 5.8).

Table 5.8 Nineteen variables were compared between LBP and control groups: three from the endurance tests; 15 from the activity monitors; and one from the questionnaire. Wilcoxon Ranked Sum tests were conducted and statistically significant differences were found for the Biering-Sørensen test, maximum METs, and percent time spent in vigorous physical activity. Statistically significant values are bolded and shaded.

Test/Variable	LBP Group		Control Group		p-value
	mean	SD	mean	SD	
Biering-Sørensen(s)	106	24.45	120	0.00	0.04
Left Plank(s)	53.1	12.39	57.3	8.32	0.37
Right Plank(s)	55.1	9.79	56.9	11.09	0.37
Maximum Kcals	29.4	17.25	34.1	10.70	0.19
Minimum Kcals	6.2	6.27	4.77	4.00	0.72
Average Kcals Daily	347	183.94	380	109.17	0.29
Maximum Mets	1.35	0.24	1.45	0.12	0.03
Minimum Mets	1.04	0.05	1.04	0.06	0.54
METs	1.13	0.09	1.18	0.08	0.06

Average Length of Sedentary Bouts(min)	38.3	21.65	32.9	21.31	0.72
Average Number of Sedentary Bouts	557	234.11	451	218.12	0.11
Percent Time in Sedentary Activity	0.746	0.06	0.708	0.07	0.10
Percent Time in Light Activity	0.22	0.06	0.25	0.06	0.20
Percent Time in Moderate Activity	0.03	0.02	0.04	0.02	0.12
Percent Time in Vigorous Activity	0.0003	0.0005	0.0028	0.0041	0.036
Percent Time in MVPA	0.03	0.02	0.05	0.02	0.08
Average Time in MVPA(min)	29.8	14.11	35	13.81	0.26
Steps Per Minute	6.69	2.16	8.55	3.03	0.07
MAQ Scores(min of PA/wk)	9.01	6.55	7.92	6.42	0.73

5.5 Relationship Between LBP, Endurance and Physical Activity

A logistic regression analysis was performed to examine the influence of trunk muscle extension endurance time (quantified through the modified Biering-Sørensen test duration) and physical activity (using the average daily caloric expenditure) on the prevalence of LBP. A longer modified Biering-Sørensen endurance time was associated with a slight decrease in the probability of LBP (Table 5.9). Additionally, an increased average daily caloric expenditure was correlated with a diminished likelihood of LBP, evidenced by an odds ratio of 0.987. The importance of this influence is underscored by a statistical significance p-value of 0.036.

Table 5.9 Logistic regression, looking at the completion of the Biering-Sørensen test, and the average Kcals expended daily, to predict the occurrence of LBP. These findings demonstrate that a greater modified Biering-Sørensen endurance time was associated with a decreased probability of LBP and an increased average daily caloric expenditure associated with a decreased probability of LBP.

	Odds Ratio	Std. Error	Lower CI	Upper CI	p-value
Modified Biering-Sørensen Test	0.131	351.8	NA	28.316	0.995
Average Kcals Daily	0.987	0.006	-0.0286	-0.003	0.036*

6. Discussion

6.1 Trunk Muscle Endurance

The control group obtained a greater mean trunk endurance time on all the measures of trunk endurance, with only the Biering-Sørensen test reaching significance. Despite the Biering-Sørensen test not being administered to failure, the control group outperformed the LBP group on this test which is consistent with previous literature (Tekin et al., 2009, Keller 2001). Again, 100% (13/13) of the control group reached the maximum endurance time compared to 69.2% (9/13) of the LBP group. While the maximum endurance time for the Biering-Sørensen test was limited to 120s, differences between the two groups were still detected.

The control groups obtained slightly greater mean hold times for both the left and right-side plank tests. However, these differences were slight and not statistically significant. It is possible that the minor differences observed between the two groups were due to the short maximum endurance times. The conclusion of this study is consistent with the literature;

however, the maximum hold times fell short with what is commonly used in research. Several studies required participants to hold the side plank positions to failure (McGill 1999, Evans et al., 2007, Durall et al., 2009, Frost et al., 2013, Correia 2016). The vast majority of the participants in both the LBP and control groups attained the maximum endurance time for the side planks. In the LBP group, 69.2% of the participants reached the maximum endurance time for the left-plank and 76.9% of the participants reached the maximum endurance time for the right-plank. Thus, it is likely that the hold time of 60 seconds precluded the unearthing of the true differences between these groups due to a ceiling effect.

6.2 Physical Activity Measures

Activity monitors were used to obtain objective measures of physical activity. For the purposes of this study, the 7-day activity monitor protocol was ideal as three to five days of monitoring is recommended in the literature (Ward et al., 2005). This helped to maximize the amount of participants who would reach the minimum required monitoring time.

For the analyses of the physical activity measures, measures such as the percentage of the accelerometer wear times were extracted. Other measures were averaged. The percentage of wear time was used to control for differences in total wear time between the participants. All the participants analyzed did have a minimum of 3 days' worth of wear, with a minimum of 3 hours of wear time each day. Using the gross physical activity time could have resulted in erroneous findings as there was variation between how long participants wore the activity monitor.

The control group obtained greater means than the LBP group for all the physical activity measures collected. The percent time spent in vigorous activity was the only measure of physical activity in which a statistically significant difference was obtained. As per the Canadian 24-Hour

Movement Guidelines, it is recommended for adults to accumulate at least 150 minutes per week of moderate to vigorous physical activity (CSEP Guidelines, 2020). The same guidelines state that any progress towards this 150-minute requirement results in some health benefits (CSEP Guidelines, 2020). This illustrates that although some of the differences detected in physical activity were shy of statistical significance, they may still be clinically and functionally significant.

6.3 Modifiable Activity Questionnaire

The Modifiable Activity Questionnaire the participants in this study completed required the participants to estimate the frequency and the duration for which they performed certain activities throughout a year. Participants were able to specify the months in which they performed activities. After calculating the gross amount of yearly leisure activity time reported by the participants, the average amount of time they would spend in leisure activity per week was then calculated. The results of the MAQ were analyzed, and it was identified that the LBP group attained a higher estimate of weekly hours spent in leisure activity. This finding is not congruent with the objective measures of physical activity, which illustrated that the control group was more physically active than the LBP group.

One possible explanation could be that the MAQ was an estimate of their yearly physical activity habits which could vary depending on the time of the year, whereas the activity monitors were worn for one week. Another explanation for the discrepancy could be due to the recall biases associated with self-reported measures of physical activity.

In a study conducted by Steene-Johannessen and colleagues (2016), they found substantial differences in the estimates of compliance with physical activity recommendations

between their self-reported measures and objective measures. However, self-reported measures are still useful as they can provide context when paired with objective measures. Attitudes, perceptions of the environment, and activity type are examples of valuable information that can be obtained via self-reported measures (Steene-Johannessen et al., 2016). The MAQ provides contextual information regarding the types of activity participants were likely engaged in based on the time of year, which is complementary to the raw physical activity measurements obtained.

6.4 Sedentary Analysis

Sedentary behaviour is defined as any waking behaviour characterized by energy expenditure ≤ 1.5 METs while in a sitting, reclining, or lying posture (Van der Ploeg & Hillsdon, 2017). The results of the sedentary analyses were not statistically significant; however, a trend was detected in the findings. Although marginal, the LBP group spent a greater percentage of their wear time in a sedentary state. The LBP group also recorded more sedentary bouts, and their sedentary bouts were longer in duration. Spending long periods of time in sedentary behaviour is linked to several health problems, but the association between sedentary time and LBP is not established (Alzahrani et al., 2022). A systematic review by Chen and colleagues in 2009 found that there was insufficient evidence to demonstrate that sedentary behaviour is a risk factor for developing LBP. People suffering from chronic LBP display pain anticipation and fear-avoidance beliefs, which influence their behaviour (Pfungsten et al., 2001). These pain anticipation and fear-avoidance beliefs may explain the greater sedentary behaviour in the LBP group.

6.5 Trunk Muscle Endurance & Physical Activity Correlation and Logistic Regression

For the measures of trunk muscle endurance, a large percentage of the observations were concentrated at the maximum hold time. This stood true for the Biering-Sørensen test, and both

the side plank tests. Effectively, a ceiling effect in the measures of trunk endurance was observed. Therefore, tests of correlation with the physical activity and endurance measures were not executed, as the findings would not have unearthed the true correlation between these two variables.

For the logistic regression conducted, an increase in the average daily calories expended was associated with a decrease in the probability of LBP with an odds ratio of 0.987. The p-value of 0.036 indicates that this influence is statistically significant. The odds ratio of 0.987 indicates that a one-unit increase in the average daily calories will decrease the odds that the dependent variable is LBP by 0.987 times. This means that a 100-unit increase in the average daily calories would decrease the odds that the dependent variable is LBP by approximately 26%.

7. Limitations

In all research studies there are limitations to consider when interpreting and applying the work. As mentioned in previous sections, the Biering-Sørensen maximum endurance time was limited to 120s. A large percentage of the participants achieved the maximum endurance time. It is likely that greater differences would have been discerned between the LBP and control groups if the maximum endurance time was greater. The ceiling effect for this test resulted in some difficulties statistically as the linear correlation between the endurance times and the physical activity measures could not be assessed. However, the use of the 120s limit did reduce the likelihood of the participants becoming fatigued during the collection and having their attention (and effort) wane as can occur during endurance testing conducted to volitional failure.

In the 1984 study by Biering-Sørensen, the maximum endurance time for the Biering-Sørensen test was 240 seconds, which is twice the maximum endurance time used in this study. Since then, many studies have conducted the Biering-Sørensen test to failure (Latimer et al., 1999, Champagne 2008, Coorevits et al., 2008, Tekin et al., 2009, Mannion et al., 2011, Demoulin et al., 2016). In the study by Demoulin and colleagues (2016), the Biering-Sørensen test was conducted to failure in a young population between the ages of 18 to 25. The whole group mean for the Biering-Sørensen test was approximately 157.2 seconds, which is greater than the maximum endurance time of 120 seconds used in this study. It is likely that greater differences between the groups would have been observed if the maximum endurance time was increased beyond 120s or conducted to failure.

Similar to the Biering-Sørensen test, the maximum endurance time for the side-planks were shy of what is found in the literature as they are normally conducted to failure (McGill 1999, Evans 2007, Durall 2009, Frost 2013, Correia 2016). In a study with a population similar to that of the current study, the time to failure for the side-plank test was about 90s (McGill, 1999). With a large percentage of the participants reaching the maximum endurance time, a ceiling effect in this test was observed, and as such, it is likely that greater differences between participants and the groups would have been detected if the maximum endurance time was greater or if the side planks were conducted to failure.

In this study, while the participants were matched to control for sex, height, and weight, they were not matched based on their fitness level nor their sport participation status. In an undergraduate student population, some students may participate in varsity or intramural athletics which would provide them with greater opportunities to be physically active compared

to a student who may not have any athletic commitments nor exercise regularly. Matching based on fitness would have helped to attenuate any confounding variables based on different fitness and activity levels between participants.

8. Conclusion

8.1 Revisiting Hypotheses

The first hypothesis was that a difference in the physical activity measures between the control and LBP groups would be detected, with the control group outperforming the LBP group in activity measures. While the control group did generally obtain higher physical activity measures than the LBP group, it is important to note that only two of the fifteen analyzed physical activity variables—maximum METs and the percent time in vigorous physical activity—showed statistically significant differences between the groups. While these results support the hypothesis that the control group was more physically active than the LBP group, this result should be interpreted with caution due to the limited statistical significance across most variables. Nonetheless, it was calculated through the logistic regression analysis that for every 100-calorie increase in the daily caloric expenditure, participants were 29% less likely to be classified into the LBP group.

The second hypothesis was that there would be a difference in the trunk endurance measures between the control and LBP groups, specifically that the control group would outperform the LBP group in these measures. Three trunk endurance tests were conducted, specifically the Biering-Sørensen, left plank, and right plank tests. For the Biering-Sørensen test, the control group performed better than the LBP Group. 100% of the control group obtained the

maximum hold time, compared to 69.2% of the LBP group. The LBP group obtained a mean (SD) hold time of 106.23 (± 24.45) seconds compared to 120s (± 0) for the control group. The difference between these groups was statistically significant based on the Wilcoxon Ranked Sum Test (* $p = 0.04$). Despite unearthing a statistically significant difference, a ceiling effect was observed as a large percentage of the participants reached the maximum endurance time. While the control group did generally show better performance in the Biering-Sørensen test, it is important to consider that the maximum endurance time was capped to 2 minutes.

The LBP group had a lower percentage of participants reaching the maximum endurance time for both the left and right planks compared to the control group. Mean endurance times for the control group were higher for both planks, but the differences were not statistically significant. Additionally, it is important to note that the maximum endurance time was capped to 1 minute, which may have constrained the ability to fully capture differences in endurance between the groups. Consequently, while the control group appeared to have greater trunk endurance, the results may be limited by the test's maximum duration, potentially underestimating the true differences in endurance between the two groups. As a result, although the hypothesis is accepted, the findings should be interpreted with caution due to the imposed limitations on endurance measurement.

The third hypothesis was that there would be a moderate correlation between the physical activity and endurance measures. However, a ceiling effect was identified in the measures of trunk endurance, rendering it unfeasible to run a linear correlation analysis between these factors. As a result, this hypothesis can neither be accepted nor rejected.

8.2 Conclusion

In the context of the prevailing concern over the prevalence of LBP among undergraduate students, this research contributes to the existing literature by adopting a comprehensive approach. While previous studies have predominantly focused on the assessment of trunk endurance as a potential factor in LBP, this research goes a step further by integrating an analysis of physical activity levels. By examining the relationship between physical activity, trunk endurance, and the prevalence of LBP, this study provides a more holistic understanding of the multifaceted nature of this issue. The inclusion of physical activity as a variable adds a nuanced dimension to the investigation, shedding light on potential lifestyle factors that may influence the occurrence of LBP in the studied population. Through a meticulous examination of both trunk endurance and physical activity, the aim of this study was to contribute insights that transcend the current discourse, informing not only the theoretical frameworks but also practical interventions aimed at mitigating the prevalence of LBP among undergraduate students. This nuanced perspective not only advances the understanding of the factors contributing to LBP but also provides a foundation for more targeted and effective preventive measures within the academic community.

8.3 Future Directions

The findings of this study open up promising avenues for future research, suggesting potential directions that can deepen the understanding of the relationships uncovered. Firstly, a recommendation for future studies involves revisiting the assessment of trunk endurance. Instead of limiting the time for participants, conducting tests to failure could provide a more accurate representation of true trunk endurance. This adjustment could offer a more nuanced perspective on participants' physical capabilities and contribute to a more comprehensive understanding of

the factors influencing LBP. Moreover, the current study lays the groundwork for a longitudinal investigation that could trace the long-term behaviors of participants and their prevalence of LBP. Such a longitudinal approach would provide invaluable insights into the dynamic nature of these relationships over an extended period, offering a more holistic view of the interplay between trunk endurance, physical activity, and the occurrence of LBP. The findings from this study should also be assessed in a broader population.

Lastly, the implications of this research extend to practical applications, suggesting the potential development of screening methods. These methods could help direct potential research participants to studies that align with their characteristics and behaviors, optimizing the efficiency of future investigations. By informing not only the theoretical discourse but also the methodological approaches, this study lays the foundation for continued exploration and refinement within the realm of LBP among undergraduate students.

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Appendix

Questionnaire

1. Please circle all activities listed below that you have done more than 10 times in the past year.

- | | | |
|--|-------------------------------------|--|
| 01 Jogging (outdoor, treadmill) | 15 Football/Soccer | 28 Stair Master |
| 02 Swimming (laps, snorkeling) | 16 Racquetball/Handball/Squash | 29 Fencing |
| 03 Bicycling (indoor, outdoor) | 17 Horseback riding | 30 Hiking |
| 04 Softball/Baseball | 18 Hunting | 31 Tennis |
| 05 Volleyball | 19 Fishing | 32 Golf |
| 06 Bowling | 20 Aerobic Dance/Step Aerobics | 33 Canoeing |
| 07 Basketball | 21 Water Aerobics | 34 Water skiing |
| 08 Skating | 22 Dancing (Square, Line, Ballroom) | 35 Jumping Rope |
| 09 Martial Arts (karate, judo) | 23 Gardening or Yard work | 36 Snow skiing (X-country, Nordic Trk) |
| 10 Tai Chi | 24 Badminton | 37 Snow skiing (downhill) |
| 11 Calisthenics/Toning exercises | 25 Strength/Weight training | 38 Snow shoeing |
| 12 Wood Chopping | 26 Rock Climbing | 39 Yoga |
| 13 Water/Coal hauling | 27 Scuba Diving | 40 Other |
| 14 Walking for exercise (outdoor, indoor at mall or fitness center, treadmill) | | |

List each activity that you circled in the “Activity” box below, check the months you did each activity over the past year (12 months) and then estimate the average amount of time spent in that activity.

2. Are your activities listed above relatively consistent from week to week? Y / N
3. On average, how many HOURS per DAY do you usually spend sitting? _____hrs
4. On average, how many HOURS per DAY do you usually spend standing? _____hrs
5. In general, how many times per week do you stretch (hold/static type)? _____

How long do you hold each stretch? _____seconds

Do you stretch prior to, following, or not related at all to a particular activity?

Prior_____ Following_____ I stretch independent of activities_____

6. Specific to hip flexor stretching (extending your hips in stretch):

Do you stretch your hip flexors? Y / N

If yes, do you often sit or stand following your stretching protocol? Sit / Stand

Activity	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average # of Times Per Month	Average # of Minutes Each Time

7. Specific to back muscle stretching:

Thinking about back lateral bend (side bending of your trunk, by extending your arm over your head and to one side or sliding one hand down your leg toward your knee), do you stretch your back from side to side (laterally bend your trunk)? Y / N

Thinking about back flexion (forward reaching, forward bending, or curling your back), do you stretch you back muscles involving forward flexing of your trunk? Y / N

If “Y” to the above, do you often sit, stand, or walk following your stretching protocol? Circle as needed.

Sit / Stand / Either sit or stand / Walk around

8. Have you ever experienced lower back pain due to injury? Y / N

If “Y”, was this caused by a work activity? Y / N

If “Y”, did you seek medical care? Y / N

If “Y”, how long ago did the most recent injury occur? _____

Was this the first time you have injured your low back? Y / N

If “N”, how many times have you injured your low back? _____

9. After exercising or work, have you ever experienced back pain that impacted your activities of daily living for the following day/days? Y / N

10. Have you ever experienced shoulder pain due to injury? Y / N

If “Y”, was this caused by a work activity? Y / N

If “Y”, did you seek medical care? Y / N

If “Y”, how long ago did the most recent injury occur? _____

Was this the first time you have injured your shoulder? Y / N

If “N”, how many times have you injured your shoulder? _____

11. After exercising or work, have you ever experienced shoulder pain that impacted your activities of daily living for the following day/days? Y / N

12. Is there anything you wish to share with the researchers regarding your activity and/or body?

*Note: Question 1 is the leisure activity section from the Modifiable Activity Questionnaire.
Questions 2-12 are custom for the current and larger study.*