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The effects of fatigue on lower extremity neuromuscular control

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THE EFFECTS OF FATIGUE ON LOWER EXTREMITY NEUROMUSCULAR CONTROL

by

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Dedications

To my family, friends, colleagues and all those who have supported me along the way. The journey has just begun….

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I would like to thank my thesis committee: Dr. Douglas Mann, Dr. Robert Sterner and Dr. Erin Pletcher. Thank you for guiding me and providing me with the knowledge and resources needed to be successful. To my family: Thank you for believing in me and always being there when I needed you. I love you. To my Rowan Athletic Training friends: Thank you for being my rocks. I would not have made it through this journey without you. To my girlfriend Gianna: Thank you for believing in me when I didn't believe in myself. You keep me strong and I am very grateful to have you in my life. I love you. To Colleen, Chris, Steve and Mark the Shark: You showed me the ropes and taught me to settle for nothing but the best. I look forward to working and dominating with you all in the future.

Abstract

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Lower extremity injuries and pathologies are amongst the most common issues recreational athletes face. Fatigue is a factor that may impact how the lower extremity performs on a neuromuscular level. Neuromuscular control is a vital aspect of athletic performance and everyday life, that when hindered, may produce pathological results. The research is contradictory on whether or not fatigue produces a significant impact during neuromuscular performance. The purpose of this study is to assess neuromuscular control following a lower extremity fatigue protocol.

This study was a randomized a controlled trial. Twenty-one recreationally active subjects, 10 males and 11 females, between the ages of 18 and 24 underwent two study sessions separated by a two-week break period. All subjects completed a pre and post Y Balance Test with the experimental group receiving a strenuous lateral step-down fatigue protocol and the control group receiving a 5 minute rest period. The effects of the fatigue protocol on all three directions during the Y Balance Test was significant ($p<.05$) (ANT $P=.001$, $PM=0.006$, $PL=0.049$).

Our results indicate that fatigue may adversely affect the neuromuscular control of lower extremity. This study represents the importance of neuromuscular control during activity and will help clinicians to further modify their rehabilitation programs to include neuromuscular control prevention.

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Chapter 1

Introduction

Approximately 8.6 million injuries occur annually that are sports and recreational related with 42%-82% of them being in the lower extremity.[26] The lower extremity is utilized to perform a variety of different functions during both physical and activities of daily living. Since it is very commonly used, many pathologies can occur, and serious damage to ligaments and the surrounding muscular is frequent.[8] In the world of athletics, situations exist where the risk of injury may increase throughout an event or activity. While preventing every injury is unlikely, there are both internal and external forces acting on the body that one should be aware of when undergoing physical activity. There are a variety of factors that can contribute to how the lower extremity performs and behaves overall, including fatigue and neuromuscular control.

Fatigue and neuromuscular control are two forces that may have an influence on how the body responds to a movement. From an orthopedic perspective, fatigue may play a major role in the exacerbation of conditions and injuries. It is important to evaluate the effects of fatigue on neuromuscular control due to its commonly occurring nature in the physically active population. Since it is hypothesized that neuromuscular performance can be hindered due to the implementation of fatigue, studies comparing neuromuscular function both pre and post fatigue will be further analyzed and evaluated to see if fatigue produces a negative effect.

Lower Extremity Function and Neuromuscular Control

During activity, the body performs a variety of different dynamic motions including cutting, running and jumping. The lower extremity continuously and at times quickly produces these motions. While it is important to be both active and reactive during activity, consequences can arise when internal mechanisms within the body start to fail or become affected. One of the systems that can become affected during activity is the neuromuscular control system. Myers et al[18] defined neuromuscular control as the unconscious activation of dynamic restraints occurring in preparation for and in response to joint motion and loading for the purpose of maintaining functional joint stability. Because there are neuromuscular forces acting upon the lower extremity, there are imbalances that may occur due to the lack of neuromuscular control, thus possibly causing injury.

Neuromuscular control can be broken down into two components, proprioception, and kinesthesia. Proprioception, while often misinterpreted, is defined as the position of joint and body movement as well as position on the body, or body segments in space.[8] Proprioception relies on mechanoreceptors throughout the body which are often referred to as proprioceptors.[8,14,17,17,20] Another factor to consider during neuromuscular performance is kinesthesia. Kinesthesia is defined as a sense of limb movement.[5] Both kinesthesia and proprioception have been studied extensively in the world of sports medicine and physical activity.[8] Joint position sense and limb motion sense have been thought to play a role in the reduction of orthopedic injuries due to joint repositioning. Joint repositioning is the repositioning of a joint before an injury related mechanism can occur. Joint repositioning is accomplished by mechanoreceptors, nociceptors, and muscle afferents located in the joints of the body.[8] The afferents responsible for aiding in joint repositioning include: Ruffini endings, Pacinian corpuscles, Golgi tendon organs and muscle spindles.[8]

Mechanoreceptors. The somatosensory system is a very complex motor control system within the body that contains sensory, motor and central imaging processing components that aid in maintaining joint homeostasis.[24,25] Important neurological organs of the somatosensory system are referred to as mechanoreceptors. Mechanoreceptors, also referred to as sensory afferents, are located in the muscles, joint capsular tissues, ligaments, tendons and skin and are thought to be the most predominant receptors that contribute to neuromuscular control. Through use of ion channels, mechanoreceptors help convert mechanical loads in joints and transform them into afferent impulses in reaction to internal and external stimuli.[24,25]

Subcutaneous receptors. The Ruffini endings and Pacinian corpuscles are thought to be the most effective subcutaneous receptors during neuromuscular control.[21,22] During a task that warrants the need for neuromuscular dependence, Ruffini endings provide low threshold, slow adapting characteristics while Pacinian corpuscles provide low threshold, quick adapting characteristics.[9,21] Ruffini endings sense stretch, movement and position while Pacinian corpuscles sense vibrations.[9,21,22] Due to the Pacinian corpuscles ability to be quick reacting, they are thought to have a more major role during neuromuscular control.[9]

Muscle spindles and golgi tendon organs. Joint stability is typically maintained through the use of both static and dynamic components.[24,25] Because joint receptors may only play a small role in neuromuscular control during the end ranges of motion, muscle spindles and Golgi tendon organs have been universally accepted by researchers as the major contributors to joint position sense.[7,8,14,16,17] Muscle spindles and Golgi tendon organs are also referred to as muscle mechanoreceptors. Muscle spindles are defined as being receptors located in the muscle belly that are sensitive to the stretch reflex along with mechanisms initiating the stretch reflex.[17,18] Muscle spindles may also detect change in length that occurs in regard to muscular movement.[17,18]

Muscle spindles first became the primary mechanoreceptor responsible for proprioception back in the 1970's when a study by Eklund et al [4] took place using muscle vibration to evaluate joint position sense. Prior to this time period, joint receptors were thought to be the main contributor to joint position sense.[4,21] The study by Eklund[4] found that when applying 100hz of vibration to both the bicep brachii and triceps brachii tendons that there was a change at the elbow in regard to joint position sense.[4] Since this change produced a muscle elongation, the study brought about the idea that muscle spindles were the primary proprioceptors and not the joint receptors. Although the research involved in this study may be considered outdated, the information produced in the study by Eklund[4] remains significant and is still replicated in modern studies. Along with impulse conversion, muscle spindles may also transfer changes from human tissue into nerve signals and send them to the central nervous system.[14] Through the integration of information, motor programming occurs and contributes to reflex muscle contraction, providing dynamic joint stability.[17]

Several researchers agree that joint receptors only play a role at the extreme ranges of motion and are not all that important in regards to joint proprioception.[5,10,14,17]

While joint receptors are thought to only play a small role in proprioception, they are still an aspect of neuromuscular control that shall be taken into consideration.

Feedback and feedforward control. Humans are in control of conscious voluntary movement, but neuromuscular control is considered both conscious and unconscious causing typical movements to become an issue during activity. Through the nervous system, the brain signals the muscles in the body to generate force and movement.[6] Two ways that the nervous system aids in movements are through the use of feedback and feedforward control mechanisms. Feedback control relies on reflexes to stimulate muscles via information transmitted to the spinal cord.[6] Feedforward control uses sensory information from instances such as past experiences in preparation of a movement. Research has found that both feedback and feedforward occur simultaneously during balance and neuromuscular control inducing activities.[6] Research on feedforward and feedback mechanisms is difficult to administer in a clinical setting due to complicity and lack of technological resources. The role that feedforward and feedback play in regard to lower limb movement during a fatigued neuromuscular state is unknown. Further research is needed to evaluate these mechanisms during both postural control and proprioceptive exercises.

Fatigue

Fatigue, also often referred to as exhaustion, is a common occurrence after strenuous physical activity. Fatigue is defined as the transient inability to maintain power output or force during repeated muscle contractions.[8,9,12,16] The impact that fatigue has on the body has been assessed in multiple studies. From a physical standpoint, fatigue has been commonly shown to be a detriment to performance. Fatigue may affect how the body performs or maintains a movement on a neuromuscular level. Fatigue affects the body using two mechanisms: central fatigue and peripheral fatigue.[14] Central fatigue affects the body through the central nervous system causing changes in the concentration of neurotransmitters.[24,25,26] Peripheral fatigue affects the body through the muscles, ligaments and joints causing metabolic depletion or lactic acid build up.[24,25] Central fatigue can also decrease the nerves ability to generate a signal and peripheral fatigue can reduce the reaction time of a muscle to contract.[11]

Fatigue can also be broken down into further elements known as local and generalized fatigue. Localized fatigue refers to a specific fatigue that occurs to a group of muscles from a direct load.[16] Generalized fatigue is defined as a non-specific fatigue that occurs after low intensity stimulus.[16] A study conducted by Linnamo et al[14] examined the two types of fatigue, central and peripheral, following a strenuous leg extension fatigue protocol. This study found that the implementation of fatigue led to increased blood lactate levels and a decreased muscular force, but both central and peripheral mechanisms were witnessed at the knee joint.[14]

Fatigue and Neuromuscular Control

Measuring aspects of neuromuscular control in relation to fatigue is important in regards to injury prevention, treatment and rehabilitation.[15] Joint defense mechanisms may be impacted negatively during a post fatigued state.[24,26] Peripheral fatigue may cause a decline in force production in the muscle or at the tendinous junction while central fatigue may cause a neurological defect on the muscles ability to contract.[26] Impaired neuromuscular control has been identified as one of the risk factors leading up to an injury.[20,26]The impact that fatigue has on neuromuscular control has been studied in depth, but there is conflicting evidence on the matter. There have been studies that have enforced the idea of fatigue playing a role in neuromuscular control, as well as studies that show a lack of relation between the two.[11,12,16, 27, 32]

A study performed by Wojtys et al[32] evaluated the neuromuscular performance of the knee joint after an administered isokinetic fatigue protocol. The fatigue protocol was completed on the Cybex isokinetic machine. Each subject performed the fatigue protocol and then underwent a tibial translation stress test. The authors found that because of the fatigue in the hamstrings and quadriceps, a delayed reaction time, muscle firing rate, and increased anterior translation at the knee joint was present.[32]

A study conducted by Johnston et al[10] compared neuromuscular control between competitive sports athletes after a Wingate fatiguing protocol. The subjects completed a pre-Y Balance Test followed by a 60 second Wingate test and then a post Y Balance Test. The Wingate test is an anaerobic cycling test that predominantly works the lower extremity. The author concluded that fatigue impacted the normalized Y Balance Test scores negatively, but scores returned to normal within twenty minutes following the post Y Balance Test.[10]

A tertiary study conducted by Joudeh et al[11] examined the effects of gastroc-soleus complex and quadriceps fatigue on standing and dynamic balance. The author reported no balance deficit during a Balance Master test following strenuous knee extensions and calf raises.[11] This study did not support previous studies in the theory that fatigue may impact neuromuscular control.[10,11,32]The hypothesized reasoning behind the failure to establish a deficit was that, due to compensatory mechanisms, other muscles may have activated in order to compensate for the gastroc-soleus complex and the quadriceps.[11] The compensation of the musculature may have caused the Balance Master scores to be non-significant.

Y Balance Test

The Y Balance Test is a three directional functional movement screening tool used to evaluate neuromuscular control and detect individuals that are at possible risk for injury.[5] During this test, the subject stands in a unilateral position while extending their limb in anterior, posteromedial and posterolateral directions. The subject must reach as far as possible with proper form and maintain contact with the reach indicator in order for the test to be considered valid. The Star Excursion Balance Test, is the eight directional predecessor to the Y Balance Test, but consumed copious amounts of time due to the eight directions a subject had to perform. Contrary to the Star Excursion Balance Test, the Y Balance test only has three directions that the subject has to perform. A study was done by Gottel et al [5] to evaluate the validity and reliability of the Y Balance Test when compared to the Star Excursion Balance Test. The Y Balance Test was found to be more time efficient and just as reliable when compared to its predecessor the Star Excursion Balance Test.[5]

The Y Balance Test has been shown to have high intra and inter-rater reliability.[5,20,29] A study performed on active service members by Shaffer et al[26] found that the Y Balance Test was a reliable tool to identify balance asymmetries by multiple raters. In addition to the study performed by Shaffer et al [29], several studies show that the Y Balance Test is both reliable and efficient at detecting balance deficits.[5,20] This test may be used in future studies to examine the relationship between neuromuscular control and fatigue.

Lateral Step-down Test

The lateral step-down test is a multi-joint exercise used by clinicians in the sports medicine field.[19,26] The subject stands unilaterally on a raised surface approximately 12 inches off the ground and performs a lateral single leg squat until their heel touches the floor. After the heel makes slight contact with the floor, the subject then re-establishes themselves at the starting position. A study by White et al[30] examined the effectiveness of the lateral step down and the 30 second side hop test as fatigue protocols when comparing hop distance between healthy individuals. The lateral step-down test was found to be significantly greater at decreasing hop distance and an effective method when attempting to mimic athletic performance.[2]

Outcomes Measures to Assess Fatigue

While there is a general definition for the word fatigue, previous studies appeared to create their own quantitative measure of fatigue in their assessments.[7,8,27] Since there is no gold standard when referring to an exact state of fatigue, there are multiple outcome-based measures that can be used in order to identify if a subject has reached their own state of fatigue. A study was conducted by Whitehead et al[31] in order to critically review the patient reported outcome measures in studies that assessed fatigue. Seven databases were searched using the time period between 1980-2007.[31] The outcome measures were evaluated using three criteria: scale usability, clinical research utility, and psychometric properties[31] The results from the study concluded that the Brief Fatigue Inventory (BFI), Fatigue Impact Scale (FIS), Fatigue Severity Scale (FSS) and the Multidimensional Assessment of Fatigue (MAF) had both sufficient psychometric characteristics and the ability to assess change over time[31]

Outcome measures are an important tool to use in the care and assessments of patients. In order to accurately assess fatigue outcome measures should be used to identify if a patient has reached a state of fatigue or not. If the examiner does not use a quantitative measure to assess fatigue, outcome measures are a useful tool to obtain further information.

Future Research

In recent years, the number of studies involving the role of fatigue in regard to lower extremity neuromuscular control has decreased. In future research, more studies must be conducted to accurately assess the lower extremity in relation to neuromuscular control. There are multiple aspects that must be considered when conducting the new research. A proper rest to work ratio must be initiated to ensure an accurate assessment of the impact of fatigue. Subjects should be going to exhaustion if the study is evaluating maximal fatigue. In addition to an accurate assessment, a functional protocol must be conducted in order to reach subjective fatigue in the lower extremity. While research has evaluated neuromuscular control at specific joints, future studies may evaluate the entire lower extremity as a whole, due to its role in physical activity. Studies involving larger sample sizes and physically active subjects would be preferred since the athletic population is more common than the general population to succumb to sports injury.[26]

Conclusion. The role of fatigue on the lower extremity during neuromuscular performance must be further evaluated. The research currently shows that fatigue may negatively impact mechanoreceptors called muscle spindles, causing deficits in neuromuscular ability. [2,8,10,12,16, 17, 29,32] While it is generally accepted that joint receptors may only play a small role in neuromuscular control in the lower extremity, more research must be performed to validate the argument. While the research is promising, future studies must be done to determine the physiological effects of fatigue on neuromuscular performance.

The Y Balance Test is a time efficient, effective tool in measuring neuromuscular control. Future studies may use this tool to evaluate a connection between fatigue and neuromuscular control. The lateral step-down test, while not used often in clinical research literature utilizes an effective functional exercise to induce fatigue. Many clinicians utilize the lateral step-down exercise because it works the entire lower extremity and may be effective at mimicking lower extremity function during athletics.

Problem Statement

This study aimed to assess the neuromuscular control of the lower extremity during the Y Balance Test after a strenuous lateral step-down fatigue protocol. This study aims to show the importance of fatigue awareness in regard to neuromuscular performance.

Specific Aims and Hypotheses

Specific Aim 1: Assess the influence of fatigue on lower extremity neuromuscular control during the Y Balance Test.

Hypothesis 1: Y Balance Test scores will decrease as a result of the lower extremity undergoing the fatigue protocol.

Specific Aim 2: Assess the influence of fatigue on contralateral limbs during the Y Balance Test

Hypothesis 2: Y Balance Test scores of the non-dominant limb will be non-significant when compared to the dominant limb

Specific Aim 3: Assess the influence of fatigue on gender during the Y balance test

Hypothesis 3: Y Balance Test scores will be higher in females when compared to males following the fatigue protocol

Chapter 2

Manuscript

Abstract

Lower extremity injuries and pathologies are amongst the most common issues recreational athletes face. Fatigue is a factor that may impact how the lower extremity performs on a neuromuscular level. Neuromuscular control is a vital aspect of athletic performance and everyday life, that when hindered, may produce pathological results. The research is contradictory on whether or not fatigue produces a significant impact during neuromuscular performance. The purpose of this study is to assess neuromuscular control following a lower extremity fatigue protocol.

This study was a randomized a controlled trial. Twenty-one recreationally active subjects, 10 males and 11 females, between the ages of 18 and 24 underwent two study sessions separated by a two-week break period. All subjects completed a pre and post Y Balance Test with the experimental group receiving a strenuous lateral step-down fatigue protocol and the control group receiving a 5 minute rest period. The effects of the fatigue protocol on all three directions during the Y Balance Test was significant ($p<.05$) (ANT P=.001, PM=0.006, PL=0.049).

Our results indicate that fatigue may adversely affect the neuromuscular control of lower extremity. This study represents the importance of neuromuscular control during activity and will help clinicians to further modify their rehabilitation programs to include neuromuscular control prevention.

Introduction

Lower extremity function and neuromuscular control are important qualities of the human body that may be adversely affected by internal forces such as fatigue. During a state of fatigue, the body undergoes changes on a physiological level. These changes may include decreased muscular force production, increased blood lactate levels, altered neurotransmitter concentration and altered reflex response. Due to these changes, an athlete's performance may be affected during physical activity. While there is previous research establishing the negative results of fatigue during activity, multiple variables exist that shall be changed in an effort to mimic actual fatigue occurring during a neuromuscular control exercise. Previous research indicates that the relationship between fatigue and neuromuscular control is controversial and contains different results. Further research was needed to evaluate the current relationship between the two variables. The addition of this research serves to aid clinicians in both the rehabilitation process and during their role on the field.

Subjects

Twenty-One recreationally active subjects, 11 females 10 males, between the ages of 18 and 24 elected to participate in this study. Subjects were of both genders and were students at Rowan University. In order to be considered for this study, all subjects had to be currently participating in physical activity three times per week for at least thirty minutes per session. Prior to the beginning of this study, all subjects had to read and sign a consent form to ensure proper safety. All details regarding the study were pre-approved by the Internal Review Board at Rowan University. In addition to the review by the IRB, the subjects were explained the possible benefits and risks involved in the experiment. If the subjects expressed any concern or were uncomfortable participating in the study, they maintained the right to refrain from continuing at any given time. Each individual subject would have to participate on two separate occasions separated by a two-week break period to minimize learning effect. In this particular study, the subjects were randomized and assigned during the first session to one of two groups, the fatigue group or the control group. The subjects were then assigned to the opposite group during their second session. All subjects had to complete the fatigue protocol, however due to randomization it could have occurred during either the first or second session.

Inclusion Criteria

- 18-24 years old
- Student at Rowan University
- Recreationally Active

Exclusion Criteria

- No lower extremity injury in the last six months
- No lower extremity surgery in the past year
- No history of neurological disorders

Y Balance Test

The Y Balance Test, developed by FMS (Functional Movement Systems) was the primary tool used during this study to assess functional movement scores. Subjects completed the Y Balance Test both prior to and following the fatigue protocol. Using this method of measurement aided in maintaining both cost effectiveness and simplicity while providing validity and reliability throughout the study. Subjects were scored based on how far they could reach out in three directions: anterior, posteromedial and posterolateral. Subjects were asked to reach out three times per each direction with both dominant and non-dominant limb being assessed both pre and post fatigue protocol. Multiple errors could negate each trial such as: failure to keep hands on the hips, failure to maintain contact with the red indicator, failure to keep their foot behind the platform line, and falling off the stance platform. Although there were instances where the errors mentioned occurred, subjects were eligible for another trial once reestablished back on the platform. Limb length was not measured due to the experimental group acting as their own control

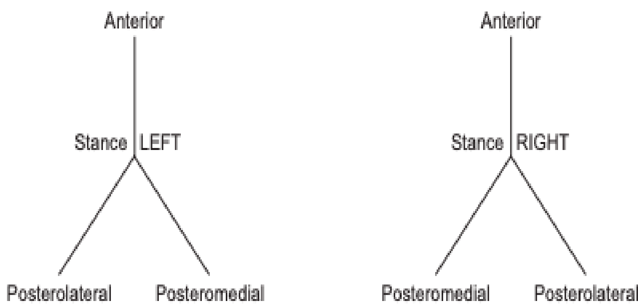

Figure 1. Y Balance Test Scheme

Lateral Step-Down Test

The lateral step-down test was the method used to initiate fatigue throughout this study. Although this method is not commonly used in the literature as a fatigue protocol, this test is used by many in the sports medicine community to evaluate functional lower extremity strength. In order for the lateral step-down test to be considered valid, subjects had to do a single leg squat on a 12-inch raised platform, touch their heel to the ground and reestablish themselves in the starting position. Errors during this test included: inability to maintain proper form, falling off the platform and performing uncontrolled repetitions.

Figure 2. Image of the Lateral Step-Down Test

Procedures

Pilot testing took place in September of 2019 following both the approval of the IRB and the author’s advisor. Pilot testing was done to establish the validity and reliability of both the Y Balance Test and the lateral step-down test as well as diminish the amount of errors that may occur during the live study. Six subjects of both genders were randomly chosen to participate in pilot testing. Prior to testing, each subject signed a consent form and was given thorough instructions of how to perform each trial and the errors that may occur. All subjects were able to practice both the Y Balance Test and lateral step-down test prior to the actual evaluation. Each subject underwent a pre and post Y Balance Test with three of the subjects performing the lateral step-down fatigue protocol in between balance tests.

Testing updates. During pilot testing, the subjects were only doing their dominant leg and were not provided specific instructions in regard to form during the lateral step-down test. Changes were made for live testing so that each subject completed each round of trials with both dominant and non-dominant limbs and proper form was initiated so that each subject fatigued the same lower extremity muscles at the same rate.

All subjects were told to keep their knee in line and behind their toes when performing the single leg squat on the platform. If the subjects were not provided form instructions, there may have been a discrepancy between fatigued muscles and different Y Balance Test scores may have been found.

Live testing. Live testing started in October of 2019 and concluded in February of 2020. All subjects were recruited in person through face to face contact. The subjects were randomized prior to their scheduled date and signed a consent form before any testing began. All subjects were given the choice to refrain from continuing both prior and during live testing. Subjects were instructed to wear shorts and take both shoes and socks off prior to testing in order to minimize proprioceptive cues. Each subject came in and were given ample opportunities to practice both the Y Balance Test and the lateral step-down test. Subjects performed three practice trials on both the Y Balance Test and lateral step-down test. Subjects in both groups performed a baseline Y Balance Test with the experimental group completing the lateral step-down fatigue protocol and the control group receiving a five-minute rest in between balance tests.

Each subject stood on the Y Balance Test with their dominant limb in a single leg stance, maintained proper form and reached out with their opposite limb as far as possible without losing their balance. The chief investigator was in position and moved each reach indicator back to the starting position in order for three trials to take place in each direction. While each subject reached out, the chief investigator called out the numbers to a secondary investigator for recording data. After the subject completed the Y Balance Test with their dominant limb, they then immediately proceeded to complete the lateral step-down test. During the lateral step-down test, subjects stood on the twelve-inch raised platform with their dominant limb and performed a lateral single leg squat touching their heel to the floor. The subjects repeated this movement until they either failed to achieve proper form or were unable to continue due to exhaustion. Once in a fatigued state, the subjects then immediately performed a second Y Balance Test with the same instructions as their baseline. Subjects then were given a two-minute rest and performed the same sequence of events using their non-dominant limb.

Statistical Analysis

A two by two ANOVA with a within factor of condition was conducted to evaluate the significance of the fatigue protocol on the Y Balance Test scores. A two by two mixed ANOVA with a between factor of sex was conducted to evaluate the fatigue protocol in relation to gender. A two by two repeated measures ANOVA with a within factor was conducted to evaluate the significance of limb dominance on Y Balance Test scores.

Results

The scores from the Y Balance Tests were separated into two groups. One group contained the scores taking the limb variable into account while the other contained the results collapsed across limb dominance. It was hypothesized that the post Y Balance Test scores would decrease as a result of the subjects undergoing the fatigue protocol. Following the fatigue protocol, Y Balance Test scores decreased significantly in all directions ($p<.05$)(ANT=.001, PM=.006 PL=.049) It is important to note that the effects of fatigue on gender and limb dominance were both non-significant ($p>.05$) in response to the fatigue protocol.

Table 1

2x2 Repeated Measures ANOVA. Fatigue and Y Balance Test Scores

Direction	Condition
Anterior	<.001*
Posteromedial	0.006*
Posterolateral	0.049*

Table 2

Y Balance Test Averages w/ limb variable

Directions	Control Pre Dominant	Control Post Dominant	Control Pre Non-Dominant	Control Post Non-Dominant	Fatigue Pre Dominant	Fatigue Post Dominant	Fatigue Pre Non Dominant	Fatigue Post Non-Dominant
Anterior	69	69.1	68.3	69.4	68.4	64.2	67.1	64.3
Postero-medial	102.9	101.1	99.7	101.1	99.1	96.8	97.7	93.2
Postero-lateral	101.6	102.2	102.9	102.8	98.8	97.7	99.8	95.3

Table 3

Y Balance Test averages collapsed across limb dominance

Directions	Control Pre(cm)	Control Post (cm)	Experimental Pre(cm)	Experimental Post(cm)
Anterior	68.6	69.2	67.7	64.2
Postomedial	101.3	101.1	98.4	95
Posterolateral	102.2	102.5	99.3	96.5

Table 4

2x2 Repeated Measures ANOVA;Within Factor of Limb Dominance

Direction	P Value
Anterior	0.805
Posteromedial	0.391
Posterolateral	0.057

Table 5

2x2 Mixed ANOVA Between Factor of Sex;Within factor of condition

Direction	Gender x Condition
Dominant Anterior	0.93
Dominant Posteromedial	0.82
Dominant Posterolateral	0.0502
Non-Dominant Anterior	0.62
Non-Dominant Posteromedial	0.444
Non-Dominant Posterolateral	0.82

Clinical significance. The Minimal Detectable Change (MDC) for the Y Balance Test has been found to be equal or greater than 4 centimeters(cm).[5,20] Researchers have found that a difference of 4 cm may increase injury rates.[5,20] Due to this finding, it is important to note that in all directions, the pre and post scores between the control and experimental groups showed a difference of 4 cm or greater, ANT=5cm, PM=6.1 cm, PL=6cm, making the results clinically significant and useful for clinical practice.

Table 6

Y Balance Test Clinical Differences collapsed across limb dominance

Direction	Control vs Experimental Differential
Anterior	5cm
Posteromedial	6.1cm
Posterolateral	6cm

Table 7

Y Balance Test Clinical Differences w/limb variable

Direction	Control vs Experimental Differential (Cm)
Dominant Anterior	4.9
Dominant Posteromedial	4.3
Dominant Posterolateral	4.5
Non-Dominant Anterior	5.1
Non-Dominant Posteromedial	7.9
Non-Dominant Posterolateral	7.5

Discussion

The purpose of this study was to evaluate the effects of a lateral step-down fatigue on neuromuscular control during the Y Balance Test. Our results indicated that neuromuscular control was impaired due to the adverse effects caused by fatigue. When comparing pre and post-test experimental versus control, Y Balance Test scores significantly decreased in all three directions following the lateral step-down fatigue protocol with posteromedial and posterolateral decreasing slightly more than the anterior direction. Due to subject's worse performance in the posterior direction, it can be hypothesized that the gluteus medius was primarily the musculature that was fatigued. Subject position during both the lateral step-down test and the Y Balance Test may have contributed to the poor posterior scores. The gluteus medius muscle was responsible for maintaining balance during both the lateral step-down fatigue protocol and the Y Balance Test. Due to the gluteus medius being a stabilizing muscle during both tests, it may have been more fatigued than other muscles causing a larger differential in pre and post scores in the posteromedial and posterolateral direction. Gender and limb dominance were both found to be non-significant in this study. Although previous studies have investigated gender and fatigue, there are inconsistencies in the research stemming from the different fatigue protocols and time it takes for recovery.[1,3 9, 10, 24,25]

This study provided further research on fatigue and its effects on neuromuscular control. While there are inconsistencies in the research, many researchers have found that neuromuscular control is affected following a strenuous fatigue protocol.[2,8,10,12,16, 17, 29,32] This study aimed to show the importance of monitoring fatigue during physical activity. If a person is fatigued, this may predispose them to poor neuromuscular control patterns, which can lead to injury.[2,8,10,12,16, 17, 29,32] It is important to modify neuromuscular prevention and training, as this may aid in the prevention of lower extremity injuries caused by poor neuromuscular control. With the amount of injuries in the United States annually, it is vital to implement proper neuromuscular training and rehabilitation techniques in an effort to prevent orthopedic injuries.

Chapter 3

Conclusion

Injuries to the lower extremity, are amongst the most common injuries seen in the recreational population. Our findings suggest that fatigue may have a significant adverse effect on neuromuscular control during dynamic balance. Dynamic balance is an aspect of physical activity that must be trained in order to reduce lower extremity injuries. By limiting fatigue and training on a neuromuscular level, recreational athletes may be better prepared for physical activity. The findings in this study can aid clinicians in rehab implementation when designing neuromuscular control-based exercises. Improving on a neuromuscular level any way possible will be beneficial to the physically active population.

Limitations

During this study, there were a small amount of limitations. There was difficulty in achieving the expected sample size. Due to subject availability, it was difficult to reach the expected number of participants. Many subjects would volunteer, but due to previous commitments or unforeseen circumstances, would not be able to make it to study sessions. Another limitation in this study was the failure to quantify fatigue. Fatigue was subjective in this study as all subjects decided when they had enough of the fatigue protocol. Previous studies did quantify fatigue with similar outcomes as this current study. Although quantifying fatigue did not seem necessary in this study due to the overall decrease in scores, it may aid in keeping future studies consistent.

The two-week break period was also a limitation. While it was necessary to implement this period to minimize learning effect, getting the subjects to come in on time at the 2-week mark was moderately difficult. It may be helpful to have subjects write up their schedule ahead of time in order to manage this limitation better.

Future Work

While this study was successful in assessing the effects of fatigue on lower extremity neuromuscular control, there are always measures that can be taken to improve. The most important variable that can be further studied is the fatigue protocol. While the lateral step-down test was effective in inducing fatigue, it was not the most sports specific exercise. If future studies are done on athletes, it is important to use a fatigue protocol that mimics athletic performance. This may help researchers in judging the effects of fatigue on athletic performance. In the current research, there are too many fatigue protocols and consistency is lacking.

Future research may also choose to focus on the effects of neuromuscular training on fatigue. It is important to understand how clinicians can reduce the effects of fatigue on the body. Future studies on the outcomes of neuromuscular training would benefit researchers, clinicians, and the physically active population.

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