UNIVERSITY OF OKLAHOMA

GRADUATE COLLEGE

INVESTIGATING THE HAMSTRING-TO-QUADRICEPS MUSCLE STRENGTH RATIO IN A FATIGUED STATE

A THESIS

SUBMITTED TO THE GRADUATE FACULTY

In partial fulfillment of the requirements for the

Degree of

MASTER OF SCIENCE

BY

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Norman, Oklahoma

2026

INVESTIGATING THE HAMSTRING-TO-QUADRICEPS MUSCLE STRENGTH RATIO IN A FATIGUED STATE

A THESIS APPOVED FOR THE
DEPARTMENT OF HEALTH AND EXERCISE SCIENCE

BY THE COMMITTEE CONSISTING OF

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ACKNOWLEDGEMENTS

I would like to begin by expressing my deepest gratitude to my advisor, Dr. Rebecca Larson, for her exceptional mentorship, unwavering support, and continuous encouragement throughout this research process. Her guidance, insightful feedback, and dedication played a pivotal role in shaping this work and helping me stay focused and confident, even during the most challenging moments. I am especially grateful for her patience, expertise, and commitment to my academic and professional growth.

I would also like to extend my sincere appreciation to my committee members, Dr. Daniel Larson and Dr. Grant Chesbro, for their continuous guidance, support, and encouragement. Their valuable feedback and contributions greatly enriched this research.

I would also like to sincerely thank my wife, for her unwavering support, guidance, and encouragement.

A special thanks goes to my friends and colleagues in the Human Performance Lab for their support and assistance throughout data collection and analysis. Your help and teamwork made a significant difference in completing this study.

I am also truly grateful to all the participants who generously gave their time to be part of this research. This study would not have been possible without their involvement.

Finally, I would like to thank my family and friends for their continued love, patience, and belief in me. Your support has been a constant source of strength throughout this journey.

ABSTRACT

Background: Muscle fatigue is known to reduce force production and alter neuromuscular performance; however, its effects on muscle balance, particularly the hamstring-to-quadriceps (H:Q) ratio, remain unclear. Understanding how fatigue influences both strength and muscle balance is important for injury prevention and performance assessment.

Methods: Fifteen healthy, untrained adults (11 males, 4 females) participated in this study. Peak torque of the hamstrings and quadriceps was assessed using isokinetic dynamometry at two angular velocities (60°/s and 180°/s) before and immediately after a fatigue protocol consisting of repeated shuttle runs. The H:Q ratio was calculated at each velocity. Perceived exertion (RPE) and performance (distance covered across six laps) were also recorded. A repeated-measures ANOVA was conducted to examine the effects of time (pre vs. post) and velocity on muscle performance outcomes.

Results: Fatigue resulted in significant reductions in peak torque, particularly at the higher velocity (180°/s), indicating greater fatigue-related decline under faster contraction conditions. In contrast, no significant changes were observed in the H:Q ratio following fatigue, suggesting that both muscle groups were affected proportionally. A significant main effect of velocity was found for the H:Q ratio, indicating differences between testing speeds independent of fatigue. Perceived exertion increased progressively across laps, confirming the effectiveness of the fatigue protocol, while performance showed a non-significant decline with substantial individual variability.

Conclusion: These findings indicate that fatigue significantly impairs muscle force production but does not necessarily alter muscle balance as measured by the H:Q ratio. The results highlight the importance of considering contraction velocity when assessing fatigue effects and suggest that the H:Q ratio alone may not be sensitive to fatigue-related changes. Additionally, substantial individual variability in fatigue responses emphasizes the need for individualized assessment in both research and applied settings.

CHAPTER 1- INTRODUCTION

Lower-limb muscle strength imbalances, particularly between the hamstrings and quadriceps, are crucial for maintaining knee joint stability and effective muscle function as it relates to activities of daily living and exercise (Croisier et al., 2002). These imbalances can negatively impact the stability of the knee which increases the risk of injuries such as anterior cruciate ligament (ACL) strains and can decrease overall movement efficiency (Li et al., 1999). A key method for assessing the stability of the knee is testing the hamstring-to-quadriceps (H:Q) strength ratio, which highlights muscle imbalances specifically to those which influence the knee joint and its overall function and stability. This ratio has been used as a way to understand muscle imbalances and to determine levels of recovery following lower leg injuries specific to the knee (Baltzopoulos & Brodie, 1989; Kellis & Baltzopoulos, 1995). The typical H:Q ratio ranges from 0.5 to 0.8 when averaged across the full range of knee motion, with faster movement speeds often resulting in higher ratios closer to 1 which indicates a higher functional capacity of the hamstrings to stabilize the knee (Rosene et al., 2001). Several approaches exist for assessing and expressing the H:Q ratio, including functional, conventional, and mixed methods (Kellis et al., 2023).

The functional method evaluates the strength of the hamstrings and quadriceps during dynamic movements that simulate everyday activities, such as walking, jumping, or running. By assessing the muscles in these real-life contexts, the functional method offers practical insights into how muscle imbalances can affect overall performance and movement efficiency (Pincivero et al., 2003). The H:Q ratio in this approach is calculated by comparing the peak torque of the hamstrings to the quadriceps during dynamic tasks. For example, testing muscle strength during sprinting can highlight how an imbalance affects acceleration or deceleration, which is crucial for athletic performance (Pincivero et al., 2003).

When the quadriceps generate force by shortening (concentric contraction), the hamstrings act as antagonists and lengthen (eccentric contraction). Because of this, some researchers have suggested that a more functional method for calculating the H:Q ratio should consider typical muscle actions during knee extension (Dvir et al., 1989). This has led to the development of the dynamic control or functional torque ratio, which is defined as the ratio of eccentric hamstring torque (HECC) to concentric quadriceps torque (QCON). Normative values for the functional ratio vary depending on the test's angular velocity, with values around 0.79 at 60°/s and exceeding 1 at velocities greater than 240°/s. Additionally, a mixed ratio is calculated by dividing the HECC torque at 30°/s by the QCON torque at 240°/s, with the resulting H:Q ratio for the typical sport population centering around 1 (Tsimahidis et al., 2011).

However, while this method provides valuable functional insights, it may lack the precision needed to detect specific muscular imbalances, as it focuses on broader, task-oriented movements rather than isolating specific concentric or eccentric contractions (Pincivero et al., 2003).

The conventional method is a widely used approach for assessing lower-limb muscle imbalances, involving the separate measurement of concentric and eccentric strength of the hamstrings and quadriceps, typically with an isokinetic dynamometer (Aagaard et al., 1998). This approach allows for controlled testing across different speeds, enabling comparison of peak torque produced by each muscle group. The H:Q ratio is determined by dividing the peak torque of the hamstrings by that of the quadriceps under various contraction types: for instance, concentric contractions measure hamstring strength in muscle-shortening actions, while eccentric-concentric ratios compare the hamstrings' eccentric (lengthening) strength against the quadriceps' concentric strength. An isokinetic test might measure peak torque at 60 degrees per second for both hamstrings and quadriceps, allowing for direct comparison (Aagaard et al., 1998). The conventional method also involves testing at various angular velocities, such as slow (12°/s), intermediate (180°/s), and fast speeds, with values ranging between 0.52 and 0.67 for isometric tests (Kellis et al., 1998). This method provides a clear and quantifiable picture of muscle strength imbalances, and its precision makes it effective in identifying specific deficits at joint angles, allowing for targeted interventions to reduce ACL injury risk and monitor rehabilitation progress (Aagaard et al., 1998). This specificity is why the conventional method is frequently chosen in clinical assessments and research on knee stability (Aagaard et al., 1998).

Finally, the mixed method combines the strengths of both the functional and conventional approaches, offering a more holistic assessment (Tsimahidis et al., 2011). This method includes both dynamic activities that simulate real-life movements and isolated measurements of muscle strength, such as those done with an isokinetic dynamometer (Tsimahidis et al., 2011). For example, an assessment using the mixed method might involve measuring peak torque in isolated exercises, followed by analyzing muscle performance during a functional task like a vertical jump (Tsimahidis et al., 2011). According to the authors who developed the mixed ratio, the main benefit is that it better reflects the true muscle performance by combining measurements from both fast and slow angular velocities. Specifically, torque values measured during fast angular velocity tests (such as concentric quadriceps torque at 240°/s) tend to show better experimental validity than those from eccentric contraction tests. Conversely, eccentric torque values measured at slower angular velocities (such as hamstring eccentric torque at 30°/s) are more valid than those taken at faster speeds. This approach provides more accurate insights into muscle performance by accounting for the different characteristics of both concentric and eccentric actions at varying speeds. While this method provides a more comprehensive understanding of muscle performance and injury risk, it tends to be more complex and time-consuming due to the inclusion of both dynamic and static assessments (Tsimahidis et al., 2011). To address the study's objectives, the conventional method will be used, as it provides a precise and reliable measurement of muscle strength imbalances between the hamstrings and quadriceps.

In addition to the various methods for assessing the H:Q ratio, the conditions under which the ratio is measured play a crucial role in interpreting its implications for joint stability and function. Factors such as fatigue, testing speed, and joint angle significantly influence the H:Q ratio and, subsequently, the understanding of knee stability (Ortiz et al., 2010).

Fatigue can elevate the risk of knee injury, especially concerning muscle imbalances (Moon et al., 2021). Fatigue is defined as the reduced ability to maintain a certain level of exercise intensity or power output, which can result from intense physical activity or insufficient recovery from repeated exertion (Tornero-Aguilera et al., 2022). Fatigue comprises both central and peripheral components; central fatigue influences the nervous system's ability to generate adequate motor output, while peripheral fatigue affects muscle contractile capacity (Tornero-Aguilera et al., 2022; Enoka & Duchateau, 2019). Together, these effects can diminish neuromuscular control, leading to impaired muscle function and a greater risk of injury. Furthermore, the accumulation of central and peripheral fatigue over time can significantly weaken the ability of the hamstrings and quadriceps to maintain knee joint stability, thus increasing injury risk (Boyas & Guevel, 2011). Acute fatigue has been linked to injuries based on epidemiological evidence; however, the gradual build-up of fatigue from continuous activity also raises the likelihood of knee injuries over time (Boyas & Guevel, 2011). Despite this understanding, most studies assessing the H:Q ratio tend to measure muscle strength in individuals when they are not fatigued (Kellis et al., 2007) This approach overlooks the real-world conditions under which injuries frequently occur, particularly during fatigued states when muscle imbalances become more pronounced and stability is compromised (Freckleton & Pizzar , 2012; Moon et al., 2021). Additionally, most existing research has focused on athletes, who typically show higher strength levels and are tested in controlled environments that do not reflect the fatigue levels experienced during actual competition or daily activities (Freckleton & Pizzar , 2012). Consequently, these studies may not provide insights relevant to untrained individuals. This lack of representation highlights the necessity for further research examining the H:Q ratio in untrained populations, particularly the impact of fatigue on said ratio. This research will investigate how fatigue influences the hamstring-to-quadriceps strength ratio, focusing on the connection between muscle imbalances and fatigue in the target population. Most studies have primarily targeted athletes, rather than untrained individuals. By concentrating on untrained populations, this research aims to offer valuable insights that could inform preventive strategies for knee injuries across a broader population. This emphasis on healthy, and untrained population will enhance the external validity of the study findings. Through this analysis, the research seeks to deepen our understanding of the factors contributing to knee injuries and to develop effective strategies for preventing them.

Purpose

This study aims to determine the differences in hamstring to quadriceps strength ratio between non-fatigue and fatigue states in college-aged individuals.

Research question

1- What is the difference between H:Q strength ratio following a fatiguing bout of exercise?

Hypotheses

1- Null Hypothesis (H0): There is no difference in H:Q strength ratio following a bout of fatiguing exercise.

2- Alternative Hypothesis (H1): The H:Q strength ratio will increase after a bout of fatiguing exercise versus before.

Significance of the Study

This study is significant for several reasons, particularly in the fields of sports science and injury prevention. By examining the impact of fatigue on the H: Q strength ratio, the study addresses a critical gap in understanding how muscle imbalances, aggravated by fatigue, contribute to knee injuries such as ACL strain. The findings could be instrumental in informing injury prevention programs in both genders and in any activity where fatigue is a common risk factor for knee injuries.

Furthermore, this research has the potential to influence rehabilitation protocols for individuals recovering from knee injuries. By identifying how fatigue influences muscle strength imbalances, therapists can develop more targeted interventions that improve muscle function and reduce the likelihood of re-injury. In addition to its relevance in sports, the study also has implications for workplace health, particularly for individuals in physically demanding jobs who experience continuous physical strain. Understanding the relationship between fatigue and knee stability can help in designing workplace health programs that aim to reduce injury risks and promote long-term musculoskeletal knee health. By addressing fatigue-induced muscle imbalances, people may be able to enhance their muscle function and overall movement efficiency, thereby reducing the risk of injury while optimizing performance during dynamic activities. In summary, this study not only aims to contribute to the scientific understanding of muscle imbalances and fatigue but also holds practical value for injury prevention (ACL), rehabilitation, and workplace health.

The delimitations of this study include:

1. The study will recruit males and females in Norman and surrounding areas.
2. Participants will be between the ages of 18-40.
3. Participants will have no neuromuscular or neurological diseases/disorders that limit muscle function.

The limitations of this study include:

1. There is no random assignment of groups.
2. There is no control group.
3. Participants will be recruited from the Norman and Oklahoma City Area

Assumptions

The assumptions of the study are:

1. The study assumes that the fatigue protocol used will effectively induce a state of muscle fatigue in the participants, allowing for an accurate comparison of muscle strength ratios in fatigue and non-fatigue states.

2. It is assumed that the equipment used to measure hamstring and quadriceps strength, Kin-Com isokinetic dynamometer, will yield precise and consistent results across all participants.
3. Participants have not participated in vigorous activity 12 hours prior to the test.
4. Participants will perform maximal effort.
5. Individuals will provide accurate medical information and health history.

Operational Definitions

1. Muscle Fatigue-A condition characterized by a decrease in the maximum force-generating capacity of a muscle, typically following prolonged or intense physical exertion. In this study, muscle fatigue will be assessed by measuring the reduction in peak torque or force output during isokinetic exercises following a fatigue protocol (Bigland-Ritchie, 1984).
2. Peripheral Fatigue- A reduction in the force-generating capacity of the skeletal muscle that occurs within the muscle itself or at the neuromuscular junction. In this study, peripheral fatigue will be measured by evaluating the decrease in muscle force production and performance during and after physical exertion (Sadri et al., 2014).
3. Central Fatigue- A progressive loss of voluntary activation or reduced nervous excitation into the muscle, leading to decreased maximal force production during exercise. Central fatigue will be indirectly assessed by monitoring participants' ability to generate voluntary muscle contractions during isokinetic exercises (Sadri et al., 2014).
4. Hamstring-to-Quadriceps (H: Q) Strength Ratio- The ratio of the peak torque or force produced by the hamstrings relative to the quadriceps during isokinetic exercises. This

ratio will be calculated to assess muscle imbalances in both fatigue and non-fatigue states (Aagaard et al., 1998; Croisier et al., 2002).

5. Fatigue Protocol- A specific exercise routine or physical activity designed to induce muscle fatigue. In this study, the fatigue protocol will involve repeated muscle contractions at a high intensity until participants demonstrate a measurable reduction in force production (Millet & Lepers, 2004).
6. Isokinetic Exercises- refers to a type of motion where the speed of muscle contraction remains constant throughout the movement, while the resistance adjusts to match the force applied by the muscle. This ensures that the muscle works evenly across its full range of motion. Isokinetic movements typically require specialized equipment to control the speed and resistance, making them useful in strength training and rehabilitation settings (Dvir, Z. 2004).

CHAPTER 2 (LITERATURE REVIEW)

This literature review will outline the current understanding of fatigue's impact on the hamstring-to-quadriceps strength ratio and its implications for knee injury risk among college-aged individuals. The search process included literature obtained from Google Scholar, MEDLINE (EBSCO), and SportsDiscus, with access to full text. The search criteria utilized a combination of keywords such as hamstring-to-quadriceps ratio, fatigue, muscle imbalances, and untrained individuals, found in the text, abstract, and title.

Hamstring-to-quadriceps ratio

The hamstring-to-quadriceps (H: Q) ratio is a crucial measurement in the fields of sports science, rehabilitation, and injury prevention. This ratio compares the strength of the hamstring muscles, located at the back of the thigh, to the quadriceps muscles, located at the front of the thigh. A balanced H:Q ratio is essential for maintaining optimal knee joint stability, which is critical for athletic performance and injury prevention (Kellis et al., 2007; Freckleton & Pizzar , 2012 et al., 2014). Generally, an H:Q ratio of 0.6 to 0.8 is considered indicative of a healthy balance between these muscle groups, suggesting that the hamstrings are adequately strong to support knee stability during dynamic movements (Moon et al., 2021). Research has established a significant relationship between the H:Q ratio and the risk of knee injuries, particularly anterior cruciate ligament (ACL) injuries, which are prevalent in both athletic and non-athletic populations (Timmins et al., 2016; Freckleton & Pizzar , 2012 et al., 2014). Lower H:Q ratios have been associated with an increased risk of knee injuries due to muscle imbalances that impair the knee’s ability to withstand high loads during physical activities (Baroni et al., 2020). For instance, Katis and Kellis (2009) demonstrated that professional soccer players with lower

H:Q ratios were at a heightened risk for knee injuries, underscoring the importance of monitoring the H:Q ratio in athletic populations where injury risk is substantial (Freckleton & Pizzar , 2012; Moon et al., 2021).

However, much of the existing literature has predominantly focused on sports-specific trained athletes, such as soccer, revealing a critical gap in understanding the implications of the H:Q ratio in non-sport specific trained individuals. This lack of research is concerning, as it limits the ability to develop effective injury prevention strategies tailored to those who engage in general athletic activities (Timmins et al., 2016; Keays et al., 2007).

Additionally, Keays et al. (2001) reported that the H:Q ratio can vary significantly among different populations based on factors such as training status, age, and activity level. Younger individuals and those involved in consistent resistance training tend to display more favorable H:Q ratios, while older adults and sedentary individuals often exhibit reduced ratios, which can increase their risk of knee injuries (Timmins et al., 2016). This discrepancy highlights the necessity for further research focused on the H:Q ratio in this populations, especially considering that they may have different muscular adaptations compared to trained athletes. The methodology used to measure the H:Q ratio also plays a crucial role in understanding its implications for injury risk. Isokinetic testing, which measures muscle strength through controlled movements, is commonly employed to assess the H:Q ratio (Harris et al., 2016). However, Harris et al. (2016) noted that variations in testing protocols, such as different speeds and angles of measurement, can yield inconsistent results. These inconsistencies highlight the need for standardized testing methods to accurately assess the H:Q ratio across diverse populations, including untrained individuals (Keays et al., 2001; Timmins et al., 2016).

Moreover, research has indicated that sex differences may also impact the H:Q ratio. Studies have shown that hormonal variations between males and females can influence muscle strength and performance, potentially leading to different H:Q ratios (Baroni et al., 2020; Moon et al., 2021). Understanding these differences is vital for developing tailored rehabilitation programs and injury prevention strategies that account for the unique needs of both sexes (Freckleton & Pizzar, 2012; Timmins et al., 2016).

Muscle imbalances

Muscle imbalances refer to the unequal strength or flexibility between opposing muscle groups, which can lead to functional limitations and increase the risk of injuries. These imbalances are particularly relevant in the context of dynamic activities, where muscles must work synergistically to maintain joint stability and proper biomechanics (Wilk et al., 2012; Myer et al., 2004). For example, in the lower body, the relationship between the hamstrings and quadriceps is crucial for knee stability; an imbalance in strength between these two muscle groups can predispose individuals to injuries, particularly ACL injuries (Kellis et al., 2007; Freckleton & Pizzar , 2012).

Research has shown that muscle imbalances can occur due to various factors, including differences in training protocols, movement patterns, and overall physical activity levels. For instance, athletes who primarily engage in sports that emphasize one muscle group may develop significant strength discrepancies, potentially leading to injury during competition (Timmins et al., 2016). Moreover, sedentary lifestyles can exacerbate muscle imbalances as certain muscle groups become weak while others may become overly tight due to a lack of regular stretching and strengthening exercises (Hewett et al., 2010; Myer et al., 2014). In the context of knee injuries, specific attention has been directed toward the H:Q ratio as an indicator of muscle balance. An insufficient H:Q ratio where the quadriceps are significantly stronger than the hamstrings has been associated with an increased risk of knee injuries (Freckleton & Pizzar , 2012 et al., 2014). This relationship highlights the importance of understanding not just individual muscle strength but also how muscle groups interact during movement (Baroni et al., 2020). Research has indicated that maintaining an adequate H:Q ratio is crucial for athletes and active individuals, as it can mitigate the risk of injury by ensuring that the hamstrings can effectively counterbalance the forces generated by the quadriceps during high-impact activities (Timmins et al., 2016).

Despite the well-established connection between muscle imbalances and injury risk in trained populations, there remains a notable lack of research focused on untrained or recreationally trained individuals. Most studies have concentrated on high-level athletes, leaving a gap in knowledge regarding how muscle imbalances affect those who do not engage in regular exercise (Keays et al., 2001; Moon et al., 2021). This is particularly concerning given that untrained or recreationally trained individuals may have different muscular adaptations, strength levels, and injury profiles compared to their trained counterparts. The measurement of muscle imbalances often relies on isokinetic testing to assess strength in different muscle groups. While this approach is effective in controlled environments, it may not accurately reflect real-world movement patterns and muscle usage (Harris et al., 2016; Freckleton & Pizzar , 2012 et al., 2014). Moreover, variations in testing protocols can lead to inconsistent results, emphasizing the need for standardized methods that can be applied across diverse populations, including untrained individuals (Keays et al., 2001; Timmins et al., 2016). The existing literature suggests that using standardized measures could provide more reliable data on muscle imbalances and their implications for injury risk.

Muscle Fatigue: Peripheral and Central Mechanisms

Muscle fatigue, a complex phenomenon that affects the ability of muscles to sustain force or power output over time, is commonly classified into two broad categories: peripheral fatigue and central fatigue. Understanding these mechanisms is critical for assessing muscle performance, preventing injury, and improving training protocols. This review explores the distinctions between peripheral and central fatigue, the role of the fatiguing exercise in evaluating fatigue, and the implications for athletic and rehabilitative settings.

Peripheral fatigue is localized within the muscle and is often associated with biochemical and physiological changes that reduce the muscle's ability to generate force. Key factors contributing to peripheral fatigue include the depletion of metabolic substrates, accumulation of metabolic by-products (e.g., lactate and inorganic phosphate), and impairments in excitation-contraction coupling (Allen et al., 2008). Research has shown that during high-intensity, sustained muscle contractions, the buildup of by-products can inhibit calcium release from the sarcoplasmic reticulum, reducing cross-bridge formation and ultimately diminishing muscle force production (Allen et al., 2008). Additionally, peripheral fatigue is influenced by muscle fiber type. Fast-twitch fibers, which generate higher force outputs, are more susceptible to fatigue than slow-twitch fibers due to their reliance on anaerobic metabolism (Enoka & Duchateau, 2008). This distinction in fatigue susceptibility highlights the need for targeted fatigue assessment protocols that consider fiber type composition, as different muscle groups may exhibit varying degrees of fatigue under similar conditions. The localized nature of peripheral fatigue makes it particularly relevant in injury prevention, as fatigued muscles are more prone to strains and tears.

In contrast, central fatigue originates within the central nervous system (CNS) and involves a decrease in the neural drive to the working muscles. Unlike peripheral fatigue, which is attributed to changes within the muscle itself, central fatigue is primarily related to psychological and physiological factors that reduce voluntary motor unit recruitment or alter motor output (Gandevia, 2001). Central fatigue is particularly challenging to assess due to the interplay between physiological and psychological factors that contribute to decreased neural drive. However, research has demonstrated that CNS fatigue can significantly affect endurance performance and is often associated with decreased cortical excitability, increased perception of effort, and alterations in neurotransmitter levels (Taylor et al., 2006). Understanding central fatigue is essential for studying its role in long-duration activities and its impact on overall muscular function. However, for short-duration activity, peripheral fatigue is an appropriate choice (Aguilera et al., 2022). Understanding peripheral fatigue is crucial for improving training and rehabilitation strategies. Peripheral fatigue happens when muscles cannot sustain force due to depleted energy stores and the accumulation of metabolic byproducts, such as hydrogen ions (H+) and inorganic phosphate, during exercise (Dawson et al., 1978; Hirvonen et al., 1987; Green, 1997; Takada et al., 2012). These byproducts disrupt enzyme activity and cross-bridge formation, essential for maintaining muscle contraction (Wilson, 1988; Metzger, 1990; Fitts, 2008). By understanding peripheral fatigue, athletes and individuals undergoing rehabilitation can benefit from more effective training programs and injury prevention strategies. With different protocols we can assess fatigue using multiple muscle contractions, and will help identify muscle imbalances, such as the hamstring-to-quadriceps ratio, that are linked to higher injury risks, particularly in sports (Meylan et al., 2009). Addressing both peripheral and central fatigue mechanisms can guide more effective interventions for muscle recovery and re-injury prevention (Larsen et al., 2020).

Untrained individuals

Untrained individuals are generally more susceptible to muscle imbalances because they often lack a consistent exercise routine that strengthens muscle groups evenly. This lack of targeted training can lead to natural disparities, which may heighten the risk of injury even during low to moderate levels of activity, as their muscles are unaccustomed to handling high loads or intense movement patterns (Myer et al., 2014; Kellis et al., 2011). Furthermore, research suggests that in untrained individuals, muscle imbalances between agonist and antagonist groups, such as the hamstrings and quadriceps, may have more pronounced impacts on joint stability and biomechanics during daily activities or sudden physical demands (Croisier et al., 2002; Lee et al., 2018). For instance, imbalances in the hamstring-to-quadriceps ratio can reduce knee stability, potentially leading to joint injuries even in non-athletes (Maly et al., 2006; Lee et al., 2018).

According to Kellis and Baltzopoulos (1995), untrained individuals often exhibit lower overall muscle strength, which may influence the ideal balance for injury prevention. Thus, using standards developed for trained athletes to assess untrained individuals could yield misleading insights, underscoring the need for research specific to this group (Myer et al., 2014).

Additionally, research on muscle imbalances in untrained individuals may provide essential information for developing preventive strategies, especially as many injuries in this group arise from acute or unanticipated movements rather than repetitive or high-intensity training (Hewett et al., 2010; Croisier et al., 2002). Given that untrained individuals may not possess the same neuromuscular coordination or strength as athletes, minor imbalances can disproportionately impact their performance and safety (Croisier et al., 2008; Nagano et al., 2007). Developing population-specific guidelines for H:Q ratios and other muscle balance measures could help reduce injury rates among untrained or recreationally active adults (Baumgart et al., 2014; Kellis et al., 2011).

CHAPTER 3- METHODOLOGY

This chapter describes the methodology used in this study to investigate the impact of fatigue on the hamstring-to-quadriceps strength ratio and its implications for knee injury risk among college aged individuals.

Participants

We recruited 15 healthy adults, aged 18 to 40. Choosing this number of participants is supported by previous research. Studies by Kellis et al. (2007) and Moon et al. (2021) found significant results with sample sizes of 10 to 15 people. The choice of 18-40 years of age is important because it includes individuals in their peak muscular strength and endurance, which helps minimize the effects of age-related declines in strength (Reeves et al., 2004). Before the study, we screened all participants for any musculoskeletal injuries or medical conditions that could affect their performance or pose risks during high-intensity exercise. Participants signed an informed consent form after we explained the study procedures, risks, compensation, confidentiality, and their right to withdraw at any time, in accordance with ethical standards (Smith & Jones, 2019).

Inclusion Criteria

1. Individuals affiliated with the University of Oklahoma or residing in the surrounding area.
2. Male and female participants aged 18 to 40.
3. Aerobically Trained: Engaged in at least 4 hours of aerobic exercise per week with no more than 1.5 hours of resistance training (American College of Sports Medicine, 2021).

-Resistance Trained: Engaged in resistance training for at least 4 hours per week, across 3 or more days, with no more than 1.5 hours of aerobic exercise (American College of Sports Medicine, 2021; National Strength and Conditioning Association, 2009).

4. Individuals are classified as untrained, not meeting the criteria specified above.

5. Individuals are free of any lower body injury (knee, hip, quadriceps, or hamstring) at the time of the study.

6. Individuals without cardiovascular diseases.

7. Individuals not taking medications for cardiovascular, metabolic, neurological, or psychiatric conditions.

8. Individuals who are not pregnant.

Exclusion Criteria

1. Individuals who answered "yes" to any PAR-Q questions or have any known cardiovascular, pulmonary, or metabolic disease.

2. Individuals with neurological, neuromuscular, or orthopedic conditions.

3. Individuals who have undergone major lower body surgery (knee or hip).

4. Individuals with a lower body injury (knee, hip, hamstring, or quadriceps) within six months prior to the study.

5. Individuals taking medications for cardiovascular, neuromuscular, neurological, or psychiatric conditions.

6. Individuals who are pregnant.

Research design

This study employs a cross-sectional, repeated measures, pre-experimental design to compare the effects of fatigue on the H:Q strength ratio in healthy adults. By using repeated measures, we assess participants' H:Q ratios under both fatigued and non-fatigued conditions. Participants were required to come to the University of Oklahoma Human Performance and Body Composition Lab on two separate occasions.

Study procedure

Visit 1: Familiarization

During the first visit, participants completed study documents and become familiar with the procedures. They received and signed an informed consent document outlining the study's procedures, risks, and their right to withdraw at any time. Next, participants performed a health and activity screening, filling out a Physical Activity Readiness Questionnaire (PAR-Q) to confirm they can safely perform the fatigue protocol. The PAR-Q screens participants for cardiovascular, pulmonary, and metabolic health risks, helping confirm their readiness for physical activity (Thomas et al., 1992). Participants must answer "no" to all items to demonstrate that they can safely participate in the study's fatigue protocol. This screening helps minimize injury risk by including only those physically capable of engaging in the study's exercise components. We will also review their training status based on ACSM criteria (ACSM, 2018).

Female participants completed a Menstrual History Questionnaire to control for potential effects of the menstrual cycle on performance (Hooper et al., 2011). All participants, regardless of sex, completed the Profile of Mood States (POMS) to assess psychological readiness prior to each testing session. The POMS is a validated questionnaire that measures transient mood states using a 5-point Likert scale ranging from 0 ("not at all") to 4 ("extremely"). Key variables of interest included fatigue, vigor, and total mood disturbance, which were used to ensure participants were in a consistent psychological state across testing days (Shacham, 1983). For female participants, testing was scheduled to avoid the follicular phase of their menstrual cycle, as this phase can affect perceived exertion and arterial resistance during resistance exercise (Augustine et al., 2018; Hooper et al., 2011; Delp, 2024). This were confirmed using the menstrual history questionnaire.

We also recorded anthropometric measurements, including height and weight. Participants familiarized with the equipment by performing 5 to 10 submaximal knee flexion and extension repetitions at 60°/sec, preparing their muscles and cardiovascular system. They were also familiarized to the fatigue protocol by showing them the area of shuttle run and the distance of it. To ensure the reliability and validity of our study results, we implemented control measures. Participants must have abstained from alcohol, caffeine, exercise, and smoking for 12 hours before each visit. They were encouraged to eat a light meal 2 to 3 hours before testing and stay adequately hydrated.

Visit 2: Fatiguing Exercise

Participants prepared for Visit 2 by avoiding caffeine, alcohol, nicotine, and strenuous exercise for at least 12 hours prior to testing. This precaution was implemented to ensure accurate strength assessments and minimize the influence of external factors that could affect neuromuscular performance.

Upon arrival, participants completed a standardized 5-minute warm-up on an ergometer bicycle. The warm-up was included to increase muscle temperature, enhance neuromuscular activation, and prepare the cardiovascular system for maximal effort testing. Prior research has demonstrated that appropriate warm-up procedures reduce injury risk and improve performance consistency (Ofori et al., 2019).

Following the warm-up, baseline strength assessments of the hamstrings and quadriceps were conducted using an isokinetic dynamometer (KinCom, Chattanooga, Tennessee, USA). Participants were securely seated and carefully aligned to ensure proper joint positioning and minimize compensatory movements. Participants performed three maximal voluntary contractions (MVCs) for both the hamstrings and quadriceps of the dominant leg at 60°/s and 180°/s, with all groups completing testing at both angular velocities. These velocities were selected to represent both slow and moderate contraction speeds, which are commonly used in isokinetic testing to assess strength under different functional conditions (ACSM, 2021; National Strength and Conditioning Association, 2009). Specifically, 60°/s is widely used to evaluate maximal strength, while 180°/s reflects more functionally relevant, higher-speed muscle actions and is sensitive to fatigue-related changes in performance (N. Aagaard et al., 1998; J. Dvir, 2004).

A 30-second rest interval was provided between trials to prevent premature fatigue and maintain measurement reliability (Folland et al., 2002). Peak torque values (Nm) were recorded, and the hamstring-to-quadriceps (H:Q) strength ratio was calculated. Following baseline strength assessments, participants completed a shuttle run–based fatigue protocol conducted at the Sarkeys Fitness Center, University of Oklahoma.

The fatigue protocol consisted of intermittent shuttle running performed over a 10-m distance (back and forth). Participants completed repeated bouts of 30 seconds of maximal-effort running followed by 35 seconds of passive recovery, for a total of six laps (~6.5 minutes). This intermittent design was selected to induce progressive physiological fatigue while incorporating brief recovery periods, which has been shown to effectively stress both aerobic and anaerobic energy systems and replicate sport-specific fatigue patterns (Jens Bangsbo et al., 2008; G. Dupont et al., 2010). Such shuttle-based protocols are commonly used to elicit fatigue and examine its effects on neuromuscular performance and strength outcomes.

This protocol closely resembles repeated high-intensity movement demands commonly observed in athletic activities.

During each running interval, participants performed continuous shuttle runs between designated markers. The total distance covered during each 30-second bout was recorded as an objective indicator of performance capacity.

At the end of each lap, participants reported their ratings of perceived exertion (RPE) using a 0–10 scale. The RPE measure provided a subjective assessment of fatigue progression and perceived effort. The combined use of performance metrics and perceived exertion ratings allowed for comprehensive evaluation of fatigue responses.

This protocol was designed to induce cumulative fatigue through repeated high-intensity efforts. A progressive decline in the distance covered across laps, along with increasing ratings of perceived exertion (RPE), was used to confirm successful fatigue induction.

Immediately following completion of the fatigue protocol, participants returned to the isokinetic dynamometer to undergo post-fatigue strength testing. They performed four maximal voluntary contractions (MVCs) at the same angular velocity used during baseline assessments. Strength measurements were obtained at four time points to evaluate recovery dynamics: immediately post-fatigue, and at 1, 3, and 5 minutes following the protocol. Peak torque values were recorded, and the hamstring-to-quadriceps (H:Q) strength ratio was recalculated. Isokinetic testing is employed because it measures muscle force at a constant speed, making it an effective, valid, and reliable method for assessing muscle performance, including strength, endurance, and balance between opposing muscle groups (Drouin et al., 2004; Meyer et al., 2013). The selection of 60°/sec and 180°/sec provides a comprehensive view of muscle function: slower speeds facilitate maximal strength assessment over a broader range of motion, while higher speeds capture explosive strength during rapid movements (Lemaire et al., 2014; Grbic et al., 2017). Speeds exceeding 180°/sec are typically avoided, as they may restrict range of motion and compromise measurement accuracy (Brown et al., 1995). Activities such as sprinting, plyometrics, and certain throwing motions in sports involve angular speeds that can exceed 180°/sec, highlighting the relevance of this threshold in high-speed athletic movements.

Instrumentation

We recorded anthropometric data, including height and weight, using a Detecto Physician's Scale (Detecto USA, Webb City, MO) to ensure precision, with height measured to the nearest 0.5 cm and weight to the nearest 0.1 kg. Isokinetic strength were evaluated using a KinCom Dynamometer (Chattanooga, Tennessee, USA), connected to a Model SB-500 force transducer (Transducer Techniques, Temecula, CA). The dynamometer system, sampling at 2000 Hz through a Biopac MP150 system, provided high-resolution data on muscle strength.

Questionnaires

A variety of validated questionnaires were used in this study to assess participants' health, activity levels, mood states, and menstrual cycle information. These measures help confirm participant eligibility, ensure safety, and establish readiness for each session, all of which contribute to the overall reliability and validity of the collected data.

Physical Activity Readiness Questionnaire (PAR-Q): The PAR-Q screens participants for cardiovascular, pulmonary, and metabolic health risks, helping confirm their readiness for physical activity. Participants must answer “no” to all items to demonstrate that they can safely participate in the study’s fatigue protocol. This screening helps minimize injury risk by including only those physically capable of engaging in the study’s exercise components.

Training Diary Review: To confirm participants’ classification as “untrained,” their weekly training diaries were reviewed. According to American College of Sports Medicine (ACSM) guidelines, untrained participants should report less than 150 minutes of moderate-intensity aerobic activity or less than 75 minutes of vigorous-intensity activity (ACSM, 2018).

Menstrual History Questionnaire: Female participants completed a menstrual history questionnaire to help identify their menstrual cycle phase and ensure testing occurs outside the follicular phase. The follicular phase in untrained individuals, generally the first two weeks of the cycle, can affect perceived exertion and vascular resistance during resistance exercises (Augustine et al., 2018; Hooper et al., 2011; Delp, 2024). Controlling for menstrual cycle phases enhances measurement consistency by minimizing hormonal influences on physical performance.

Profile of Mood States (POMS): The POMS questionnaire assessed participants’ mood states on each testing day. It includes descriptions of emotions like “tired,” “energetic,” and “anxious,” which participants rate on a scale from 0 (“not at all”) to 4 (“extremely”). This shortened version of POMS assesses mood factors relevant to exercise readiness, including fatigue, vigor, and total mood disturbance (Shacham, 1983). Tracking mood states helps verify participants' psychological readiness for exercise, allowing for the control of psychological variables that might influence exercise performance and enhance data interpretation.

Data Management:

Participants' study-related documents and data collection sheets were stored in individual folders, each securely locked in the Human Performance and Body Composition lab at the University of Oklahoma. Collected data, including measurements recorded by study instruments, was saved on a designated flash drive to ensure data integrity and confidentiality. In the future, all data will be managed and stored according to strict protocols, ensuring participant privacy and the study's integrity.

Statistical analysis:

Statistical analyses were conducted using IBM SPSS (Version 29; IBM Corp., Armonk, NY, USA) Statistics to examine the effects of fatigue on muscle performance variables. Descriptive statistics (mean ± standard deviation) were calculated for all key variables. Normality of the data was assessed using the Shapiro–Wilk test. To evaluate differences between pre- and post-fatigue conditions, paired samples t-tests were performed. In addition, a repeated-measures analysis of variance (ANOVA) was conducted to examine the effects of time (pre vs. post) and velocity (60°/s vs. 180°/s) on peak torque and the hamstring-to-quadriceps (H:Q) ratio. Both time and velocity were treated as within-subject factors, as all 15 participants completed testing at both angular velocities across all time points When appropriate, Bonferroni adjustments were applied for post hoc comparisons. Effect sizes were reported using partial eta squared (ηp^2) for ANOVA and Cohen's d for pairwise comparisons. The magnitude of ηp^2 was interpreted as small ($\geq .01$), medium ($\geq .06$), and large ($\geq .14$), while Cohen's d was interpreted as small (0.2), medium (0.5), and large (0.8), based on conventional thresholds (Jacob Cohen, 1988). Statistical significance was set at $p < .05$.

CHAPTER 4 RESULTS

Participants characteristics

A total of 15 participants completed all study procedures and were included in the final analysis. Participant training status was evaluated using weekly training diaries, which assessed the frequency and duration of physical activity. Based on these records, 13 out of 15 participants were classified as untrained, indicating low levels of structured exercise consistent with the study's inclusion criteria. Detailed descriptive statistics for participant characteristics, including comparisons between male and female participants, are presented in Table 1

Table 1

Comparison of Age, Height, and Weight Between Male and Female Participants

Variable	All (N=15)	Male (n=11)	Female (n=4)	P value
Age (y)	25.13 ± 5.90	23.82 ± 5.27	28.75 ± 6.90	0.16
Height (cm)	178.13 ± 9.21	181.73 ± 8.51	168.25 ± 1.50	< 0.001
Weight (kg)	78.39 ± 16.11	78.58 ± 16.84	77.85 ± 15.65	0.94

Note. All values are mean ± SD.

Profile of Mood States

A repeated-measures ANOVA was conducted to examine changes in mood states between the familiarization session (Day 1) and the experimental session (Day 2) using the fatigue and vigor subscales of the Profile of Mood States (POMS). This analysis was performed to verify that participants entered the experimental session in a comparable or improved psychological state, thereby minimizing potential confounding effects of mood on performance outcomes. Results indicated a significant decrease in perceived fatigue from Day 1 ($M = 1.20$, $SD = 0.86$) to Day 2 ($M = 0.73$, $SD = 1.03$), $F(1, 14) = 7.98$, $p = 0.014$, partial $\eta^2 = 0.36$. There was no significant difference in vigor between Day 1 (M = 1.20, SD = 1.42) and Day 2 (M = 1.07, SD = 1.28), $F(1, 14) = 0.32$, $p = 0.582$, partial $\eta^2 = .02$ as shown in Table 2. These findings indicate that participants reported lower fatigue and stable vigor at the start of the experimental session, suggesting that baseline psychological readiness was not a confounding factor in subsequent performance testing.

Table 2

Changes in Mood States Between Familiarization (Day 1) and Experimental Session (Day 2)

Variable	Day 1 M (SD)	Day 2 M (SD)	F(1, 14)	p	ηp^2
Fatigue	1.20 (0.86)	0.73 (1.03)	7.98	.014	.36
Vigor	1.20 (1.42)	1.07 (1.28)	0.32	.582	.02

Note. M = mean; SD = standard deviation; ηp^2 = partial eta squared.

Normality Testing

Before conducting statistical analyses, statistical assumptions were evaluated using the Shapiro–Wilk test. Results indicated that all strength variables were normally distributed ($p > 0.05$), supporting the use of parametric statistical procedures. Normality of hamstring-to-quadriceps (H:Q) ratio variables was also confirmed ($p > 0.05$).

Fatigue Induction

To examine whether the Shuttle run protocol induced fatigue, a repeated measures ANOVA was conducted to evaluate differences in the distance covered across the six laps. Prior to interpreting the ANOVA results, Mauchly's test of sphericity was examined to determine whether the assumption of sphericity was met. The test indicated that the assumption of sphericity was violated, $W = 0.065$, $p = 0.003$. Therefore, the Greenhouse Geisser correction was applied to adjust the degrees of freedom. The repeated-measures ANOVA indicated that the effect of lap number on distance covered was not statistically significant, $F(2.29, 32.08) = 2.35$, p = 0.105, partial $\eta^2 = 0.14$ as shown Figure 1. Although the mean distance tended to decrease across later laps, the change in performance was not large enough to reach statistical significance. As illustrated in Figure 2, there was considerable variability in individual performance across laps. While most participants demonstrated a gradual decline in distance, indicating fatigue, a small number showed stable or even increased performance over time. This variability in individual responses may help explain the absence of a statistically significant overall effect.

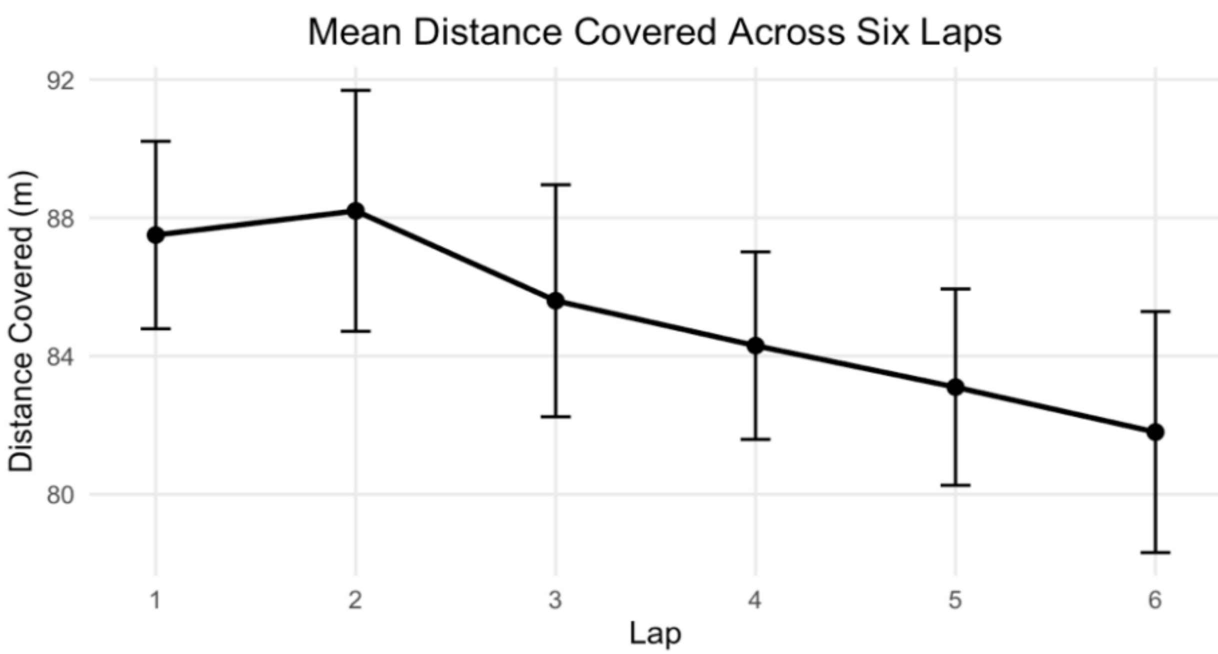

Figure 1. Mean distance covered across six laps. Values are mean ± SD.

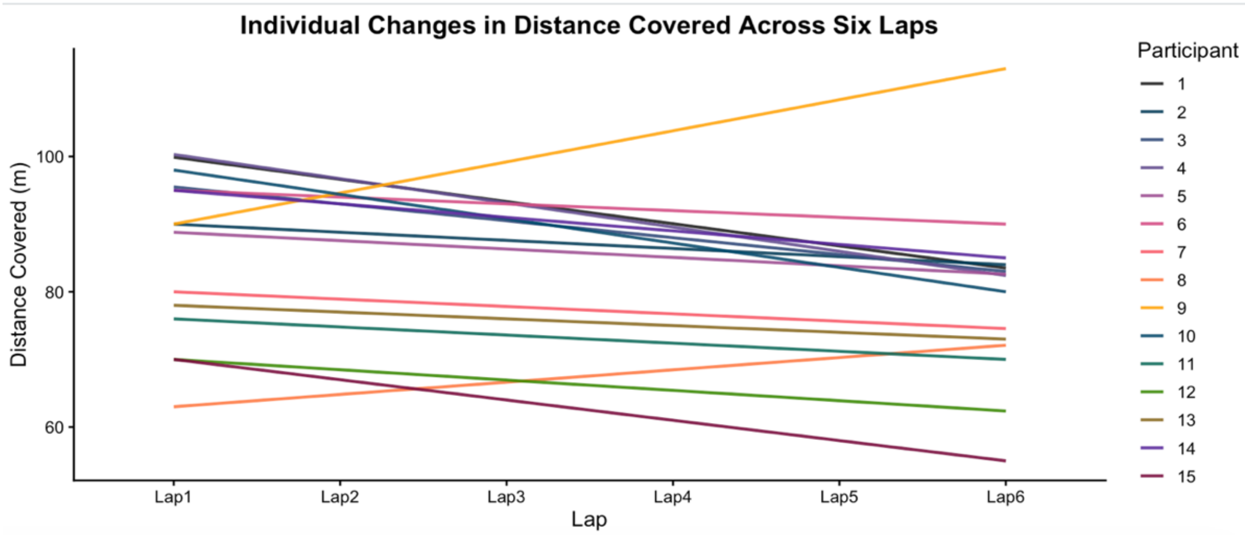

Figure 2. Individual changes in distance covered across six laps for each participant.

Percent Decline Analysis

A One-Way ANOVA was conducted to examine whether using percent decline in performance differed significantly from zero. A value of zero represents no change in performance between the first and final laps. The analysis indicated that the mean percentage decline in performance was 6.65% (SD = 13.60). Although the average decline suggested a reduction in Shuttle run performance across laps, the result did not reach statistical significance, $t(14) = 1.89$, $p = 0.079$. The 95% confidence interval for the mean difference ranged from −0.88 to 14.18. Table 3 shows the percent decline for each individual.

Table 3

Percentage Decline in Performance from Distance 1 to Distance 6

Participant	Fatigue (%)
1	16.42
2	6.67
3	13.09
4	17.85
5	6.98

Participant	Fatigue (%)
6	5.26
7	6.80
8	−14.45
9	−25.56
10	18.37
11	7.89
12	10.90
13	6.41
14	10.53
15	21.43

Note. Fatigue (%) represents the percentage decline in performance between Distance 1 and Distance 6 calculated as $(Distance_1 - Distance_6)/Distance_1 \times 100$. Positive values indicate a decline in performance, whereas negative values indicate improved performance across trials.

Perceived Exertion

A paired samples t-test revealed a significant increase in perceived exertion from lap 1 (M = 2.47, SD = 1.06) to lap 6 (M = 9.47, SD = 0.92), $t(14) = -20.71$, $p < 0.001$. Perceived exertion increased significantly from the beginning to the end of the protocol, indicating substantial fatigue development across laps as shown in Figure 3.

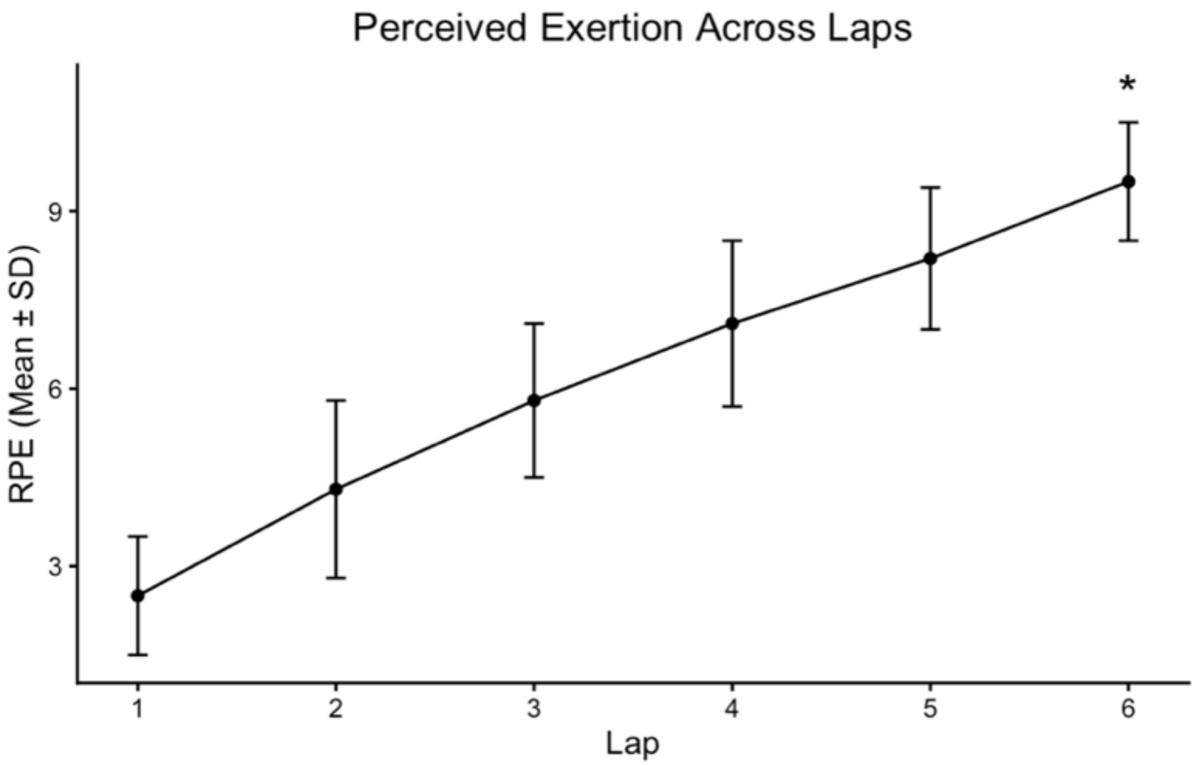

Figure 3. Perceived exertion across six laps. Values are mean ± SD. *Significantly different from lap 1 ($p < .05$).

Peak Torque

A series of 2 × 2 repeated-measures ANOVAs was conducted to examine the effects of time (pre vs. post) and velocity (60°/s vs. 180°/s) on peak torque for both the hamstring and quadriceps muscles. For the hamstrings**,** results indicated a significant main effect of time, with peak torque decreasing from pre-fatigue (M = 94.61, SE = 10.35) to post-fatigue (M = 78.28). A main effect of velocity was also observed, with slightly higher torque values at 60°/s compared to 180°/s. Examination of the interaction pattern showed that hamstring torque remained relatively stable at 60°/s but showed a larger decline at 180°/s. Bonferroni-adjusted pairwise comparisons indicated no significant difference between velocities in the pre-fatigue condition (p = .960); however, in the post-fatigue condition, torque at 60°/s was significantly higher than at

180°/s (Mean Difference = 11.78 Nm, SE = 4.82, p = .028), suggesting a greater fatigue effect at higher velocity. For the quadriceps**,** a similar pattern conducted. Peak torque decreased from pre-fatigue (M = 166.52, SE = 14.68) to post-fatigue (M = 154.06, SE = 14.96), and torque values were higher at 60°/s compared to 180°/s. However, the velocity-specific response differed across conditions. At 60°/s, quadriceps torque showed no meaningful change from pre- to post-fatigue, whereas at 180°/s, a substantial decline was observed. Bonferroni-adjusted pairwise comparisons confirmed that the pre–post difference at 60°/s was not statistically significant ($p = .570$), while the decline at 180°/s was statistically significant (Mean Difference = 31.06 Nm, SE = 7.27, $p < .001$) as illustrated in Table 4, Figure 4 and 5.

Table 4

Mean Differences in Peak Torque from Pre- to Post-Fatigue Across Muscles and Velocities

Muscle	Velocity	Pre (M ± SD)	Post (M ± SD)	Mean Difference (Nm)
Hamstring	60°/s	94.73 ± 41.49	84.17 ± 37.23	10.56
Hamstring	180°/s	94.49 ± 40.73	72.39 ± 30.45	22.10
Quadriceps	60°/s	164.13 ± 51.80	170.28 ± 55.29	-6.15
Quadriceps	180°/s	168.90 ± 67.39	137.84 ± 70.14	31.06

Note. Mean difference = Pre − Post; positive values indicate a decrease in peak torque, and negative values indicate an increase.

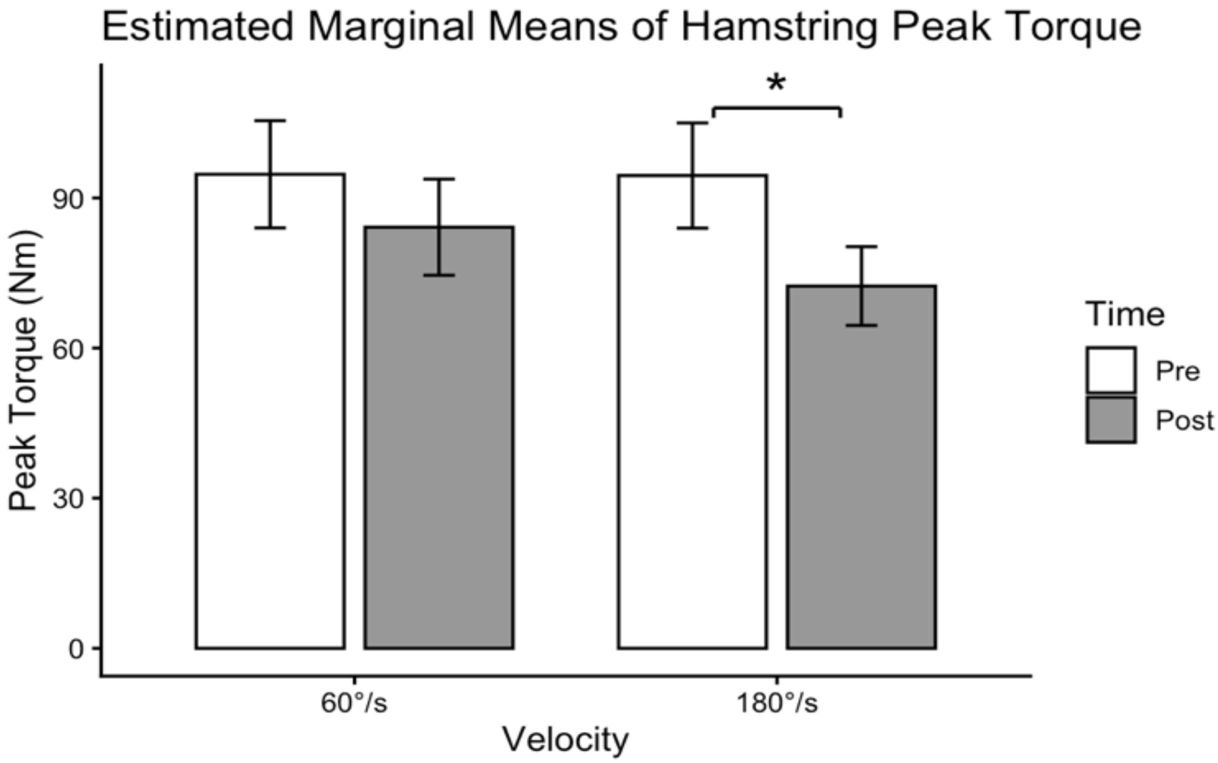

Figure 4. Estimated marginal means of hamstring peak torque before and after the fatigue protocol at 60°/s and 180°/s. Error bars represent standard errors.

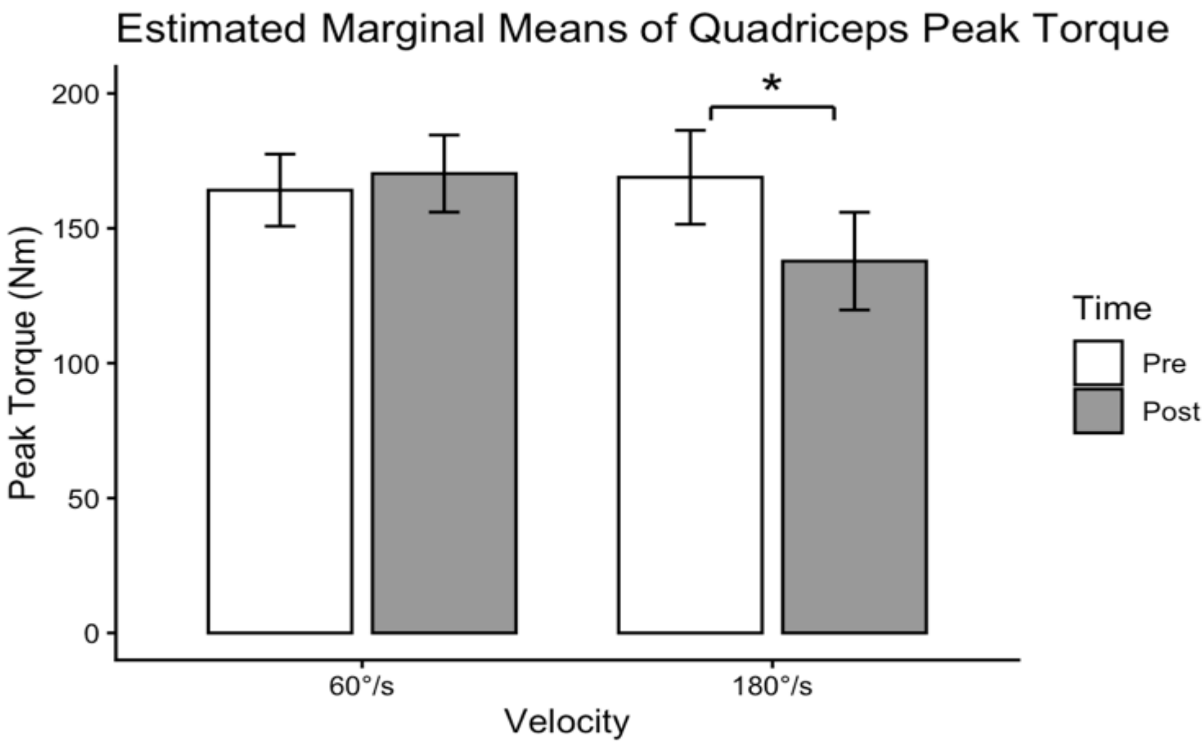

Figure 5. Estimated marginal means of quadriceps peak torque before and after the fatigue protocol at 60°/s and 180°/s. Error bars represent standard errors.

Hamstring-to-Quadriceps (H:Q) Strength Ratio

A repeated measures ANOVA was conducted to examine the effects of time (pre vs. post) and velocity (60°/s vs. 180°/s) on the H:Q ratio. Results indicated that there was no significant main effect of time, $F(1, 14) = 0.03$, $p = .868$, partial $\eta^2 = .002$. Bonferroni-adjusted pairwise comparisons confirmed that there was no significant difference in H:Q ratio between pre- and post-fatigue conditions (mean difference = −0.007, SE = 0.043, $p = .868$, 95% CI [−0.100, 0.085]). In contrast, there was a significant main effect of velocity, $F(1, 14) = 5.30$, $p = .037$, partial $\eta^2 = .275$. Bonferroni-adjusted pairwise comparisons indicated that the H:Q ratio was significantly higher at 60°/s compared to 180°/s, with a mean difference of 0.068 (SE = 0.030, $p = .037$, 95% CI [0.005, 0.131]). The interaction between time and velocity was not statistically significant, $F(1, 14) = 3.63$, $p = .077$, partial $\eta^2 = .206$; however, the moderate effect size suggests a potential trend. This indicates that the effect of fatigue may differ across velocities, even though this pattern did not reach statistical significance in the present sample, as illustrated in Figure 5. As shown in Figures 6 and 7, individual changes in H:Q ratio varied across participants at both 60°/s and 180°/s. Some participants showed increases from pre- to post-fatigue, while others showed decreases, indicating no consistent pattern of fatigue across individuals. Differences between velocities are also visible, supporting the effect of contraction speed on H:Q ratio.

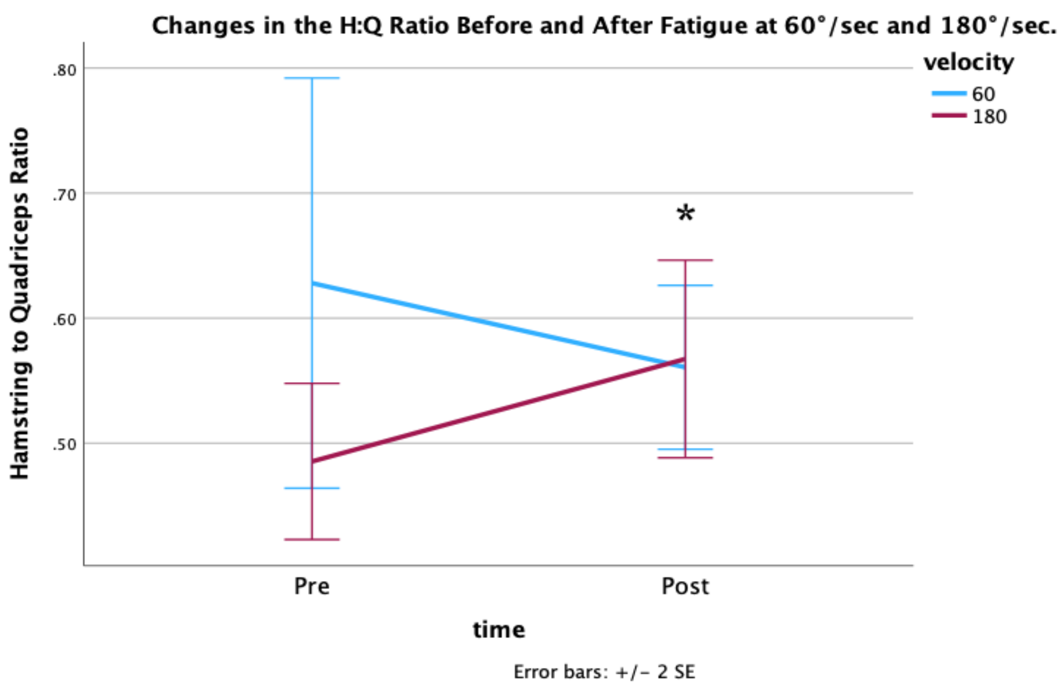

Figure 6. Changes in H:Q ratio before and after fatigue at 60°/s and 180°/s (M ± SD). Error bars = ±2 SE. *$p < .05$.

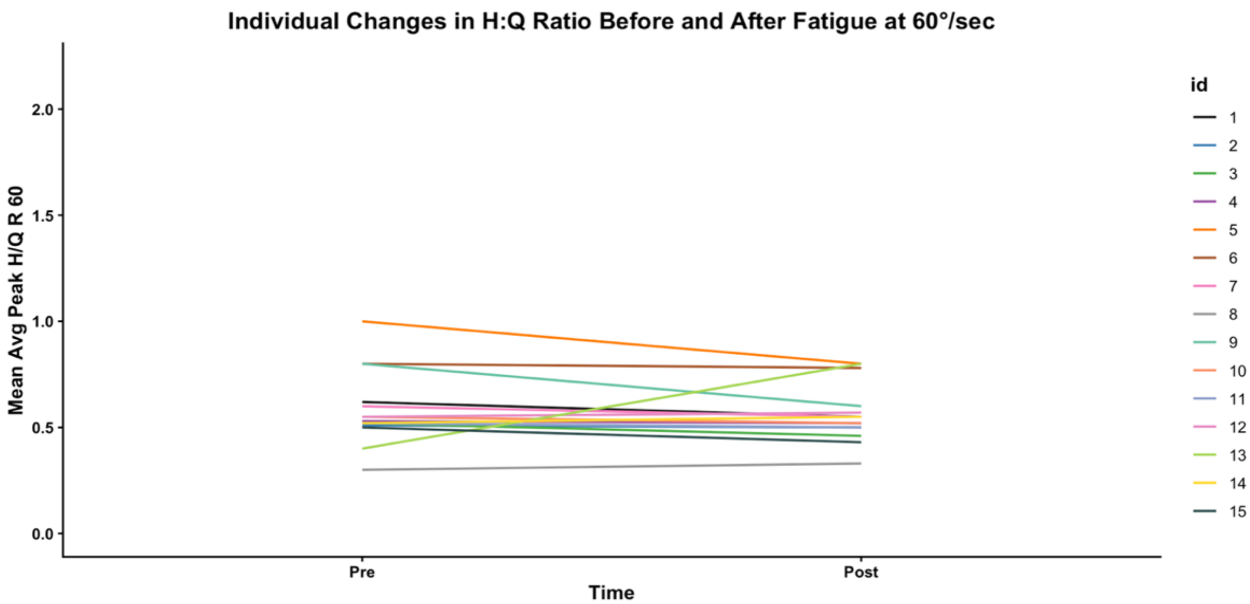

Figure 7. Individual responses show high variability, with most participants exhibiting minimal change, supporting the non-significant time effect.

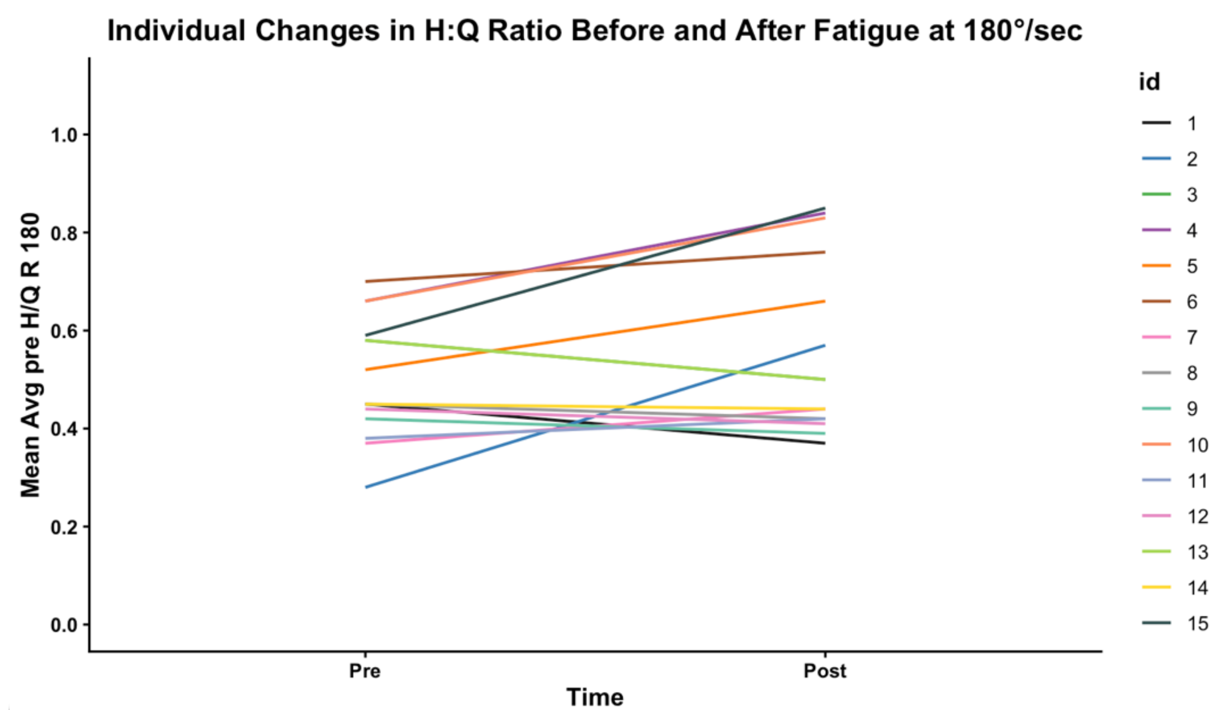

Figure 8. Greater variability and more noticeable changes were observed across individuals, though responses remained inconsistent, aligning with the lack of a consistent time effect.

Post Hoc Power Analysis

To further assess the statistical sensitivity of the pre–post comparisons, a post hoc power analysis was conducted. The results indicated limited statistical power to detect changes in the H:Q ratio following the fatigue protocol. Specifically, statistical power for the H:Q ratio at 60°/s was low (power = 0.13), reflecting the small observed effect size. At 180°/s, statistical power was moderate (power =0 .55), but remained below the conventional threshold of 0.80.

Effect Size Analysis

To further evaluate the magnitude of pre–post changes, standardized effect sizes were calculated. The results indicated a small effect for the H:Q ratio at 60°/sec (Cohen's d = 0.24; Hedges' g = 0.23), suggesting minimal changes following the fatigue protocol. In contrast, a moderate effect size was observed at 180°/sec (Cohen's d = 0.54; Hedges' g = 0.51), indicating a greater magnitude of change in the H:Q ratio at the higher angular velocity.

CHAPTER 5: DISCUSSION AND CONCLUSION

The purpose of this study was to examine the effects of fatigue on hamstring-to-quadriceps (H:Q) strength ratio among different individuals. Specifically, this study aimed to determine whether a fatigue protocol would alter force production, muscle balance, and performance outcomes across different angular velocities. Understanding these relationships is important, as muscle imbalances and fatigue have been strongly associated with injury risk, particularly at the knee joint (Kellis et al., 2007; Timmins et al., 2016). Overall, the findings demonstrated that fatigue significantly reduced peak torque at both contraction velocities, while the H:Q ratio remained relatively stable. Additionally, perceived exertion increased significantly across laps, indicating that participants experienced substantial fatigue, even though objective performance measures such as distance covered did not significantly decline. These findings suggest that fatigue affects force production, perception, and muscle balance differently, highlighting the complexity of neuromuscular fatigue responses.

Fatigue Induction: Performance and Distance Covered

To evaluate whether the fatigue protocol was effective, changes in performance across laps were first examined. Although descriptive trends suggested that the distance covered declined progressively from the early laps to the later laps, this decline was not statistically significant. The lack of statistical significance appears to be largely explained by the high variability observed across participants. While many individuals demonstrated a gradual reduction in performance, others maintained or even improved their performance across laps. This variability likely reduced the overall statistical power to detect a consistent decline. These findings suggest that, although the fatigue protocol may have influenced performance at the descriptive level, it did not produce a consistent or statistically significant reduction in distance covered within this sample. This pattern is consistent with previous research indicating that individuals may maintain performance through compensatory mechanisms, such as pacing strategies or increased central drive (Enoka & Duchateau, 2008). Additionally, untrained individuals often exhibit greater variability in fatigue responses due to differences in neuromuscular coordination and conditioning (Myer et al., 2014; Kellis et al., 2011).

Perceived Exertion and Subjective Fatigue

In contrast to performance outcomes, perceived exertion increased significantly from the beginning to the end of the fatigue protocol. This finding indicates that participants clearly experienced fatigue at a subjective level, even though objective performance measures did not demonstrate a statistically significant decline. The steady rise in RPE across laps further supports that the protocol successfully induced a progressive sense of effort and physiological strain. This discrepancy between subjective fatigue and objective performance is well established in the literature (Samuele Marcora.,2009). Central fatigue mechanisms, including alterations in motor drive, neurotransmitter activity, and afferent feedback from working muscles, are known to elevate perceived effort during prolonged or repeated exercise (Gandevia, 2001; Taylor et al., 2006). These mechanisms influence how effort is perceived without necessarily causing an immediate reduction in force production or performance output. In other words, individuals may feel increasingly fatigued even while maintaining their physical performance.

The present findings align with this body of evidence, suggesting that participants experienced substantial subjective fatigue despite maintaining performance output. This pattern may also be explained by compensatory mechanisms, such as increased central motor drive or altered movement strategies, which allow individuals to sustain performance temporarily under fatigued conditions (Enoka & Duchateau, 2008). Furthermore, variability in individual fatigue perception, motivation, and tolerance to discomfort may have contributed to the observed divergence between subjective and objective measures. Overall, these results highlight the importance of incorporating both subjective and objective indicators when evaluating fatigue. Relying solely on performance-based measures may underestimate the true extent of fatigue experienced by individuals, particularly in short-term or moderate-intensity protocols.

Peak Torque and Peripheral Fatigue

Peak torque results provided clear evidence of fatigue-related impairments in force production, particularly at higher contraction velocities. Both hamstring and quadriceps muscles demonstrated reductions in torque following fatigue; however, these changes were not uniform across velocities. For the hamstrings, torque declined from pre- to post-fatigue, with a greater reduction observed at 180°/s compared to 60°/s. Similarly, quadriceps torque showed a substantial decline at 180°/s, while little to no change was observed at 60°/s. Notably, the quadriceps demonstrated a greater reduction in torque at 180°/s compared to 60°/s from pre- to post-fatigue, suggesting increased sensitivity to fatigue during higher-velocity contractions. In contrast, hamstring torque remained relatively consistent across testing velocities. These findings are consistent with the force–velocity relationship, which states that muscles produce greater force at slower contraction speeds and less force at higher velocities (Fitts, 2008). Furthermore, differences between contraction velocities during maximal voluntary contractions (MVCs) may be explained by the force–velocity relationship and velocity-dependent susceptibility of neuromuscular function to fatigue, rather than differences in initial motor unit recruitment.

Although MVCs involve near-maximal voluntary activation across conditions, high-velocity contractions produce lower force output due to inherent limitations in cross-bridge cycling and force generation at faster shortening speeds. Consequently, these contractions are more sensitive to fatigue-related impairments in both peripheral and central components of neuromuscular function. From a physiological perspective, these responses are consistent with peripheral fatigue mechanisms, including impairments in excitation–contraction coupling, accumulation of metabolic byproducts, and reduced calcium availability within muscle fibers (Roger M. Enoka & Jacques Duchateau, 2008; Robert H. Fitts, 2008). These mechanisms may contribute to the greater reduction in torque observed at 180°/s. The muscle-specific responses observed in this study further suggest that the quadriceps may exhibit greater fatigue-related reductions in torque under high-velocity conditions compared to the hamstrings. This difference may be influenced by variations in muscle architecture, functional role during dynamic contractions, and neuromuscular control strategies between muscle groups

Hamstring-to-Quadriceps (H:Q) Ratio

Although individual responses varied, most participants demonstrated minimal changes in H:Q ratio from pre- to post-fatigue, supporting the non-significant main effect of time. However, while the ratio appeared stable from a statistical perspective, individual-level data revealed divergent patterns, with some participants showing increases and others decreases in H:Q ratio. This suggests that the group-level stability may reflect averaging effects rather than a true absence of change.

For example, Participant 1 demonstrated increases in H:Q ratio at both velocities, rising from 0.60 to 0.81 at 60°/s and from 0.52 to 0.76 at 180°/s, indicating greater fatigue in the quadriceps relative to the hamstrings. In contrast, Participant 7 exhibited decreases in H:Q ratio at both velocities, from 0.64 to 0.55 at 60°/s and from 0.46 to 0.33 at 180°/s, suggesting greater fatigue in the hamstrings. Participant 11 showed a mixed response, with an increase at 60°/s (0.60 to 0.76) and a decrease at 180°/s (0.70 to 0.60), indicating that fatigue did not affect both muscle groups uniformly and may depend on contraction velocity or individual neuromuscular characteristics**,** as illustrated in Figure 8.

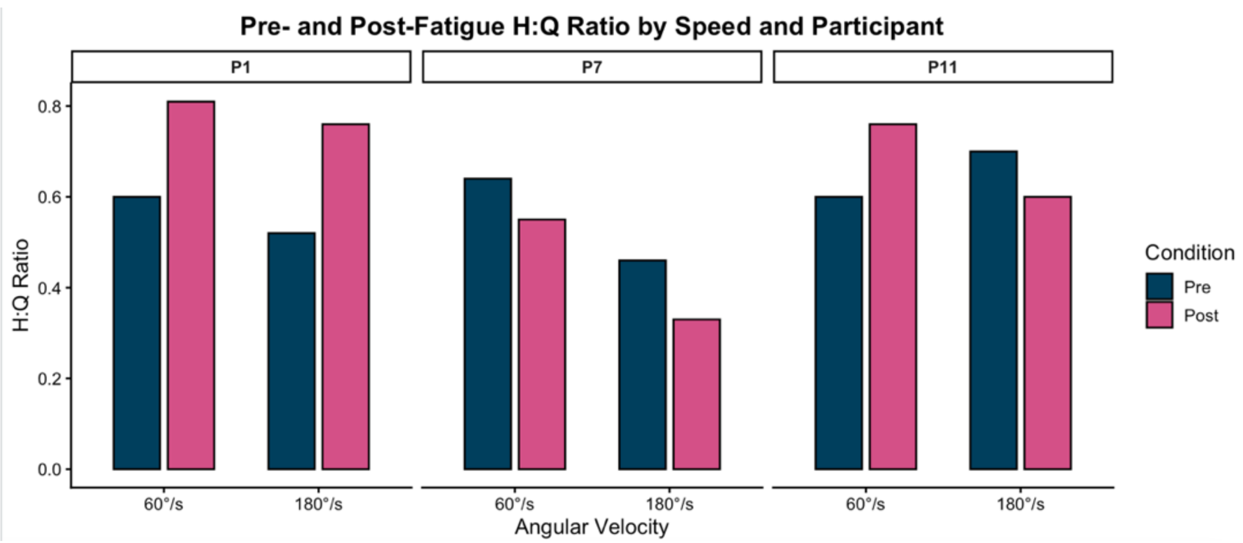

Figure 8. Pre- and post-fatigue H:Q ratio values at 60°/s and 180°/s for Participants 1, 7, and 11.

These individual examples illustrate that fatigue responses were highly variable and muscle-specific, even when the overall group trend remained non-significant. This pattern is further supported by the individual profile plots, which demonstrated considerable variability in H:Q ratio responses at both velocities. At 60°/s, most participants exhibited minimal changes despite some increases and decreases, whereas at 180°/s, greater variability and more noticeable changes were observed, suggesting a potential trend toward velocity-dependent fatigue effects.

A significant main effect of velocity was observed, with higher H:Q ratios at 60°/s compared to 180°/s. This finding aligns with previous research demonstrating that contraction speed influences the H:Q ratio, as muscle activation patterns and force production characteristics differ across velocities (Aagaard et al., 1998; Rosene et al., 2001) . Despite the absence of a significant time effect, the moderate effect size for the interaction between time and velocity suggests a potential trend. This indicates that fatigue may influence the H:Q ratio differently across contraction speeds, but the current sample size may have limited the ability to detect statistically significant changes.

Importantly, these findings highlight a key limitation of relying solely on the H:Q ratio. While the ratio remained stable, both hamstring and quadriceps peak torque values declined, particularly at higher velocities. This suggests that individuals may maintain a "normal" H:Q ratio while still experiencing substantial reductions in absolute muscle strength, which may have important implications for performance and injury risk.

Individual Variability in Fatigue Responses

A key strength of this study is its focus on an untrained population, which is underrepresented in the literature. Most previous studies have primarily focused on trained athletes, limiting the generalizability of findings to the broader population, particularly individuals who engage in recreational or irregular physical activity. By examining untrained individuals, the present study provides insights that are more reflective of the general population, where injury risk may be influenced by different neuromuscular characteristics. The high variability observed across participants is consistent with research indicating that untrained individuals exhibit greater variability in neuromuscular performance and fatigue responses (Myer et al., 2014; Kellis et al., 2011). This variability was particularly evident in the shuttle run fatigue protocol. Although the overall decline in distance covered across laps was not statistically significant, individual responses varied considerably. For example, some participants demonstrated a clear reduction in distance covered across successive laps, indicating fatigue development, whereas others maintained or even increased their performance. These findings suggest that fatigue responses are highly individualized, especially in untrained populations, where differences in pacing strategies, motivation, and neuromuscular efficiency may influence performance outcomes.

Similarly, variability was observed in peak torque responses, where some participants showed substantial declines following fatigue, while others exhibited minimal changes. This pattern reinforces the idea that fatigue is not a uniform phenomenon and may manifest differently depending on individual characteristics such as baseline strength, coordination, and fatigue resistance. Additionally, untrained individuals may be more susceptible to muscle imbalances and injury due to lower baseline strength and reduced neuromuscular control (Croisier et al., 2002; Hewett et al., 2010) . For instance, individuals with relatively weaker hamstrings compared to quadriceps may have difficulty stabilizing the knee during dynamic activities such as running or rapid deceleration, thereby increasing the risk of anterior cruciate ligament (ACL) injury. In untrained populations, these imbalances may be more pronounced because the neuromuscular system is not conditioned to efficiently coordinate muscle activation under physical stress.

These findings confirm the importance of developing population-specific guidelines for assessing and addressing muscle imbalances. Unlike trained athletes, untrained individuals may require different benchmarks for muscle balance, fatigue tolerance, and performance assessment. Therefore, evaluating fatigue through both performance-based measures, such as shuttle run distance, and physiological measures, such as peak torque, is essential for obtaining a comprehensive understanding of fatigue in this population. Such an approach can inform the development of targeted interventions aimed at improving neuromuscular function, enhancing fatigue resistance, and ultimately reducing injury risk.

Practical Implications

The findings of this study have several important implications. First, fatigue can significantly reduce muscle force production even when performance appears stable, indicating that performance measures alone may not fully capture fatigue-related changes. Second, the H:Q ratio may not be sensitive to acute fatigue in untrained individuals, suggesting that multiple assessment methods should be used when evaluating muscle function and injury risk. Third, the influence of contraction velocity highlights the importance of selecting appropriate testing conditions. Finally, the high variability in individual responses suggests that personalized approaches may be necessary in both research and applied settings.

Limitations and Future Directions

This study has several limitations. The small sample size may have limited statistical power, particularly for detecting changes in the H:Q ratio. Additionally, the use of an untrained population may limit generalizability to trained or athletic populations. Investigating different types of fatigue protocols may also provide further insight into how fatigue affects muscle balance.

Conclusion

In conclusion, this study examined the effects of fatigue on the hamstring-to-quadriceps (H:Q) strength ratio, peak torque, and performance outcomes in an untrained population. It was hypothesized that there would be no difference in the H:Q ratio following fatigue (H_0), while the alternative hypothesis (H_1) proposed that the H:Q ratio would increase after a bout of fatiguing exercise. The findings of this study did not support the alternative hypothesis. Instead, the H:Q ratio remained relatively stable following the fatigue protocol, indicating that fatigue affected both muscle groups proportionally. Therefore, the null hypothesis cannot be rejected. Despite the stability of the H:Q ratio, fatigue significantly reduced peak torque at both contraction velocities, confirming that the fatigue protocol effectively impaired force-producing capacity. In contrast, performance outcomes, as measured by distance covered during the shuttle run, did not show a statistically significant decline, although descriptive trends suggested a gradual reduction. At the same time, perceived exertion increased significantly, indicating that participants experienced substantial fatigue from a subjective perspective. Together, these findings highlight a dissociation between subjective fatigue, objective performance, and muscular force production.

Additionally, the significant effect of contraction velocity on the H:Q ratio underscores the importance of testing conditions when evaluating muscle function and interpreting injury risk indicators. A key contribution of this study is the demonstration of considerable individual variability in fatigue responses, suggesting that fatigue is not a uniform process and may be influenced by individual neuromuscular characteristics. From a theoretical perspective, these findings support the multidimensional nature of fatigue, involving both central and peripheral mechanisms. From a practical standpoint, the results suggest that practitioners should adopt a multidimensional approach when assessing fatigue, incorporating strength, perception, and performance measures rather than relying on a single indicator. Overall, this study contributes to the growing body of literature by emphasizing the complexity of fatigue responses and the need for comprehensive evaluation strategies in both research and applied settings.

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APPENDIX I: IRB OUTCOME LETTER

The UNIVERSITY of OKLAHOMA

Institutional Review Board for the Protection of Human Subjects

Approval of Annual Check-In Form

Date: December 01, 2025 **IRB#:** 18085

Principal Investigator: Rebecca Larson, PhD
Status Report Due: 11/30/2026
Approval Date: 12/01/2025
Expedited Category: 4 & 7
Study Title: Investigating the Hamstring-to-Quadriceps Muscle Strength Ratio in a Fatigued State

On behalf of the Institutional Review Board (IRB), I have reviewed and approved your annual check-in form. To view the documents approved for this study, open the study from the *My Studies* option, and click on either "Study Application," "Informed Consent," or "Other Study Documents" for a list of approved documents.

You are reminded that, as principal investigator of this research, it is still your responsibility to:

- Conduct the research study in a manner consistent with the requirements of the IRB and federal regulations 45 CFR 46.
- Obtain informed consent and research privacy authorization using the currently approved, stamped forms and retain all original, signed forms, if applicable.
- Request approval from the IRB prior to implementing any/all modifications.
- Promptly report to the IRB any harm experienced by a participant that is both unanticipated and related, per HRPP SOP 407.
- Maintain accurate and complete study records for evaluation by the HRPP Quality Improvement Program and, if applicable, inspection by regulatory agencies and/or the study sponsor.
- **Submit an annual status report to the IRB to provide the study/recruitment status and report all harms and deviations that may have occurred.**
- **Submit a final closure report at the completion of the project.**

You will receive notification approximately 60 days prior to the status report due-date noted above. You are responsible for submitting check-in forms in a timely fashion in order to maintain continued IRB approval.

If you have questions about this notification or using iRIS, contact the IRB at 405-325-8110 or irb@ou.edu.

Cordially,

Lara Mayeux, Ph.D.
Chair, Institutional Review Board

APPENDIX II: RECRUITMENT FLYER

SUBJECTS NEEDED FOR RESEARCH STUDY

Investigating the Hamstring-to-Quadriceps Muscle Strength Ratio in a Fatigued State

We are looking for:

Males and Females

- Age 18-40
- Free of cardiovascular and neurological disorders or injuries that may affect the lower limbs.

If interested, contact:

Reza Namavar
Reza.namavar@ou.edu

Or Rebecca Larson, PhD
rdlarson@ou.edu

Requires only 2 visits for ~30 min each
First visit: familiarization + Remaining visits: H:Q ratio test

Compensation: US $20 Amazon gift card

COLLEGE OF ARTS AND SCIENCES
DEPARTMENT OF HEALTH AND EXERCISE SCIENCE
The UNIVERSITY of OKLAHOMA

The University of Oklahoma is an equal opportunity institution. Approved by ______

Reza Namavar
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Human Research Participant Protection
The University of Oklahoma
IRB APPROVED
AAHRPP

IRB NUMBER: 18085
IRB APPROVAL DATE: 01/07/2025

APPENDIX III: CONSENT FORM

Signed Consent to Participate in Research
University of Oklahoma

Would you like to be involved in research at the University of Oklahoma?

I am Reza Namavar from the health and exercise science Department, and I invite you to participate in my research entitled Investigating the Hamstring-to-Quadriceps Muscle Strength Ratio in a Fatigued State. This research is being conducted at HES department body composition lab. You were selected as a possible participant because you are free of any lower body injuries (knee, hip, quadriceps, or hamstring), do not have cardiovascular diseases, are not taking medications for cardiovascular, metabolic, neurological, or psychiatric conditions, and are not pregnant. You must be at least 18 years of age to participate in this research.

<u>Please read this document and contact me to ask any questions you may have BEFORE agreeing to participate in my research.</u>

What is the purpose of this research? This study aims to determine the differences in hamstring to quadriceps strength ratio between non-fatigue and fatigue states in college-aged individuals.

How many participants will be in this research? About 100 people will take part in this research.

What will I be asked to do? If you agree to participate in this research, you will be asked to attend two visits, each lasting about 30 minutes. During the first visit, you will provide informed consent, complete screening questionnaires, and familiarize yourself with the equipment. You will also fill out a mood assessment to measure your motivation before exercise, and if you are female, you will complete a menstrual history questionnaire on your first visit.

During the second visit, you will perform three maximum voluntary contractions (MVC) for both your hamstring and quadriceps muscles. During the MVCs you will be asked to perform leg extension and leg curl exercise movements at slow and fast speeds (60° and 180° per second or 180° and 60° per second). Following the MVCs you will complete a fatiguing run test, followed by MVCs at the same speeds. The fatiguing run test consists of running back and forth on a 10-meter course for 30 seconds followed by 35 seconds of rest. This will be performed 6 times for a total of 180 seconds of running. You will also perform 5 minutes of cycling before and after the MVCs to provide your muscles with a warm-up and a cool-down. Muscle force production will be recorded throughout the testing to track how fatigue affects muscle strength.

How long will this take? Your participation will take about 1 hour in total, with two visits, each lasting approximately 30 minutes.

What are the risks and benefits if I participate? There are no significant risks associated with participating in this study. The procedures involve standard muscle strength testing and exercise protocols that are commonly used in research. However, as with any physical activity, there is a very small chance of experiencing mild muscle soreness or discomfort, especially after the fatiguing exercise.

The researcher will ensure that any risks are minimized, and you will be given the opportunity to withdraw from the study at any time without penalty.

What are the benefits if I participate? By participating in this study, you will have the opportunity to gain insights into your own muscle strength and how it changes under different conditions (non-fatigue vs. fatigue). Specifically, you will receive a detailed assessment of your hamstring and quadriceps strength, which can help you understand your muscle balance and performance. This information may be valuable for your overall fitness and training goals.

Additionally, at the end of the study, you will receive a **$20 Amazon gift card** as a token of appreciation for your time and participation.

What do I do if I am injured? If you are injured during your participation, report this to a researcher immediately. Emergency medical treatment is available, but you or your insurance company will be responsible for the usual charges for this treatment. The University of Oklahoma Norman Campus has not set aside funds to compensate you in the event of injury. The research team will ensure that any risks are minimized, and you will be monitored throughout the study to prevent injury.

Will I be compensated for participating? You **will** be compensated for your time and participation in this research. Upon completing both visits (each approximately 30 minutes), you will receive a **$20 Amazon gift card** as compensation.

If you do not complete both visits or do not complete all data collection activities (e.g., failure to perform required strength tests or complete the fatiguing protocol), you **will not** be eligible for compensation. Additionally, if you do not follow the instructions or withdraw from the study before completing both visits, compensation will not be provided.

Compensation will be provided at the end of the second visit after all study requirements are completed.

Who will see my information? Your personal information will be kept confidential. There will be no information in research reports that will make it possible to identify you without your permission. Research records will be stored securely, and only approved researchers and the University of Oklahoma Institutional Review Board (IRB) will have access to the records. Your data will be kept private and used only for the purposes of this study. Any published results will not include identifying information about you.

You have the right to access the research data that has been collected about you as a part of this research. However, you may not access this information until the entire research has finished and you consent to this temporary restriction.

Do I have to participate? No. If you do not participate, you will not be penalized or lose benefits or services unrelated to the research. If you decide to participate, you don't have to answer any questions and can stop participating at any time.

Will my identity be anonymous or confidential? Your name will not be retained or linked with your responses unless you agree to be identified. Please check all of the options that you agree to:

I agree for data records to include my identifiable information. ___Yes ___ No

I agree to be quoted directly, without the use of my name. ___ Yes ___ No

I agree to have my name reported with quoted material. ___Yes ___ No

I agree for my research data to be archived for scholarly and public access. ___Yes ___No

What will happen to my data in the future?

We might share your (identifiable or de-identified) data with other researchers or use it in future research without obtaining additional consent from you.

IRB NUMBER: 18085
IRB APPROVAL DATE: 01/07/2025

Will I be contacted again? The researcher might contact you to gather additional data or recruit you for new research.

I give my permission for the researcher to contact me in the future. ___Yes ___ No

Who do I contact with questions, concerns, or complaints? If you have questions, concerns, or complaints about the research or have experienced a research-related injury, contact me at 405-314-9149 or email me at Reza.namavar@ou.edu

You can also contact the University of Oklahoma – Norman Campus Institutional Review Board (OU-NC IRB) at 405-325-8110 or irb@ou.edu if you have questions about your rights as a research participant, concerns, or complaints about the research and wish to talk to someone other than the researcher(s) or if you cannot reach the researcher(s).

You will be given a copy of this document for your records. By providing information to the researcher(s), I agree to participate in this research.

Participant Signature	Print Name	Date
Signature of Researcher Obtaining Consent	Print Name	Date

IRB NUMBER: 18085
IRB APPROVAL DATE: 01/07/2025

APPENDIX IV: HIPAA FORM

University of Oklahoma – Norman CampusResearch Privacy Form 1
Version 2/12/2016 PHI Research Authorization

AUTHORIZATION TO USE or SHARE
HEALTH INFORMATION[1] THAT IDENTIFIES YOU FOR RESEARCH
An Informed Consent Document for Research Participation may also be required.

Title of Research Project: **Investigating the Hamstring-to-Quadriceps Muscle Strength Ratio in a Fatigued State**

IRB Number:

Leader of Research Team: **Rebecca Larson, PhD**

Address: **1401 Asp Ave. SJSC Room 109, Norman, OK 73019**

Phone Number**: (405) 325-5211**

If you decide to sign this document, University of Oklahoma (OU) researchers may use or share information that identifies you (protected health information) for their research. Protected health information will be called PHI in this document.

PHI To Be Used or Shared. Federal law requires that researchers get your permission (authorization) to use or share your PHI. If you give permission, the researchers may use or share with the people identified in this Authorization any PHI related to this research from your medical records and from any test results. Information used or shared may include all information relating to any tests, procedures, surveys, or interviews as outlined in the consent form; medical records and charts; name, address, telephone number, date of birth, race, and government-issued identification numbers.
No identifiable information will be shared with anyone outside the research team.

Purposes for Using or Sharing PHI. If you give permission, the researchers may use your PHI to explore if current medical conditions or medications used affect your eligibility to participate in this study. Other PHI will help the researchers determine the extent to which 4 different sets of bunker gear mitigate changes in body temperature and heart rate in response to physical work following heat exposure.

[1] **Protected Health Information includes all identifiable information relating to any aspect of an individual's health whether past, present or future, created or maintained by a Covered Entity.**

IRB NUMBER: 18085
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Other Use and Sharing of PHI. If you give permission, the researchers may also use your PHI to develop new procedures or commercial products. They may share your PHI with other researchers, the research sponsor and its agents, the OU Institutional Review Board, auditors and inspectors who check the research, and government agencies such as the Department of Health and Human Services (HHS), and when required by law.

Confidentiality. Although the researchers may report their findings in scientific journals or meetings, they will not identify you in their reports. The researchers will try to keep your information confidential, but confidentiality is not guaranteed. The law does not require everyone receiving the information covered by this document to keep it confidential, so they could release it to others, and federal law may no longer protect it.

YOU UNDERSTAND THAT YOUR PROTECTED HEALTH INFORMATION MAY INCLUDE INFORMATION REGARDING A COMMUNICABLE OR NONCOMMUNICABLE DISEASE.

Voluntary Choice. The choice to give OU researchers permission to use or share your PHI for their research is voluntary. It is completely up to you. No one can force you to give permission. However, you must give permission for OU researchers to use or share your PHI if you want to participate in the research and, if you cancel your authorization, you can no longer participate in this study.

Refusing to give permission will not affect your ability to get routine treatment or health care unrelated to this study from OU.

Canceling Permission. If you give the OU researchers permission to use or share your PHI, you have a right to cancel your permission whenever you want. However, canceling your permission will not apply to information that the researchers have already used, relied on, or shared or to information necessary to maintain the reliability or integrity of this research.

End of Permission. Unless you cancel it, permission for OU researchers to use or share your PHI for their research will end when the study is completed and its results published.

Contacting OU: You may find out if your PHI has been shared, get a copy of your PHI, or cancel your permission at any time by writing to:

Privacy Official
University of Oklahoma
PO Box 26901
Oklahoma City, OK 73190

or

Privacy Board
University of Oklahoma
201 Stephenson Pkwy, Suite 4300A
Norman, OK 73019

If you have questions, call: (405) 271-2511 or (405) 325-8110

Access to Information. You have the right to access the medical information that has been collected about you as a part of this research study. However, you may not have access to this medical information until the entire research study is completely finished. You consent to this temporary restriction.

Giving Permission. By signing this form, you give OU and OU's researchers led by the Research Team Leader permission to share your PHI for the research project listed at the top of this form.

Participant Name (Print): ___________________________

______________________________________ ______________
Signature of Participant Date
or Parent if Participant is a minor

Or

______________________________________ ______________
Signature of Legal Representative** Date

**If signed by a Legal Representative of the Participant, provide a description of the relationship to the Participant and the authority to act as Legal Representative:

____
OU may ask you to produce evidence of your relationship.

A signed copy of this form must be given to the Participant or the Legal Representative at the time this signed form is provided to the researcher or his representative.

IRB APPROVED
IRB NUMBER: 18085
IRB APPROVAL DATE: 01/07/2025

APPENDIX V: PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PARQ)

FORM 3.1 Physical Activity Readiness Questionnaire

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

PAR-Q & YOU

(A Questionnaire for People Aged 15 to 69)

Regular physical activity is fun and healthy, and increasingly more people are starting to become more active every day. Being more active is very safe for most people. However, some people should check with their doctor before they start becoming much more physically active.

If you are planning to become much more physically active than you are now, start by answering the seven questions in the box below. If you are between the ages of 15 and 69, the PAR-Q will tell you if you should check with your doctor before you start. If you are over 69 years of age, and you are not used to being very active, check with your doctor.

Common sense is your best guide when you answer these questions. Please read the questions carefully and answer each one honestly: check YES or NO.

YES	NO	
☐	☐	**1. Has your doctor ever said that you have a heart condition and that you should only do physical activity recommended by a doctor?**
☐	☐	**2. Do you feel pain in your chest when you do physical activity?**
☐	☐	**3. In the past month, have you had chest pain when you were not doing physical activity?**
☐	☐	**4. Do you lose your balance because of dizziness or do you ever lose consciousness?**
☐	☐	**5. Do you have a bone or joint problem (for example, back, knee or hip) that could be made worse by a change in your physical activity?**
☐	☐	**6. Is your doctor currently prescribing drugs (for example, water pills) for your blood pressure or heart condition?**
☐	☐	**7. Do you know of any other reason why you should not do physical activity?**

If you answered

YES to one or more questions

Talk with your doctor by phone or in person BEFORE you start becoming much more physically active or BEFORE you have a fitness appraisal. Tell your doctor about the PAR-Q and which questions you answered YES.

- You may be able to do any activity you want — as long as you start slowly and build up gradually. Or, you may need to restrict your activities to those which are safe for you. Talk with your doctor about the kinds of activities you wish to participate in and follow his/her advice.
- Find out which community programs are safe and helpful for you.

NO to all questions

If you answered NO honestly to all PAR-Q questions, you can be reasonably sure that you can:

- start becoming much more physically active – begin slowly and build up gradually. This is the safest and easiest way to go.
- take part in a fitness appraisal – this is an excellent way to determine your basic fitness so that you can plan the best way for you to live actively. It is also highly recommended that you have your blood pressure evaluated. If your reading is over 144/94, talk with your doctor before you start becoming much more physically active.

DELAY BECOMING MUCH MORE ACTIVE:

- if you are not feeling well because of a temporary illness such as a cold or a fever – wait until you feel better; or
- if you are or may be pregnant – talk to your doctor before you start becoming more active.

PLEASE NOTE: If your health changes so that you then answer YES to any of the above questions, tell your fitness or health professional. Ask whether you should change your physical activity plan.

Informed Use of the PAR-Q: The Canadian Society for Exercise Physiology, Health Canada, and their agents assume no liability for persons who undertake physical activity, and if in doubt after completing this questionnaire, consult your doctor prior to physical activity.

No changes permitted. You are encouraged to photocopy the PAR-Q but only if you use the entire form.

NOTE: If the PAR-Q is being given to a person before he or she participates in a physical activity program or a fitness appraisal, this section may be used for legal or administrative purposes.

"I have read, understood and completed this questionnaire. Any questions I had were answered to my full satisfaction."

NAME ________________________________

SIGNATURE ________________________________ DATE ________________

SIGNATURE OF PARENT or GUARDIAN (for participants under the age of majority) ________________________________ WITNESS ________________

Note: This physical activity clearance is valid for a maximum of 12 months from the date it is completed and becomes invalid if your condition changes so that you would answer YES to any of the seven questions.

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PAR-Q & YOU

Physical Activity Readiness Questionnaire - PAR-Q (revised 2002)

Canada's Physical Activity Guide to Healthy Active Living

Physical activity improves health.

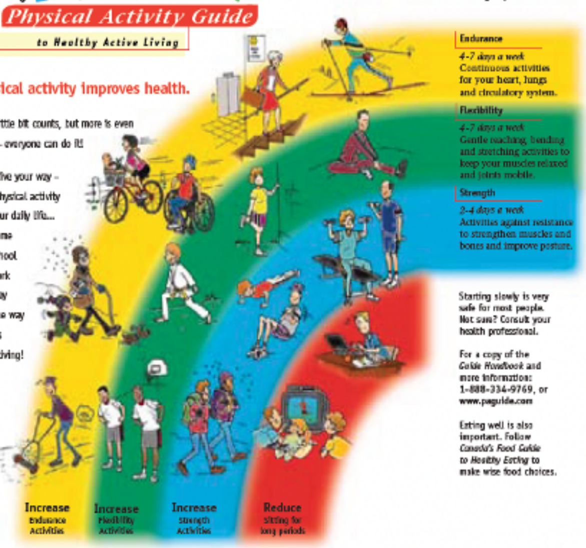
Every little bit counts, but more is even better – everyone can do it!

Get active your way – build physical activity into your daily life...

- at home
- at school
- at work
- at play
- on the way

...that's active living!

Choose a variety of activities from these three groups:



Starting slowly is very safe for most people. Not sure? Consult your health professional.

For a copy of the *Guide Handbook* and more information: 1-888-334-9769, or www.paguide.com

Eating well is also important. Follow *Canada's Food Guide to Healthy Eating* to make wise food choices.

Get Active Your Way, Every Day–For Life!

Scientists say accumulate 60 minutes of physical activity every day to stay healthy or improve your health. As you progress to moderate activities you can cut down to 30 minutes, 4 days a week. Add-up your activities in periods of at least 10 minutes each. Start slowly... and build up.

Time needed depends on effort

Very Light Effort	Light Effort *60 minutes*	Moderate Effort *30-60 minutes*	Vigorous Effort *20-30 minutes*	Maximum Effort
• Strolling • Dusting	• Light walking • Volleyball • Easy gardening • Stretching	• Brisk walking • Biking • Raking leaves • Swimming • Dancing • Water aerobics	• Aerobics • Jogging • Hockey • Basketball • Fast swimming • Fast dancing	• Sprinting • Racing

Range needed to stay healthy

You Can Do It – Getting started is easier than you think

Physical activity doesn't have to be very hard. Build physical activities into your daily routine.

- Walk whenever you can – get off the bus early, use the stairs instead of the elevator.
- Reduce inactivity for long periods, like watching TV.
- Get up from the couch and stretch and bend for a few minutes every hour.
- Play actively with your kids.
- Choose to walk, wheel or cycle for short trips.
- Start with a 10 minute walk – gradually increase the time.
- Find out about walking and cycling paths nearby and use them.
- Observe a physical activity class to see if you want to try it.
- Try one class to start – you don't have to make a long-term commitment.
- Do the activities you are doing now, more often.

Benefits of regular activity:	Health risks of inactivity:
• better health • improved fitness • better posture and balance • better self-esteem • weight control • stronger muscles and bones • feeling more energetic • relaxation and reduced stress • continued independent living in later life	• premature death • heart disease • obesity • high blood pressure • adult-onset diabetes • osteoporosis • stroke • depression • colon cancer

Health Canada Santé Canada

Canadian Society for Exercise Physiology

Source: *Canada's Physical Activity Guide to Healthy Active Living*, Health Canada, 1998 http://www.hc-sc.gc.ca/hppb/paguide/pdf/guideEng.pdf

FITNESS AND HEALTH PROFESSIONALS MAY BE INTERESTED IN THE INFORMATION BELOW:

The following companion forms are available for doctors' use by contacting the Canadian Society for Exercise Physiology (address below):

The **Physical Activity Readiness Medical Examination (PARmed-X)** – to be used by doctors with people who answer YES to one or more questions on the PAR-Q.

The **Physical Activity Readiness Medical Examination for Pregnancy (PARmed-X for Pregnancy)** – to be used by doctors with pregnant patients who wish to become more active.

References:

Arraix, G.A., Wigle, D.T., Mao, Y. (1992). Risk Assessment of Physical Activity and Physical Fitness in the Canada Health Survey Follow-Up Study. **J. Clin. Epidemiol.** 45:4 419-428.

Mottola, M., Wolfe, L.A. (1994). Active Living and Pregnancy, In: A. Quinney, L. Gauvin, T. Wall (eds.), **Toward Active Living: Proceedings of the International Conference on Physical Activity, Fitness and Health.** Champaign, IL: Human Kinetics.

PAR-Q Validation Report, British Columbia Ministry of Health, 1978.

Thomas, S., Reading, J., Shephard, R.J. (1992). Revision of the Physical Activity Readiness Questionnaire (PAR-Q). **Can. J. Spt. Sci.** 17:4 338-345.

To order multiple printed copies of the PAR-Q, please contact the:

Canadian Society for Exercise Physiology
202-185 Somerset Street West
Ottawa, ON K2P 0J2
Tel. 1-877-651-3755 • FAX (613) 234-3565
Online: www.csep.ca

The original PAR-Q was developed by the British Columbia Ministry of Health. It has been revised by an Expert Advisory Committee of the Canadian Society for Exercise Physiology chaired by Dr. N. Gledhill (2002).

Disponible en français sous le titre «Questionnaire sur l'aptitude à l'activité physique - Q-AAP (revisé 2002)».

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APPENDIX VI: MENSTRUAL HISTORY QUESTIONNAIRE

Department of Health and Exercise Science
University of Oklahoma

MENSTRUAL HISTORY QUESTIONNAIRE

Participant ID:_______________Date:____________________

We are asking you to give us as complete a menstrual history as possible. All information is strictly confidential.

Are you pregnant (circle your response)
YES- Do not complete the rest of this form
NO- Continue to section A.

SECTION A: CURRENT MENSTRUAL STATUS

1. Approximately how many menstrual periods have you had during the past 12 months?
(please circle what months you have had a period. This means from this time last year to the present month)

Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec

2. What is the usual length of your menstrual cycle (first day of your period to the next onset of your period)?

_____________days. Today is day ___________ of your present menstrual cycle.

3. When was the date of the onset of your last period?

4. When do you expect you next period?

5. What is the average length (number of days) of your menstrual flow? ________________ days

How many of these days do you consider "heavy"?__________________days

6. Do you take oral contraceptives or any other medication that includes estrogen and/or progesterone?

If yes, how long have you been taking this medication?__________________________

What is the brand name and dosage of this mediation?__________________________

Has this medication affected your menstrual cycle (regularity, length and amount of flow)? If yes, indicate changes.

APPENDIX VII: PROFILE OF MOOD (POMS)

I.D. Number: ____________________ **Session Number:** ____________________ **Date:** ____________________

POMS-B QUESTIONNAIRE

INSTRUCTIONS: Below is a list of words that describe feelings that people have. Please read each word carefully. Then circle the number that best describes:

☐ How you have been feeling during the PAST WEEK, INCLUDING TODAY.

☐ How you feel RIGHT NOW.

	Not At All	A Little	Moderately	Quite a Bit	Extremely
1. Tense	0	1	2	3	4
2. Angry	0	1	2	3	4
3. Worn out	0	1	2	3	4
4. Lively	0	1	2	3	4
5. Confused	0	1	2	3	4
6. Shaky	0	1	2	3	4
7. Sad	0	1	2	3	4
8. Active	0	1	2	3	4
9. Grouchy	0	1	2	3	4
10. Energetic	0	1	2	3	4
11. Unworthy	0	1	2	3	4
12. Uneasy	0	1	2	3	4
13. Fatigued	0	1	2	3	4
14. Annoyed	0	1	2	3	4
15. Discouraged	0	1	2	3	4

PLEASE ANSWER QUESTIONS ON OTHER SIDE

I.D. Number: ____________________ **Session Number:** ____________________ **Date:** ____________________

POMS-B QUESTIONNAIRE

INSTRUCTIONS: Below is a list of words that describe feelings that people have. Please read each word carefully. Then circle the number that best describes:

☐ How you have been feeling during the PAST WEEK, INCLUDING TODAY.

☐ How you have been feeling during the PAST 24 HOURS.

	Not At All	A Little	Moderately	Quite a Bit	Extremely
16. Nervous	0	1	2	3	4
17. Lonely	0	1	2	3	4
18. Muddled	0	1	2	3	4
19. Exhausted	0	1	2	3	4
20. Anxious	0	1	2	3	4
21. Gloomy	0	1	2	3	4
22. Sluggish	0	1	2	3	4
23. Weary	0	1	2	3	4
24. Bewildered	0	1	2	3	4
25. Furious	0	1	2	3	4
26. Efficient	0	1	2	3	4
27. Full of Pep	0	1	2	3	4
28. Bad-tempered	0	1	2	3	4
29. Forgetful	0	1	2	3	4
30. Vigorous	0	1	2	3	4

APPENDIX VIII: TRAINING DIARY

Training Diary

1. In the last week, how many days did you train?

2. How many days per week did participate in resistance training?

3. For how long each day did you resistance train?

4. How many days did you participant in aerobic training?

5. What type of aerobic training did you participate in (e.g., running, cycling, swimming, etc.)?

6. How long each day did you participate in aerobic training?

7. How long have you engaged in this routine?