THE RELATIONSHIP OF STATIC AND DYNAMIC HIP MUSCLE ACTIVATION ON RUNNING RELATED INJURY RATES IN RECREATIONAL RUNNERS

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

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In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Program:
Advanced Athletic Training

March 2016

Fargo, North Dakota

North Dakota State University
Graduate School

Title

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Running has become an increasingly popular sport and research is necessary to examine the variables associated with running related injury. The purpose of this study was to analyze the overall relationship between static and dynamic hip strength and the rate of running related lower limb injuries in recreational runners. In addition, gender differences in hip muscle activation were analyzed. Surface electromyography was used to quantify static and dynamic hip muscle activation. Statistically significant decreases in muscle activation were observed in the one-mile testing period in both genders. Significant differences in muscle activation were present between genders. Although there was no statistically significant differences in muscle activation between injured and uninjured runners, the trends reported can help guide future researchers. As the running population continues to increase, number of running related injuries will follow. This research has provided evidence for allied health care providers to base future running related injury evaluations.

ACKNOWLEDGEMENTS

I want to start by thanking my family, especially my Mom and Dad for their guidance and support up to and throughout graduate school. My Mom always says they gave me "roots and wings." My parents created my "roots" by guiding me to be an honest, compassionate, and hard-working individual. Without them, I wouldn't have the "wings" to become the person or Athletic Trainer I have become and will continue to grow to be. I love you both and hope I can continue to make you proud!

Logan Seipel, my fiancé and soon to be husband, has been my number one cheerleader and my rock since the day we met. There were many times during graduate school that it would have been easy to simply give up; however, he knew that although it was tough, the completion of my degree was important to me and my career and he did everything he could to help me maintain a positive attitude and keep working hard to finish what I had started. I love you and can't wait to start enjoying all the hard work we've put in to the life we are starting together!

Dr. Katie Lyman has been the best advisor a graduate student could ask for. As a professor and an advisor, her number one priority is always to address the needs of each, individual student. I found that even when my to-do list grew after a thesis meeting with her, rather than being more stressed, she was able to give me the confidence to know that I could do it and the guidance to handle the tasks at hand. Katie is someone that I will always look up to both personally and professionally, and I am so grateful for the time and support she has given me throughout the past two years.

I also want to thank Dr. Christensen and Dr. Marx for taking the time out of their busy schedules to serve as members on my thesis committees. I appreciate the contributions of their individual expertise to make my project the best it could be.

Finally, I would like to thank Mark Knutson with the Fargo Marathon and the Post-Professional Athletic Training program at North Dakota State University for their financial support. These two entities believed in the purpose of this project and I greatly appreciate their contributions.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1. INTRODUCTION

1.1. Overview of the Problem

Running has become an increasingly popular activity for people of all ages. Although the incidence rate of running related injury has remained constant over the years, more people are participating in the sport. Thus, the gross number of injuries has increased over the years. The cause of running related injuries is multidimensional with many trends of possible causes observed in the available literature. However, conclusive results have not been found and further research is necessary in order to determine the predictive factors of running related injury.

The reported incidence rate of injuries among the millions of runners in the United States varies within each publication as a result of inconsistent definitions and means of reporting data. According to a recent systematic review, between 19.4% and 79.3% of runners experience a lower extremity, running related injury each year with the most commonly reported injury occurring in the knee[1]. This large variance in reported incidence rates is observed as a result of the numerous factors that can be adjusted on a daily basis by each, individual runner. Trends of specific intrinsic and extrinsic factors have been observed; however, statistically significant reports of the cause of running related injuries are minimal[2-5].

Due to the repetitive nature of running, it is hypothesized that lower extremity running related injuries may occur due to weakness in more proximal aspects of the kinetic chain, such as hip musculature[6-8]. After an exhaustive literature review, limited research of a prospective nature has been found to analyze hip strength and its correlation with a broad scope of lower extremity running related injuries. The correlation of hip strength and specific injuries, such as patellofemoral pain and medial tibial stress syndrome, have been analyzed, with very few studies using a prospective approach. The current research aimed to begin filling the gap caused by the lack of prospective research.

1.2. Statement of Purpose

The purpose of this research study was to analyze hip muscle activation in the following three ways: to analyze hip muscle activation using electromyography (EMG) in male and female recreational runners throughout a one-mile run, to determine if there was a difference in maximal static hip muscle activation when compared to dynamic hip muscle activation, and to determine if there was a difference in hip muscle activation in injured compared to uninjured recreational runners.

1.3. Research Questions

Q_1: To what extent does recreational runners' hip muscle activation change throughout a one-mile run?

Q_2: Is there a statistically significant difference between static and dynamic muscle activation in male and female recreational runners?

Q_3: What is the relationship between relative hip muscle activation and rate of running related injury in recreational runners?

1.4. Definitions

Definitions of running related injury and recreational runner vary greatly between each research study which makes comparison of reported results very difficult. In an effort to keep definitions consistent between studies, the following definitions were used for this research study.

Recreational Runner: A recreational runner was defined using the definition provided by Niemuth et. al.[9], "[someone] averaging a minimum of 10 miles per week for the past 3 months, not competing on a team at the high school, college, or professional level, or an individual competing for a team in a marathon or distance running race (pg. 15)."

Running Related Injury: The following definition is similar to that used by Macera et. al.[10] and Hreljac[11]. A running related injury is any "musculoskeletal ailment that is attributed to running that causes a restriction of running speed, distance, duration, or frequency[11]" (pg. 651).

Electromyography (EMG): A diagnostic technique which uses surface electrodes to measure motor nerve function[12-14].

Static Hip Muscle Activation: EMG analyzed Maximal isometric voluntary contraction (MVIC) as determined by the standardized manual muscle test for each individual muscle being examined[7,9].

Dynamic Hip Muscle Activation: For the purpose of this study, dynamic hip muscle activation was defined as the average muscle activation, measured by EMG, during the designated running gait testing period.

1.5. Limitations

The limitations of this research study may affect the power of the results. First, there are variables associated with surface EMG that may have caused unpredictable outcomes. EMG has been reported to be a valid and precise tool when used with proper electrode placement and research based parameters[15,16]. Although evidence-based methods were used for placement of surface EMG, muscular anatomy varies slightly between each individual. Therefore, without radiographic imaging to determine precise location of each muscle, slightly different muscle contractions may have been measured in each participant[13]. Furthermore, although the reliability of surface EMG to analyze muscle contractions during physical activity has been supported by past research[15,16], the most accurate method for normalization of dynamic results remains unclear[14,17,18]. The use of MVIC as a normalization method has been supported by past reports[14,17]. MVIC assumes that participants were able to reach their full muscle contraction potential which may not occur each time the MMT is performed[17]. In conclusion, although surface EMG is a precise and reliable tool to measure muscle activation, slight alterations in application can cause drastic changes in results.

Furthermore, muscle activity throughout the one-mile testing period was based solely on EMG data. Without further gait analysis, it was unclear if changes in muscle activation were due to fatigue or a period of gait normalization on the treadmill. Until future research analyzes both hip muscle activation and running kinematics, the cause of changes in muscle activation throughout the one-mile run in this study remains unclear.

In addition, this study relied on self-reported running data and running related injury information rather than clinical diagnoses. In an attempt to keep results consistent, the definition of running related injury used for this study resembled definitions used in past research[10,11]. The definition was explained in detail to each participant, but each person may have interpreted when to report an injury in different ways. Therefore, there may have been slight variability in reports of running related injury.

Finally, there was a high rate of attrition in returning completed running logs and only 21 running logs were analyzed. Due to the low number of completed running logs, the number of injuries reported was insufficient to draw strong correlations between injured and uninjured runners. Due to these limitations, clinician discretion should be used when making recommendations based off the evidence provided. These limitations should be considered prior to conducting future research regarding hip strength and running related injury.

1.6. Delimitations

Due to lack of time and relevance to the purpose of this study, a few running related variables were not accounted for throughout the data collection. These variables include running shoe type, detailed history of running experience, personality type, and BMI. These factors have been previously analyzed more thoroughly than hip strength as a predictive factor to running related injury. These factors were outside the scope of the current study and, therefore, the data reported by previous studies can be used by runners for information regarding these particular variables.

1.7. Assumptions

Assumptions were made throughout this research study as a result of runners continuing with their normal daily running routine rather than in a controlled environment. Due to the lack of environment controlled research, it was assumed that subjects were honest and accurate when reporting daily running and running related injuries. These terms were defined and provided to subjects consistently throughout data collection in order to reduce variability of reporting between subjects. Diet, sleep habits, time of day of training, running shoe type and duration of use, and warm up or cool down were not controlled. Previous evidence suggests these factors to have little to no influence on the incidence of running related injuries[19,20]. Therefore, for the purpose of this study, it was assumed that these factors did not play a role in the rate of running related injury.

Assumptions were also be made as a result of the use of surface electromyography during data collection. Research has been analyzed and methodology was duplicated to ensure the use of the most reliable procedures in the application of EMG electrodes; however, even these well researched procedures assume that muscles are located in the same location in each individual which may cause minor discrepancy between subjects in the exact muscles measured by EMG. Maximal voluntary isometric contraction (MVIC) was used as the normalization method for EMG. This normalization method assumes that each subject will apply their maximal effort to the contraction and that they are able to reach their maximal muscle contraction on a voluntary basis. Precise instructions were given to guide subjects in fully contracting the muscle in hopes of increasing likelihood of a maximal contraction being reached. Despite the assumptions made of EMG, it is still reported as a reliable measure of muscle activity[17,18].

1.8. Variables

The independent variables in the current study were both static and dynamic hip muscle activation and gender. The dependent variable in the current study was number of injuries sustained over the sample period.

1.9. Significance of the Current Study

As stated previously, the number of recreational runners has increased greatly over time. This increase in popularity is shown in the increase of registrants for the Boston Marathon. The first year of the Boston Marathon, 1897, had a mere 18 registrants. In the spring of 2014, there were 35,755 registered runners for the race[21]. As the number of runners increases around the world, the number of running related injuries also increases. Lower extremity running related injury can hinder the ability of these athletes to run without restriction. Evidence of a correlation between hip strength and running related injury allows clinicians to provide evidence-based suggestions in regards to hip strengthening exercises as a preventative mechanism to running related injury. Runners tend to be relentless, and will continue to train regardless of the possibility of injury. Therefore, continuous research is needed to add to what is known regarding factors affecting running related injury[22]. This research study was conducted in order to add to the research on predictive factors of running related injury.

CHAPTER 2. LITERATURE REVIEW

Due to the growth in the running population, an increase of running related injuries has prompted the need for examination of the causative variables of these injuries. Throughout the past few decades, recreational running has increased in popularity. This increase was seen in number of registrants of the Boston Marathon. 1897, the first year of the Boston Marathon had only 18 registrants. A yearly gradual increase in registrants has been reported. A drastic increase was seen in 1996 when there were 38,708 registrants compared to the 9,410 registrants in 1995. Registration numbers have increased since then with a total number of registrants for the 2014 Boston Marathon being 35,755 runners[21]. There are numerous variables that contribute to the incidence rate of running related injuries; past research has examined a variety of known variables[1,19,20]. However, the gaps in the research has left clinicians and runners questioning ways to prevent running related injury. Therefore, the purpose of this literature review was to analyze past research in order to determine causes of running related injury and establish the necessary direction of future research in regards to running related injury.

The convenient nature of the sport, along with the numerous health benefits associated with it, and the minimal costs necessary to become a runner, make it an easy choice of exercise for many people[2,19]. In 1986, Jacobs and Berson[22] reported an estimated total of 30 million runners in the United States, 10 million of which ran consistently throughout the year. According to USA Running, the 2013 National Sporting Goods Association's sport participation survey reported approximately 54 million runners in the United States, with nearly 30 million of those runners running at least 50 days each year[23].

The reported incidence rate of running related injury among the millions of runners in the United States varies within each publication. Due to the repetitive nature of distance running, running injuries tend to be overuse, chronic injuries[3,24]. The most recent systematic review of running related injury research completed by Van Gent et al.[1] reported a yearly incidence rate of lower extremity injury to be between 19.4% and 79.3% with the most common site of injury being the knee. This large variability between reported incidence rates occurred due to the large time span in published research and the inconsistent definition of the words "runner" and "running related injury" between each study. This systematic review analyzed publications between 1982 and 2004. This large time span of data could contribute to the large variability in injury rates. Also, some research studies qualified a runner if they were entered into a race or specific training program to prepare for a race[2,22,25]. In contrast, additional studies used the reported number of miles or days ran per week over a certain course of time in order to qualify a subject as a runner[4,9,26-28]. For the purpose of this study, the definition of recreational runner provided by Niemuth et al.[9] was used: "[someone who is] averaging a minimum of 10 miles per week for the past 3 months, not competing on a team at the high school, college, or professional level, or an individual competing for a team in a marathon or distance running races (pg. 14)." This definition was used to ensure results yielded information pertaining to those individuals not on competitive teams. Recreational runners may not have convenient access to a health care professional such as an Athletic Trainer or team physician. By conducting research on recreational runners, this study made a contribution to the existing literature by providing objective data specific to an active population.

The definition to qualify an injury as a running related injury also varies between each publication. Most commonly reported in the literature is any lower extremity ailment that causes a runner to modify their running in any way for a certain period of time. Although this definition seems all encompassing, many research studies define an injury using more specific criteria which causes difficulty in comparison of results[2,22]. For the purpose of this study, running related injury was defined using the definition also cited by Macera et al.[10] and Hreljac[11]. A running related injury was any "musculoskeletal ailment that is attributed to running that causes a restriction of running speed, distance, duration, or frequency[29]" (pg. 651). This definition was used in order to include all adjustments made to running due to a musculoskeletal impairment. For the purpose of this study, all musculoskeletal ailments were self-reported by subjects.

2.1. Epidemiology of Running Related Injuries

Many publishers divide running into two categories: intrinsic factors and extrinsic risk factors. Intrinsic factors have been classified as inherited traits of an individual and include gender, age, and genetic alignment such as the quadriceps angle. Extrinsic factors, more commonly known as training variables, are able to be manipulated by runners and include factors such as number of miles run per week, pace of typical training days, and training surfaces. Similar to previously discussed factors, the literature was inconclusive due to the various definitions of running related injury and the definition of a "runner" throughout the research. However, after an exhaustive review of the available literature, the following commonly reported trends of intrinsic and extrinsic risk factors have been reported[2-5].

Similar to gender differences in athletic ability such as relative strength, muscle mass, and various anatomical alignment, there were gender differences in incidence of running related injuries. As the running population has grown over the past decades, the number of women runners has also steadily increased[23]. In 1986, Jacobs and Berson[22] analyzed entrants into a 10,000 meter race that took place in 1984. Of the 2,664 entrants in this particular race, 615, or about 23%, were female runners. Comparatively, in 2002, Taunton et al.[2] investigated participants registered in a clinic to guide runners through a training program in preparation for a 10,000 meter race. Of the 844 runners registered for the clinic, 635, or about 75%, were female runners. Consequently, the low number of female subjects in historical research limits what is known on running related injury rates in female recreational runners.

Although the results of many studies have not shown gender to be a significant risk of running related injury[19,22,28], gender specific trends of predictive factors have been seen in the literature[2,5,10]. For men, these predictive trends include a running related injury within the previous twelve months and a consistent weekly mileage of at least 32 kilometers per week for a minimum of three months. In comparison, the predictive trends for women were running primarily on a concrete surface and running between 48 and 63 kilometers per week. Running at least one marathon within the previous year was the only similar trend observed between men and women[10]. Additionally, women were more likely to report low back pain induced by running, specifically in conjunction with increased weekly mileage or lower than average (< 21 kg/m^2) body mass index[2,5]. These trends were reported in a limited amount of published literature and generalization based on this data should be used with caution.

As stated previously, reports most commonly express no significant correlation between gender and risk of running related injury[19,22,28]. However, contrary to common results, the systematic review of 11 articles by Van Gent et al.[1] states, "the only significant association for overall lower extremity running injuries showed a positive correlation with female sex (pg. 470)." This particular systematic review had very specific article inclusion criteria with only one of the cited sources shown to support this positive correlation. It was emphasized however, that each article correlated age with injury to a different body part. Therefore, it is possible that the trend discrepancy in correlations of running related injury and age stems again, from the lack of specificity of reported results. Although occasional trends in predictive factors of each gender have been observed, the dominating evidence shows no correlation of gender as a risk factor for running related injury[19,22,28].

Additional intrinsic factors explored in the literature included anatomical factors, such as quadriceps angle (Q-angle), rear foot and arch posture, and leg length discrepancy[3,19,24,27,30-32]. These were all factors that recreational runners were likely born with, however using what is known based on these research results, factors such as type of running shoe, an orthotic, or adjusting running stride, could potentially assist clinicians in prevention of running related injury. Commonly cited in literature, and summarized in the systematic reviews of Van Mechelen[19] and Wen[3], arch and foot posture often affect rates of injury below the knee, such as shin splints or ankle injuries, while greater than normal Q-angle is often a predictor of overuse knee injury, specifically patellofemoral pain[24,27,30-32].

Leg length discrepancy was not as thoroughly studied. Structural leg length discrepancy can be measured by determining the length between the anterior superior iliac spine and the medial malleolus while the patient is lying supine. Discrepancy in leg lengths is commonly due to a disturbance of one or more of the growth plates in the lower limb[12]. In a survey of 1,505 recreational runners, Brunet et al.[5] found significant correlation between lower extremity running related injury and clinically diagnosed leg length discrepancy. Both men and women runners with leg length discrepancy were twice as likely to have ever experienced hip pain throughout the time they have been consistently running. This particular research study used a questionnaire which asked if subjects have ever experienced hip pain. Rate of running related injury is often calculated based on the exposure of running time and reported as the amount of injuries per 1000 hours of running[19]. Contrasting reports were published by Van Mechelen[19] and Wen[3]. These reports state there was lack of sufficient evidence to support this claim and there was no association between the two variables, respectively. In summary, there is a lack of supporting evidence to support leg length discrepancy as a well-defined risk factor of running related injury. The definitive correlation between intrinsic factors and running related injury is not thorough and should be evaluated further by future researchers.

In contrast, research examining the extrinsic risk factors of running related injury dates back to 1986 when Jacobs and Berson[22] reported the only significant risk factors of running related injury to be extrinsic. Both Van Mechelen[19] and Hoeberigs[20] also concluded similar results after review of the epidemiological reports available at that time. The most commonly reported statistically significant extrinsic risk factor for running related injury was weekly running distance[1,10,19,20,22]. Jacobs and Berson[22] as well as Macera et. al.[10] reported weekly mileage greater than 40 miles per week to be a predictor of running related injury. The other reports simply stated that there was a positive linear relationship between weekly mileage and running related injuries[1,19,20]. This leaves room for interpretation with no definitive data on the maximum number of miles recreational runners should be doing each week. It is possible that injury threshold of each individual runner is different and therefore the number of miles each person is able to run prior to experiencing a running related injury is different in every individual.

Epidemiological literature has also revealed a relationship between a faster running pace and running related injury[20,22,28]. Data on running pace was reported to be very similar to the data on weekly mileage. Jacobs and Berson[22] reported a training pace faster than 8 minutes per mile to be a risk of running related injury whereas other authors simply stated that increased pace was associated with increased risk of running related injury[20,28]. Although it was unclear the exact pace that puts runners at risk for injury, it is likely that similar to weekly mileage, the pace that causes increased risk of running related injury varies in each individual.

Correlations between running surface and incidence of running related injury have yet to be confirmed. Van Mechelen's[19] review of epidemiological literature presented the hypothesis that due to the greater mechanical shock applied to the joints after running on hard surfaces compared to soft surfaces, injury rates would increase. This hypothesis was not supported by the literature and, in fact, a majority of the available research actually refutes this hypothesis[1,5,10,19,28]. Jacobs and Berson[22] found no increase in running related injury in runners who consistently ran on a hard surfaces. However, it should be noted that of the 451 runners analyzed in this particular study, only 50 of these runners reported running regularly on soft surfaces leaving little room for comparison between the two groups. Macera et al.[10] found increased risk of running related injury when constantly running on hard surfaces only in women, with no correlation found in men subjects. Although the hypothesis about running on hard surfaces has been refuted by current available literature, there has been little to no research directly looking at this association and until research of this manner is conducted, no conclusions can be made on this topic.

The most controversial extrinsic risk factor discussed in the literature is stretching prior to running sessions. Van Gent[1] conducted a systematic review and concluded there were no significant associations between a warm up and running related injury. Brunet et al.[5] and Macera et al.[10], found similar results with no statistically significant differences in runners who stretched before running when compared to those who did not stretch. In contrast, Jacobs and Berson[22] reported an association with stretching before running and increased injury risk however no statistical significance was reported in the research. The review of the epidemiological literature done by Van Mechelen[19] indicated no conclusion on the effects on running related injury of stretching or warming up prior to running because the available findings were inconclusive. Especially in self-reported research, it is likely that the differences in data stemmed from differences in warm up and stretching in each individual that is reporting. Again, until research is conducted that specifically looks at a controlled warm up or stretching protocol on the incidence of running related injuries, few conclusions can be made about how stretching or warming up affects rate of running related injuries.

The most consistent research results in epidemiological running literature were found when discussing incidence of re-injury. Macera et al.[10], VanMechelen[19], Hoebrigs[20], Wen[3], Van Gent[1], and Hespanhol Jr. et al.[28] all reported strong statistically significant positive correlations between previous running related injury and re-injury rate. Significance of previous injury was not reported after an analysis of 1505 competitive and recreational runners completed by Brunet et al.[5]; however, the methodology used to reach these conclusions could have caused the discrepancy in results. This study differed from the others in that, researchers asked if subjects had ever been injured rather than only over a certain time period preceding the data collection period. A majority of the articles used methodology similar to Macera et al.[10] who asked subjects if they had experienced a running related injury within the 12 month period before the research was conducted. Therefore, it is unknown whether running related injury poses an increased risk of injury for the rest of that runner's life or only for a short time frame following the injury. It is hypothesized that previous injury plays a role in future re-injury because the injury was never fully healed; if the tissue was healed, it may function less optimally than it did prior to the injury; or the original cause of the injury was never corrected[19]. Although these hypotheses seem quite logical, until research is conducted to support this hypothesis, the reason for previous running related injury playing such a large role in the re-injury of athletes remains unknown.

2.2. Hip Strength

In recent years, researchers have begun to examine the role of the proximal kinetic chain on lower extremity running related injuries. Little research was done in the late 1990's on hip musculature and its effects on running related injury which created a large gap in the literature with many questions still unanswered. In 1993, Van Mechelen et al.[19] examined the balance between the hamstrings and quadriceps muscle groups in male runners. Isometric muscle strength was measured with a cybex II device and reported in absolute torque. There was no statistically significant difference in absolute hamstring torque, absolute quadriceps torque, or the ratio between hamstring and quadriceps torque when comparing injured to non-injured runners. This study was, however, a retrospective case control and therefore the cause and effect relationship between these two variables was unable to be extrapolated from this particular study. Authors reported that a prospective study needed to be conducted in order to determine the true relationship.[19]

After approximately a 20-year interval lacking literature on hip strength and running related injury, this correlation was reintroduced as a topic of research over the past decade. Fredericson et al.[6] was the first published literature to show an association between hip strength and running related injury. Subjects for this research study were recruited from a pool of patients diagnosed with iliotibial band syndrome at the Runners' Injury Clinic. Injured runners were all collegiate or club-long distance runners. The uninjured, control group consisted of all collegiate distance runners. A hand-held dynamometer was used to measure hip abductor strength. For statistical analysis, all measurements were reported in percent of each subject's body weight and height for normalization purposes. Injured runners not only showed statistically significant weaker hip abductors than their uninjured counterpart but also significantly weaker hip abductors on their injured limb when compared to their uninjured limb. The analysis of already injured runners continues to leave clinicians questioning if hip strength was the cause of injury; therefore, future prospective research should be conducted in order to confirm or deny the cause and effect relationship[6].

In the descriptive analysis completed by Niemuth et al.[9], 30 recreational runners who were already diagnosed with a running related injury and referred by a health care professional, were tested with a hand held dynamometer to determine hip peak force in the following movements: flexion, extension, abduction, adduction, internal and external rotation. When compared to the uninjured leg, injured limbs had statistically significant weaker hip adductors and hip flexors. Hip external rotators also showed a trend toward weakness however, the weakness reported was not statistically significant[9]. Due to the fact that runners had already been diagnosed with a running related injury prior to data collection, it is unknown whether the weakness caused the injury or the lack of activity by the runners due to injury caused the hip weakness.

Comparable results were reported by Ireland et al.[7] after analyzing hip strength of 15 young females with patellofemoral pain. Strength of the hip abductors and external rotators was quantified using a hand held dynamometer. Authors justified the testing of these specific muscles due to the role these muscle groups play in stabilization of the femur. With weak hip abductors and external rotators, the femur can potentially adduct or internally rotate more than in a strong lower limb. With this excess motion, increased pressure is placed on the patella. Authors used this information to hypothesize a correlation between weak hip musculature and patellofemoral pain. Their hypothesis was supported by the results of this particular study. Hip abduction and external rotation were both significantly weaker in injured individuals when compared to the hip strength of their age-matched counterpart. On average, hip abductors were 26% weaker and hip external rotators were 36% weaker in the subjects experiencing patellofemoral pain[7]. Although authors did not target a running population, the results of this study are applicable to the current research project because stabilization of the femur during running gait is crucial.

With a research design parallel to that of both Fredericson et al.[6] and Niemuth et al.[9], it remains unclear which occurs first; hip weakness or lower extremity injury. Upon interpretation of results, authors directly stated, "Future study of a prospective nature is necessary to more completely delineate the role of proximal muscle strength in the etiology of lower-extremity injuries including PFP [patellofemoral pain][7]" (pg. 675).

In 2011, Finnoff et al.[8] conducted a prospectively designed research study analyzing hip strength and knee pain in high school runners. Although statistically significant results of diminished hip strength as a risk factor to knee pain were reported, demographics and training variables of high school runners bear little resemblance of recreational runners, and therefore, the results of this study are not able to be generalized to different running populations.

Due to the aerobic requirements of running, many runners will continue to run an excessive amount of miles at a rapid pace despite the evidence based correlations of intrinsic and extrinsic factors on running related injury. It is necessary that future research is conducted to support or refute specific portions of currently inconclusive data. Upon report of more conclusive data, this information can be used to educate recreational runners on factors they need to be aware of in order to reduce their risk of running related injury[22].

2.3. Anatomy

Hip strength plays a large role in the biomechanics of the lower extremity[33,34]. In order to understand why this holds true, a detailed awareness of the anatomy of the hip and surrounding musculature is necessary. Running gait differs from walking because there is a brief period during running, where neither foot is in contact with the ground: flight phase. Also, unlike walking, during running gait there is no period of double limb support. There are two distinct phases in running gait; the stance phase and the swing phase. The stance phase begins when the limb makes contact with the ground and continues until the limb leaves the ground. The swing phase occurs as the non-weight bearing limb "swings" thru to accept the role of the weight bearing limb. As one limb is in the stance phase, the other is in swing phase. Different muscles of the hip activate during various portions of the running gait. The following section provides a description of each of the hip muscles examined in the current research study and how each of these muscles contributes to motion throughout running gait[12].

2.3.1. Gluteus Maximus

The most powerful hip extensor that makes up the mass of the buttocks is the gluteus maximus. The gluteus maximus is isolated as the primary hip extensor when the knee is in a flexed position. The gluteus Maximus also plays a small assisting role in adduction and lateral rotation of the hip[12].

This large hip extensor originates from the posterior aspects of the ilium, sacrum, and coccyx. The ilium and sacrum are two portions of the large innominate bones that make up the pelvic girdle. The coccyx, commonly known as the tailbone, is the distal end of the spinal column. The muscle fibers run from the midline of the body to the lateral aspect of the femur where they insert on the gluteal tuberosity of the femur. A portion of the fibers also insert by means of a fibrous tissue band to the posterior iliotibial tract. The gluteus Maximus is innervated by the inferior gluteal nerve which roots from the spinal cord at the L5, S1 and S2 levels[12].

Manual muscle testing of the gluteus maximus requires the patient to lie prone with the knee flexed at least 90 degrees. The clinician should apply downward pressure to the lower part of the posterior thigh in order to resist hip extension[12,35]. Not only is this method for manual muscle testing referenced in Starkey and Kendall's textbooks but also in the literature that examined gluteal and/or hip extensor group strength[9,34,36].

Near or full extension of the knee occurs in only the initial contact phase of gait, which is approximately only 20% of total gait. Therefore, the gluteus maximus acts as the primary hip extensor during gait. The gluteus maximus activates just before initial contact in running gait when the foot is placed on the ground and remains activated until the loading response phase of running gait. At this time, the body has absorbed the impact of the body weight hitting the ground and the gluteus maximus will remain contracted until the opposite limb has left the ground and only one limb is supporting the body[12].

2.3.2. Gluteus Medius

The Gluteus Medius, a primary hip abductor, assists in pelvic posture and acts as a core stabilizer keeping the torso upright during gait. This muscle is the most superior muscle on the lateral aspect of the upper thigh and hip. The largest band of fibers originates on the external surface of the ilium; however, Gluteus Medius fibers also originate on the anterior gluteal line and the Gluteal aponeurosis. The Gluteal aponeurosis is a fibrous membrane that assists in attaching the Gluteus Medius to the ilium. The muscle fibers run in an inferior fashion and insert on the greater trochanter of the femur. The Gluteus Medius is innervated by the Superior Gluteal Nerve which roots from the spinal cord at the L4, L5, and S1 levels[12].

In order to manual muscle test the Gluteus Medius, the patient must be in a side lying position with the leg to be tested stacked on top of the other leg. The leg should be rotated slightly forward. The clinician should instruct the patient to use the trunk muscles to help stabilize their body. The hand opposite of the hand applying pressure can assist patient in stabilizing their body while they perform the manual muscle test. As the patient abducts the hip, the joint should also be in a slightly extended and externally rotated position. The clinician should apply pressure near the ankle against hip adduction and slight hip flexion. Pressure should not be applied against the rotation component of the patient's position. Strong force should be applied in order to accurately test patient's maximal isometric strength capacity. Weakness of the Gluteus Medius can also be observed by Trendelenburg's sign during gait. As the patient ambulates, if increased hip adduction is observed with each weight-bearing phase of gait, testing and strengthening of the Gluteus Medius and the other muscles of the hip abductor group might be indicated[35].

2.3.3. Tensor Fascia Latae

The Tensor Fascia Latae serves to flex, internally rotate, and abduct the hip joint. This muscle originates at the anterior superior iliac spine as well as the external lip of the iliac crest. The fibers run in an inferior fashion and insert on the iliotibial tract on the proximal, middle third of the thigh. The Tensor Fascia Latae is also innervated by the superior gluteal nerve which roots from the spinal cord at the L4, L5, and S1 levels[12,35].

In order to manual muscle test the Tensor Fascia Latae, the patient should be lying in a supine position, and should hold onto the examination table with their hands in order to stabilize the rest of their body. With the knee extended, the patient should move their leg into an abducted, flexed, and internally rotated position and the clinician should apply pressure against the flexion and abduction motions. No rotational resistance should be applied to the limb[35].

During the standard running gait, the hip does not fluctuate more than 10 degrees in the adduction-abduction plane. Therefore, although the Gluteus Medius and Tensor Fascia Latae may be considered smaller muscles, their role in stabilization of not only the hip, but stabilization of the torso and pelvis is crucial in order to prevent lateral movement during running. The fibers of these hip abductors activate at very similar times in running gait as the gluteus maximus. The fibers fire at their peak level during the loading response and by the end of the mid-stance phase, the fibers gradually deactivate. The transfer of weight from both limbs to single limb stance requires increased muscle activation in order to stabilize the body. Due to the assisting role in hip flexion of the Tensor Fascia Latae, the posterior fibers of this muscle also tend to fire throughout the terminal stance phase of gait[12]. It has been reported that resistance training of the hip, specifically of the hip abductors, increases isometric strength and adjusts lower extremity kinematics during running gait. Results showed that as isometric hip strength increased, rear foot eversion and hip internal rotation also decreased during running gait. These decreases in unwanted motions throughout gait could potentially place less stress on the ankle and knee joints and decrease risk of overuse injury due to faulty biomechanics. This statement, however, is simply a hypothesis and until the relationship between hip strength and injury rates is analyzed in a prospective manner, definitive conclusions cannot be assumed[33].

2.3.4. Rectus Femoris

The Rectus Femoris, a large muscle which makes up the bulk of the quadriceps muscle group, is a primary muscle in knee extension but also assists in hip flexion. This muscle originates on the anterior inferior iliac spine as well as the groove located superior to the acetabulum and runs in an inferior fashion to insert on the tibial tuberosity by means of the patella and patellar ligament. The femoral nerve, which roots from the spinal cord at the L2 and L3 levels, innervates this muscle[12].

In order to manual muscle test the Rectus Femoris, the patient should be short sitting with their knees over the edge of the examination table. The patient can use their hands to stabilize their body while the manual muscle test is performed. If additional stabilization is necessary, the clinician can use the opposite hand of which is applying pressure in order to assist the patient in stabilization of the thigh. The patient should extend the knee straight forward with no rotation of the thigh or lower leg. The clinician should apply pressure on the lower leg above the ankle, against extension of the knee joint. In order to ensure a true manual muscle test of the Rectus Femoris, the clinician should ensure the body remains in an upright position throughout the test. If the patient attempts to move their upper body or rotate the limb being tested, outside muscles may be recruited to assist knee extension and findings of the manual muscle test will be inaccurate[35].

During running gait, the Rectus Femoris, as well as other muscles of the hip flexor group, act to advance the limb forward. Therefore, these muscles are activated through a majority of the gait cycle including the pre-swing phase, initial swing phase, and mid-swing phase. Due to the rectus femoris also playing a large role in motion of the knee joint, this muscle contracts eccentrically on initial contact in order to control the amount of flexion[12].

Based on the intricate role of each muscle during running gait, it is evident that weakness of one muscle could alter the entire running gait cycle. However, it is unknown whether or not this alteration increases the likelihood of running related injury. Therefore, future research needs to be completed in order to determine if a correlation exists between hip strength and rate of running related injury.

2.4. Electromyography

Electromyography (EMG) is a diagnostic technique which uses surface electrodes to measure motor nerve function[12-14]. A variety of muscular characteristics can be measured with EMG, including but not limited to magnitude of muscle contraction, muscle action intervals, or fatigue[12,13]. When used with proper electrode placement and specific parameters supported by research, EMG is a valid and precise tool[15,16].

Reliability is the ability of a tool to produce consistent and precise results[17]. For the purpose of this research study, it is imperative to expand on the reliability of dynamic EMG testing during running.

EMG reliability research dates back to 1996 when Guidetti et al.[15] analyzed intra- and inter-individual variability of EMG patters during running. The coefficient of variation was used to determine whether there was variability between trials of each subject. The Erector Spinae, Rectus Femoris, Vastus Lateralis, Vastus Medialis, Biceps Femoris, Tibialis Anterior, and Gastrocnemius muscles were all tested. Of these seven muscles that were tested with surface EMG, no statistical differences between running trials in any of the muscles tested were reported[15]. In 2010, Smoliga et al.[16] also examined reliability of dynamic EMG muscle analysis while running. This study was slightly more in depth as 13 muscles were examined. The lower extremity muscles examined in this study included the Vastus Lateralis, Semimembranosus, Gluteus Maximus, and Rectus Femoris. The Vastus Lateralis was one of the least reliable muscles with an inter-class correlation coefficient (ICC) of less than 0.80 with all parameters testing. All other lower extremity muscles exceeded the ICC of 0.80 for at least three tested parameters and are considered very reliable[16]. Based on the results of these studies, the use of EMG for dynamic muscle abilities is supported.

In order to make interpretation of results of dynamic EMG measures reliable, normalization method is required[17,18]. Similar to dynamic reliability, the most accurate normalization method depends on which muscle is being examined. Based on the interclass correlation coefficients in this study, the use of maximal voluntary isometric contraction (MVIC) as a normalization method was supported for the Rectus Femoris, Vastus Lateralis, and Biceps Femoris[14]. Due to the comprehensive, dynamic relationships the hip adductor muscle group, Gluteus Maximus, and Gluteus Medius muscles have in the multi-planar motions of the hip joint, Norcross et al. recommended the use of single leg stance as a normalization method for these muscles. This recommendation contradicts the recommendations made by both Bolgla and Uhl[17]. Bolgla and Uhl[17] report the highest reliability of normalization in hip musculature EMG to be MVIC regardless of which muscle is being analyzed. Although future research is recommended by these authors, normalization recommendations were based off the premise that in order to compare how much of the full muscle potential is being used, a maximal normalization method is required. A limitation of the maximal isometric voluntary contraction normalization method is that the normalization is based on the assumption that the subject was able to produce a maximal contraction. Also, injured individuals may not be able to reach their full muscle contraction due to pain or injury. However, even with these known limitations, it is reported that MVIC remains the most reliable method of EMG normalization[17]. In summary, based on the combination of results from these research studies, maximal voluntary isometric contraction and single leg stance are both reliable measures. In future research studies, preference of the researchers and the type of subjects being analyzed should be considered in order to decide which normalization method will be the best for that study.

2.5. Conclusion

In summary, future research was warranted to determine if a correlation exists between hip muscle weakness and incidence rates of running related injury. The multi-faceted nature of running and the numerous variables that have been analyzed still leave clinicians questioning whether or not a cause and effect relationship exists between these two variables. As stated previously, due to the nature of the sport and the training desires of recreational runners, many runners will continue to run an excessive number of miles at a rapid pace, regardless of the possibility of injury. Therefore, it is necessary for research to be continued in order to advise runners of the risk factors of running related injury[22].

CHAPTER 3. METHODOLOGY

3.1. Purpose

The purpose of this research study was to analyze hip muscle activation in the following three ways: to analyze hip muscle activation using electromyography (EMG) in male and female recreational runners throughout a one-mile run, to determine if there was a difference in maximal static hip muscle activation when compared to dynamic hip muscle activation, and to determine if there was a difference in hip muscle activation in injured compared to uninjured recreational runners. For the purpose of this study the following definitions were used:

1. Static Hip Muscle Activation: EMG analyzed Maximal isometric voluntary contraction (MVIC) as determined by the standardized manual muscle test for each individual muscle being examined[7,9].

2. Dynamic Hip Muscle Activation: For the purpose of this study, dynamic hip muscle activation was defined as the average muscle activation, measured by EMG, during the designated running gait testing period.

This research was conducted with a goal of answering the following research questions:

Q_1: To what extent does recreational runners' hip muscle activation change throughout a one-mile run?

Q_2: Is there a statistically significant difference between static and dynamic muscle activation in male and female recreational runners?

Q_3: What is the relationship between relative hip muscle activation and rate of running related injury in recreational runners?

A randomized, within subject design was used. The independent variables in the current study were both static and dynamic hip muscle activation and gender. The dependent variable in the current study was number of injuries sustained over the sample period.

3.2. Participants

Thirty participants (n= 15 males, n= 15 females) were recruited from a mid-sized, Midwestern, United States city. Subjects were recruited by word of mouth and posters in local running stores.

Runners were included in this study if they have averaged a minimum of 10 miles per week for the previous three months; were not currently competing on a team at the high, school, college, or professional level; or competing for a team in a marathon or distance running race. Subjects were between the ages of 20 and 45 years old and were excluded if they were outside of that age range. Other exclusion criteria included rheumatoid arthritis and nerve conduction health history including but not limited to amyotrophic lateral sclerosis (ALS, Lou Gehrig's Disease), Multiple Sclerosis (MS), or Parkinson's Disease. Subjects were also excluded from this study if they had any current lower extremity injury (this includes hip injury) or injury within the three months prior to data collection. For the purpose of this study a running related injury was defined as any "musculoskeletal ailment that is attributed to running that causes a restriction of running speed, distance, duration, or frequency[11]" (p. 651).

3.3. Electromyography

Raw data was obtained using electromyography analysis through Biopac Systems, Inc. (Version 4.1, Goleta, CA). Manual Muscle Tests (MMT) were conducted pre- and post-testing which served as reference contractions for each of the four muscles. Each contraction lasted five seconds with at least three to five seconds of rest between the contractions. For each muscle, MMTs were performed with a joint angle that maximized EMG activity under isometric conditions and within a normal range of motion[35]. The MMT results were used as a baseline for EMG data collection during the dynamic running testing.

According to Rainoldi et al.[13], a precise placement of the surface electrodes can determine the measurement reliability of each muscle. This study quantified the innervation zone, area where nerve terminations and muscle fibers are connected, and the signal amplitude of the surface EMG. For the purpose of this research study the Gluteus Maximus, Gluteus Medius, Tensor Fascia Latae, and Rectus Femoris were analyzed. The Tensor Fascia Latae was the only one of these muscles reported to have a high signal quality in addition to a high innervation zone location uniformity. Although the reported innervation zone uniformity of the gluteus maximus between subjects was only fair, the signal quality was excellent meaning that although researchers were not able to find a common site of innervation zones among the healthy subjects that were examined, they were still able to get an excellent EMG signal from that muscle. These findings indicate the need for a more time intensive procedure to find the most accurate electrode placement in order to analyze EMG readings of the gluteus maximus. For both categories, the Gluteus Medius was categorized as fair. The innervation zone of this muscle was still identifiable but more difficult because there is more variability of this zone between subjects. The Rectus Femoris muscle was not analyzed by Rainoldi et al.[13] and therefore knowledge on electrode placement accuracy is not known. The precise muscular anatomy varies among individuals and therefore, the anatomy of each subject was analyzed prior to electrode pad placement. As a general guideline, the electrode pads were placed half way between the point of muscle origin and the point of muscle insertion of each muscle being tested.

3.4. Documentation

Prior to data collection, this study was approved from the Institutional Review Board at North Dakota State University (Appendix A). Each participant was asked to read and sign an informed consent form (Appendix B) and complete the American College of Sports Medicine's Physical Activity Readiness Questionnaire (PAR-Q) (Indianapolis, IN) (Appendix C). Data collection was conducted in the Human Performance Laboratory at North Dakota State University.

3.5. Participant Preparation

Surface electrode placement was determined by finding the mid-point between the origin and insertion of the Rectus Femoris, Tensor Fasica Latae, Gluteus Medius, and Gluteus Maximus. Areas of electrode placement were cleansed with 70% isopropyl alcohol pads, shaved and abraded when necessary, and cleansed again with the alcohol preparation pads. In order to conduct bipolar recording, one electrode was placed on the anterior superior iliac spine and another on the posterior superior iliac spine to serve as dispersion electrodes which functioned to complete the circuit; they were not used in EMG analysis[37]. Two 40 millimeter, self-adhesive silver/silver-chloride bipolar surface electrodes were placed approximately 2 centimeters apart. Wires from a portable transmitter were connected to the electrodes, and accurate electrode placement was confirmed by real-time visual inspection of the EMG signal during manual muscle testing.

Analog channels, rather than digital channels, were initially established to collect static and dynamic variables at a continuous rate rather only from a single source (Biopac Systems, Inc., Version 4.1; Goleta, CA). The raw signal was collected at a sample rate of 2,000 samples/second and a channel sampling rate established at 2.000 kHz for each of the four muscles. Acquisition length was set at 1,800.00 seconds.

3.6. Muscle Testing

Static muscle activation was quantified with participants' maximal voluntary isometric contraction (MVIC) by using manual muscle tests (MMTs) to isolate the four muscles being analyzed. Raw data were obtained using surface electromyography (EMG) through Biopac Systems, Inc. (Version 4.1; Goleta, CA). MMTs were completed in the following order: Gluteus Maximus, Gluteus Medius, Tensor Fascia Latae, and Rectus Femoris. MMTs were conducted three times continuing through the same order each time in an attempt to reduce fatigue. Data collected over a five second window established the average MVIC throughout the three trials and were analyzed using Biopac Systems, Inc. (version 4.1; Goleta, CA).

Manual muscle testing of the Gluteus Maximus was performed with the participant lying prone with the knee flexed at least 90 degrees. The clinician applied downward pressure to the lower part of the posterior thigh in order to resist hip extension[12,35]. Manual muscle testing of the Gluteus Medius required the participant to be in a side lying position with the leg to be tested stacked on top of the other leg. As the participant abducted the hip, the joint was also in a slightly extended and externally rotated position. The clinician applied pressure near the ankle against hip adduction and slight hip flexion[35]. The Tensor Fascia Latae was tested with the participant lying in a supine position with the knee fully extended. As the participant moved the leg into an abducted, flexed, and internally rotated position and the clinician applied pressure against the flexion and abduction motions, ensuring no rotational resistance was applied to the limb[35]. Finally, manual muscle testing of the Rectus Femoris was performed with the participant short sitting with their knees over the edge of the examination table. As the participant stabilized his or her body with hands on the edge of the table and core muscles, the clinician provided resistance against hip flexion[35]. It should be noted that the performed MMT has been published as testing the Iliopsoas complex. Because of the superficial nature of the Rectus Femoris and deep configuration of the Iliacus, Psoas Major, and Psoas Minor, surface EMG monitoring of hip flexion was likely indicative of the Rectus Femoris. It is possible that components of the Iliopsoas complex were involved when performing this study[38,39].

Following three rounds of MMTs, participants completed a five minute running warm-up at a pace determined by the participant. Participants were asked to run at a pace similar to their daily training pace on a Trackmaster TMX425C treadmill (Full Vision, Inc., Newton, KS) for one mile at a zero percent incline. At each quarter (¼) mile increment, EMG data was collected for a distance of 0.05 miles. Data were collected at the following intervals: 0.20-0.25, 0.45-0.50, 0.70-0.75, and 0.95-1.00 miles. Upon completion of the one-mile treadmill run, subjects gradually slowed the speed of the treadmill for five minutes or until they felt comfortable stepping off the treadmill. The transmitter and electrode pads were removed and areas of pad placement were cleaned.

3.7. Running Log

At the end of the testing procedures, the clinician provided subjects with a running log to fill out throughout the data collection period (Appendix D). Participants were instructed on how to use the running log to self-report details of daily training and any running related injury they experienced for the three months following hip strength testing at the Human Performance Laboratory. Running logs were used to report number of miles ran each day, time spent running, and the terrain in which each run was completed. Participants were asked to report running related injury as any musculoskeletal ailment that was attributed to running that caused a restriction of running speed, distance, duration, or frequency. Running logs were e-mailed to the primary author at the end of each month. Upon receipt of the final running log, a research incentive was provided to reimburse the participants' time associated with the research project.

3.8. Statistical Analysis

Statistical analysis was completed using the latest SPSS software available (Version 23). In order to make research-based conclusions, the following statistical methods were conducted based on the original research questions:

Q_1: To what extent does recreational runners' hip muscle activation change throughout a one-mile run?

a. Repeated measures ANOVA tests were conducted with gender as a between-subject factor. Post hoc comparisons of average muscle contractions at the four time measurements during the one-mile run were made with Tukey's honestly significant difference (Tukey's HSD).

Q_2: Is there a statistically significant difference between static and dynamic muscle activation in male and female recreational runners?

a. Paired t-tests were conducted between static muscle activation and the quarter-mile and the one-mile dynamic activation periods. The overall sample was analyzed as well as separately for men and women.

Q_3: What is the relationship between relative hip muscle activation and rate of running related injury in recreational runners?

a. Independent samples t-test was conducted to compare average muscle activation of each muscle between injured and uninjured recreational runners.

As stated previously, the purpose of this research study was to analyze hip muscle activation in the following three ways: to analyze hip muscle activation using electromyography (EMG) in male and female recreational runners throughout a one-mile run, to determine if there was a difference in maximal static hip muscle activation when compared to dynamic hip muscle activation, and to determine if there was a difference in hip muscle activation in injured compared to uninjured recreational runners. As the population of recreational runners increases, this prospective research will be used in conjunction with past publication to determine factors associated with increased risk of running related injury.

CHAPTER 4. MANUSCRIPT

4.1. Abstract

Objective: To evaluate muscle activation by surface electromyography in recreational runners throughout a one-mile run.

Design: Randomized, within subject design

Setting: Human Performance Laboratory at Research 1 Institution

Participants: Thirty recreational runners (15 males, 15 females; age: 30.9±8.9 years; height: 173±7.5 cm; mass: 70.3±12.1 kg) participated.

Interventions: Participants ran a total of one mile on a treadmill at zero percent incline. They were asked to run at a pace comparable to their daily training pace. Surface Electromyography (EMG) Data was collected for 0.05 miles at each of the following increments: 0.20-0.25, 0.45-0.50, 0.70-0.75, and 0.95-1.0 miles.

Main Outcome Measures: EMG Output of the Rectus Femoris, Tensor Fascia Latae, Gluteus Medius, and Gluteus Maximus during static and dynamic muscle contraction.

Results: Throughout the one mile testing period, runners showed a decrease in hip muscle activation in all four muscles analyzed. Females activated the Gluteus Maximus ($p<0.001$), the Rectus Femoris ($p<0.001$) and the Tensor Fascia Latae ($p=0.014$) at a greater capacity than males.

Conclusions: These findings indicate that in as little as a one mile run, recreational runners' hip muscles exhibit fatigue. In addition, it is interesting to find that females used more of the Rectus Femoris and Gluteus Maximus muscles during running gait. Because no to little research reports on the activation of hip musculature throughout a specified distance, these results can assist athletic trainers with injury evaluations as well as developing evidence-based rehabilitation protocols.

4.2. Introduction

Running has become an increasingly popular activity for people of all ages. A recent systematic review reported between 19.4% and 79.3% of runners experience a lower extremity, running related injury each year[1]. Although the injury incidence rates have remained constant over the years, more people are participating in the sport; therefore, the gross number of injuries has increased over time[1,3,10].

There are numerous variables that contribute to the incidence rate of running related injuries. Past research has examined a variety of known variables, both intrinsic and extrinsic, that contribute to the rate of running related injury[1,19,20]. Intrinsic factors include variables such as age, gender, and anatomical alignment. Comparatively, extrinsic factors include number of miles ran per week, pace of daily runs, and running surface. Although there are common trends reported in the literature, inconsistencies in reporting methods, such as definitions of runner and/or running related injury, have left clinicians and runners alike questioning injury prevention techniques within the running population.

Due to the repetitive nature of running, it is hypothesized that lower extremity running related injuries may occur because of weakness in more proximal aspects of the kinetic chain, such as hip musculature[6-8]. Limited research of a prospective approach has been conducted to analyze hip strength and its correlation with a broad scope of lower extremity running related injuries. The correlation of hip strength and specific injuries, such as patellofemoral pain and medial tibial stress syndrome, have been analyzed, with very few studies using a prospective approach. Therefore, the purpose of the current study was to analyze both static and dynamic hip strength in a group of healthy, recreational runners. A prospective research approach was used to examine correlations between hip strength and running related injury.

4.3. Methods

4.3.1. Participants

This study was approved by the institutional review board at North Dakota State University. Thirty recreational runners (15 males, 15 females) were recruited by word of mouth from local running groups. A convenience sample was obtained from a mid-sized, midwestern, United States city. For the purpose of this study, runners were classified as recreational based on the following criteria: run an average of at least 10 miles a week for the past three months[9,11]; not currently competing on a team at the high school, college, or professional level; or competing for a team in a marathon or distance running race.

Subjects were excluded from participation if they were outside the age range of 20-45 years old. Other exclusion criteria included rheumatoid arthritis and/or nerve conduction health history including but not limited to Amyotrophic Lateral Sclerosis (ALS, Lou Gehrig's Disease), Multiple Sclerosis (MS), or Parkinson's Disease. Subjects were also excluded from this study if they had any current lower extremity injury (this includes hip injury) or injury within the three months prior to data collection.

4.3.2. Participant Preparation

Upon arrival to a Human Performance Laboratory at a Research 1 Institution, participants were asked to read and sign the informed consent. Participants also completed the American College of Sports Medicine's Physical Activity Readiness Questionnaire (PAR-Q) (Indianapolis, IN). Demographic information including age, gender, height and weight were recorded.

Surface electrode placement was determined by finding the mid-point between the origin and insertion of the Rectus Femoris, Tensor Fascia Latae, Gluteus Medius, and Gluteus Maximus. Areas of electrode placement were cleansed with 70% isopropyl alcohol pads, shaved and abraded when necessary, and cleansed again with the alcohol preparation pads. In order to conduct bipolar recording, one electrode was placed on the anterior superior iliac spine and another on the posterior superior iliac spine to serve as dispersion electrodes which functioned to complete the circuit; they were not used in EMG analysis[37]. Two 40 millimeter, self-adhesive silver/silver-chloride bipolar surface electrodes were placed approximately 2 centimeters apart. Wires from a portable transmitter were connected to the electrodes, and accurate electrode placement was confirmed by real-time visual inspection of the EMG signal during manual muscle testing.

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4.3.3. Muscle Testing

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Manual muscle testing of the Gluteus Maximus was performed with the participant lying prone with the knee flexed at least 90 degrees. The clinician applied downward pressure to the lower part of the posterior thigh in order to resist hip extension[12,35]. Manual muscle testing of the Gluteus Medius required the participant to be in a side lying position with the leg to be tested stacked on top of the other leg. As the participant abducted the hip, the joint was also in a slightly extended and externally rotated position. The clinician applied pressure near the ankle against hip adduction and slight hip flexion[35]. The Tensor Fascia Latae was tested with the participant lying in a supine position with the knee fully extended. As the participant moved the leg into an abducted, flexed, and internally rotated position and the clinician applied pressure against the flexion and abduction motions, ensuring no rotational resistance was applied to the limb[35]. Finally, manual muscle testing of the Rectus Femoris was performed with the participant short sitting with their knees over the edge of the examination table. As the participant stabilized his or her body with hands on the edge of the table and core muscles, the clinician provided resistance against hip flexion[35]. It should be noted that the performed MMT has been published as testing the Iliopsoas complex. Because of the superficial nature of the Rectus Femoris and deep configuration of the Iliacus, Psoas Major, and Psoas Minor, surface EMG monitoring of hip flexion was likely indicative of the Rectus Femoris. It is possible that components of the Iliopsoas complex were involved when performing this study[38,39].

Following three rounds of MMTs, participants completed a five minute running warm-up at a pace determined by the participant. Participants were asked to run at a pace similar to their daily training pace on a Trackmaster TMX425C treadmill (Full Vision, Inc., Newton, KS) for one mile at a zero percent incline. At each quarter (¼) mile increment, EMG data was collected for a distance of 0.05 miles. Data were collected at the following intervals: 0.20-0.25, 0.45-0.50, 0.70-0.75, and 0.95-1.00 miles. Upon completion of the one-mile treadmill run, subjects gradually slowed the speed of the treadmill for five minutes or until they felt comfortable stepping off the treadmill. The transmitter and electrode pads were removed and areas of pad placement were cleaned.

4.3.4. Running Log

Participants were instructed on how to use the running log to self-report details of daily training and any running related injury they experienced for the three months following hip strength testing at the Human Performance Laboratory. Running logs were used to report number of miles ran each day, time spent running, and the terrain in which each run was completed. Participants were asked to report running related injury as any musculoskeletal ailment that was attributed to running that caused a restriction of running speed, distance, duration, or frequency. Running logs were e-mailed to the primary author at the end of each month. Upon receipt of the final running log, a research incentive was provided to reimburse the participants' time associated with the research project.

4.4. Results

Demographic data is presented in Table 1. The targeted group for this study was runners between the ages of 20 and 45 years-old. Both males (30.27±9.00 years old) and females (31.47±8.72 years old) average age were within those guidelines. Correlations between runners' height and/or weight and running related injury were not included in this statistical analyses.

Table 1. Participant Demographics (Mean and SD)

	n	*Age (years)*	*Height (cm)*	*Weight (kg)*
Males	15	30.27±9.00	177.47±5.45	77.81±10.23
Females	15	31.47±8.72	168.53±6.44	62.88±8.72
Total	30	30.87±8.88	173.00±7.45	70.35±12.09

Following specific procedures and protocols for collecting surface EMG of four muscles for 30 participants, event flags were placed before and after each MMT or running interval (0.20-0.25, 0.45-0.50, 0.70-0.75, and 0.95-1.00). Mean frequency patterns using the cycle detector were reported as raw data in Volts through the Biopac System. All raw data were converted to Root Mean Square (RMS) values. RMS has been established as one of the most common formats of quantifying electrical signal using surface EMG techniques[40]. As such, the average of the three MMT and the intervals of dynamic measurement were quantified with the derive Root Mean Square EMG option from the Biopac System (version 4.1).

Dynamic hip muscle activation was analyzed for changes over the four data collection periods throughout the one-mile testing period. Repeated measures ANOVA tests were conducted with gender as a between-subject factor. Post hoc comparisons of average muscle activation at the four time measurements were made with Tukey's honestly significant difference (HSD). In no case were there statistically significant interactions between gender and the repeated measures, so only results for main effects are presented.

Gender differences for the Rectus Femoris were statistically significant (F [1, 115] =11.41, $p<0.001$, η_p=.051) with females consistently activating anterior hip muscles more than males (Figure 1). The repeated measures factor for difference in Rectus Femoris activation between each distance measured was not statistically significant (F[3, 115] =2.06, p=.109).

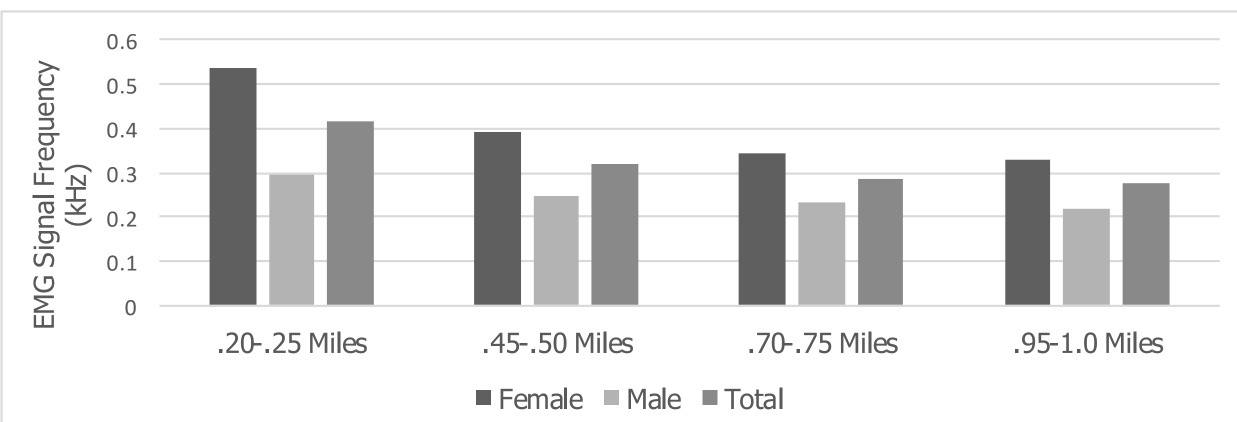

Figure 1. Mean Rectus Femoris Activation throughout One-Mile Test

The within-subjects factor was statistically significant overall for the Tensor Fascia Latae (F[3, 115] =2.533, p=.060, η_p=.062). Tukey's HSD showed significant differences between the first and fourth observations (p=0.061), activation decreased throughout the mile. Differences in amount of Tensor Fascia Latae activation were strongly significant between genders (F[1, 115] =6.193, p=0.014, η_p=.051) with females activating the muscle at a higher capacity (Figure 2).

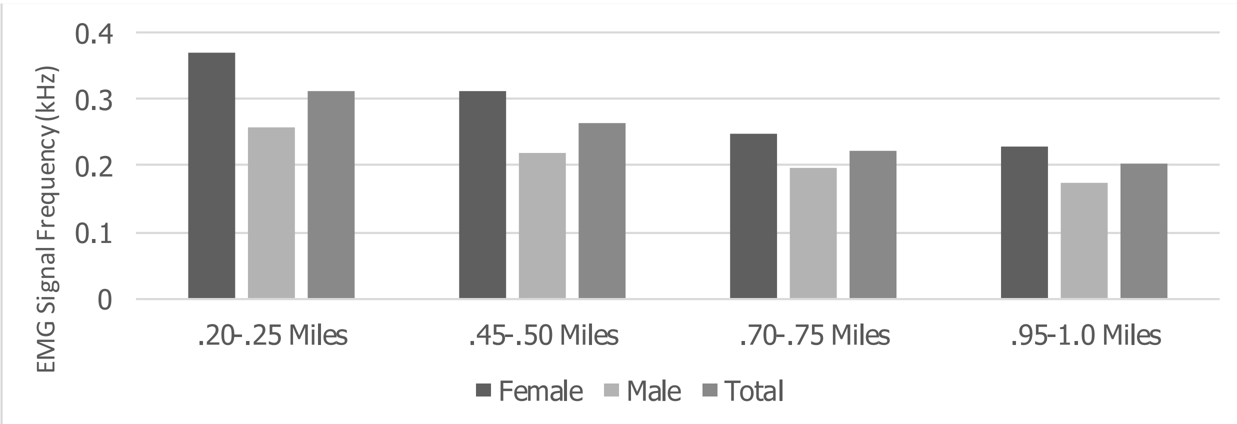

Figure 2. Mean TFL Activation throughout One-Mile Test

The within-subjects factor was also significant for the Gluteus Medius (F[3, 115] =2.573, p=.058, η_p=.063). Tukey's HSD revealed a statistically significant difference between the first and forth observations (p=.056) (Figure 3). Again, a decreasing trend was observed in muscle activation. Gender differences were not statistically significant (F[1, 115] =0.859, p=.356).

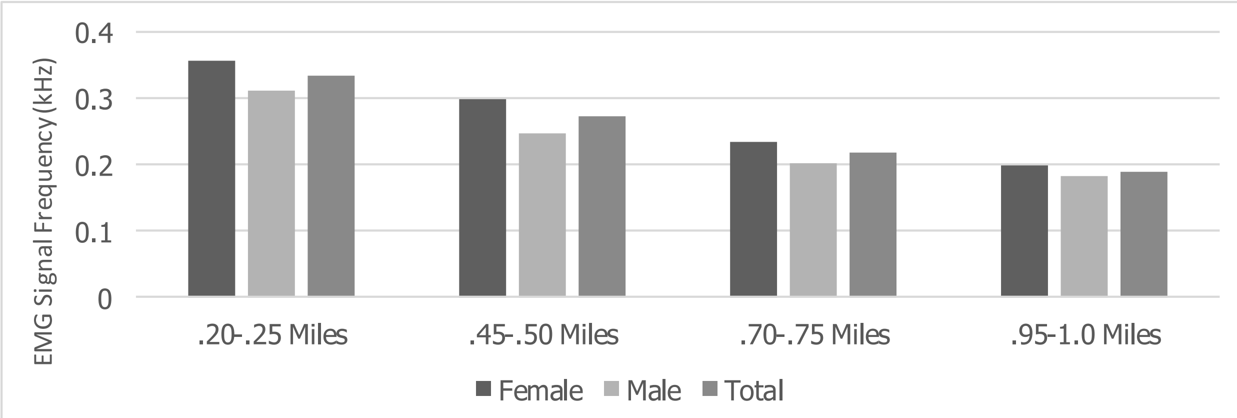

Figure 3. Mean Gluteus Medius Activation throughout One-Mile Test

Gender difference in the Gluteus Maximus was statistically significant ($F[1, 115] = 14.51$, $p < .001$, $\eta_p = .112$) with females activating the Gluteus Maximus more than males. The within-subjects factor was also statistically significant in the overall ANOVA ($F[3, 115] = 4.47$, $p = .005$, $\eta_p = .104$). Gluteus Maximus observations were statistically significantly different in two cases according to post hoc HSD tests: between the first and third observations ($p = .015$) and the first and fourth observations ($p = .0074$; Figure 4).

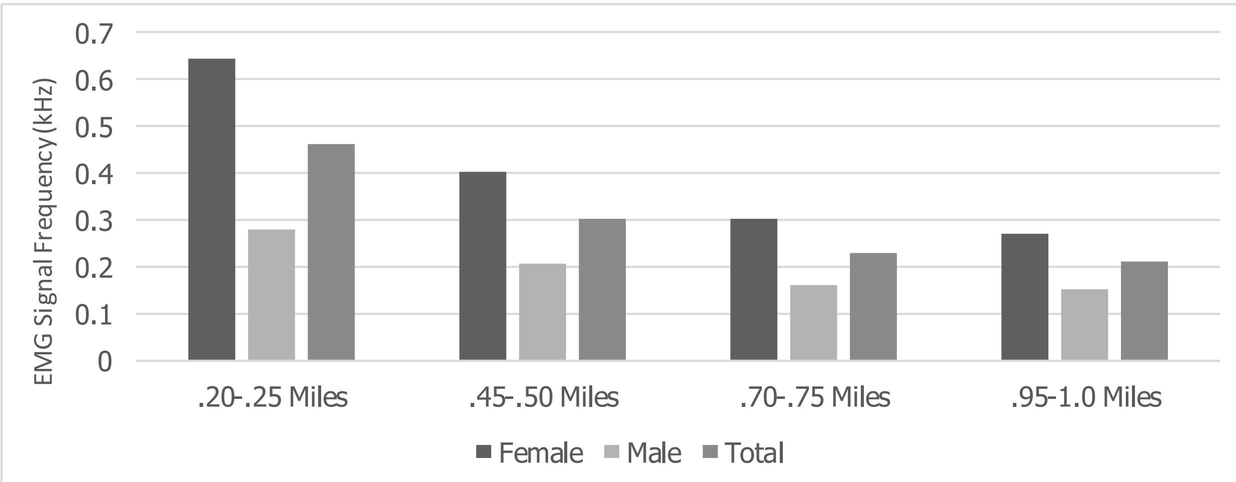

Figure 4. Mean Gluteus Maximus Activation throughout One-Mile Test

A second component of this research project analyzed the ratio of dynamic hip muscle activation compared to MVIC. Analyses were conducted at the two extreme points observed in the results: the quarter-mile and one-mile measurements. Paired t-tests were conducted for the overall sample as well as separately for men and women. In general, runners activated their hip muscles at a higher capacity in the first quarter mile of running than their MVIC measurement. As the mile progressed, the ratio of dynamic to static muscle activation decreased greatly. At the one mile mark, both men and women activated hip muscles less while running than their MVIC; however, men showed greater difference in ratio of dynamic activation to MVIC than women. Tables 2 and 3 depict paired t-tests for differences between MVIC and dynamic muscle activation at the .25 mile and the 1.0 mile measurements.

Table 2. Paired *t*-tests between MVIC and Dynamic Measurement (0.25 miles)

	Max			Med		
	Diff	p	d	Diff	p	d
Men	-0.133	0.055*	0.615	0.056	0.445	0.218
Women	0.357	0.038**	0.803	0.148	0.08*	0.661
Overall	0.112	0.246	0.302	0.102	0.063*	0.429
	Rec			**TFL**		
	Diff	p	d	Diff	p	d
Men	-0.176	0.002***	1.022	-0.088	0.097*	0.386
Women	0.025	0.855	0.061	0.157	0.037**	0.766
Overall	-0.075	0.312	0.230	0.035	0.468	0.156

Table 3. Paired *t*-tests between MVIC and Dynamic Measurement (1 mile)

	Max			Med		
	Diff	p	d	Diff	p	d
Men	-0.260	<.001***	1.826	-0.073	0.036**	0.575
Women	-0.018	0.727	0.109	-0.010	0.818	0.087
Overall	-0.139	0.002***	0.855	-0.041	0.126	0.348
	Rec			**TFL**		
	Diff	p	d	Diff	p	d
Men	-0.252	<.001***	1.667	-0.169	0.021**	0.834
Women	-0.181	0.066*	0.628	0.015	0.726	0.113
Overall	-0.216	<.001***	0.942	-0.077	0.077*	0.433

Statistical significance at the 10%, 5%, and 1% levels are represented by *, **, and ***, respectively. The mean difference, *p*-value, and Cohen's *d* are provided for paired t-tests.

Although hip muscle activation testing was completed with all 30 participants, due to the three month running log data collection period, attrition rate was high and only 23 participants completed all 3 months of running logs. Two participants' running logs were inaccurate and therefore, a total of 21 running logs were analyzed. Of the 21 runners that submitted completed running logs, six runners reported at least one running related injury throughout the three month reporting period. Demographic information of injured and uninjured groups is provided in Table 4. An independent samples t-test was conducted to compare the average dynamic muscle activation of each muscle between the injured and non-injured runners. Although data suggested that Tensor Fascia Latae and Rectus Femoris activation are correlated with a lower injury rate, there were no statistically significant correlations between hip muscle strength of injured runners compared to uninjured runners. *P*-values and and Cohen's *d* for the four comparisons are presented in Table 5.

Table 4. Demographic Information for Injured and Uninjured Runners (Mean and SD)

	N	*Sex*	*Age (years)*	*Height (cm)*	*Weight (kg)*
Injured	6	2♀ 4♂	32.33±9.41	174.75±8.66	70.04±14.16
Uninjured	15	8♀ 7♂	31.00±9.99	173.17±7.58	70.35±10.96

Table 5. Independent Samples *t*-test: Average Dynamic Muscle Activation in Injured and Uninjured Runners

	Injured	*Uninjured*	*p*	*d*
Gluteus Medius	0.228	0.236	0.91	0.04
Gluteus Maximus	0.306	0.309	0.98	0.01
Tensor Fascia Latae	0.206	0.261	0.29	0.37
Recuts Femoris	0.221	0.307	0.23	0.44

4.5. Discussion

4.5.1. Dynamic Hip Muscle Activation

One purpose of this study was to evaluate recreational runners' hip muscle activation throughout a one-mile run. All four hip muscles that were analyzed showed a marked decrease in activation level in as little as one mile of running. It is remains unclear if this decrease in muscle activation was due to muscle fatigue or normalization of gait on the treadmill. This study did not analyze joint kinematics so it is outside the scope of this study to determine the cause of decrease in muscle activation during the one-mile run. Regardless of the cause of this muscle activation decrease, clinicians should be aware that when analyzing running gait in distance runners, at least one mile of running should be reviewed to account for this significant decrease in hip strength.

Females activated the Rectus Femoris, Gluteus Maximus, and Tensor Fascia Latae at significantly higher level than males. These findings are consistent with those of Wilson et al. who reported that females ran with 53% greater average Gluteus Maximus activation than males in as little as a 20 meter run[36]. Results reported by Chumanov et al. were comparable with females having a greater peak Gluteus Maximus activation than males at a variety of paces and inclines[41]. Unlike previous reports of Gluteus Maximus activation, the difference in Rectus Femoris and Tensor Fascia Latae activation between genders is rarely reported in past research. The greater incidence rate of running related injury in female runners has been attributed to earlier fatigue due to greater Gluteus Maximus activation while running[36,41]. However, until further prospective research examines the effect of muscle activation on joint kinematics and its effect on running related injury, evidence based conclusions cannot be made.

4.5.2. Ratio of Static to Dynamic Hip Muscle Activation

In order to further compare hip muscle activation between male and female runners, the ratio of static to dynamic hip muscle activation was analyzed and compared between genders. Interestingly, at the one-mile dynamic activation measurement, males activated all four hip muscles at a statistically significantly lower percentage than their maximal static activation level. Comparatively, females showed no statistical significance between their dynamic and static muscle activation at the one-mile point. Past research emphasizes the importance of hip muscle fatigue in female runners; however, the current study concludes that when dynamic hip muscle activation is compared to maximal static hip muscle activation, a fatigue factor is actually more apparent in male runners[36]. Additionally, running related injury correlations have been made solely with static strength data[9]. The results of the current study suggest that there is also a large fatigue factor in male runners which needs to be evaluated. In addition, this evidence should guide clinicians to evaluate not only static hip muscle activation using manual muscle tests, but also to evaluate dynamic hip strength.

4.5.3. Injured vs. Uninjured Comparisons

The final purpose of this study was to use a prospective approach to determine correlations between hip muscle activation and running related injury in recreational runners. Due to the high attrition rate over the three month data collection period and the small sample size of injuries, statistical analysis of injury data is limited. Although there was a lack of statistical significance in the results, the trends observed in this study suggest that greater activation of the Rectus Femoris (p=0.23) and Tensor Fascia Latae (p=0.29) may lead to lower injury rates in recreational runners. Previous retrospective research has reported similar findings; however, strength of hip muscle actions were reported rather than the significance of individual muscles. Fredericson et al. reported weaker hip abduction strength in runners with iliotibial band syndrome than their uninjured counterparts[6]. Neimuth et al. also reported evidence of increase in injury rates due to decreased hip abductor and flexor muscle groups when compared to the uninjured limb[9]. The clinical recommendation made as a result of these findings was to strengthen the Gluteus Medius muscle due to its role as a hip external rotator. The findings of the current study show little difference in the activation of the Gluteus Medius between injured and uninjured runners. Therefore, injury prevention strengthening should focus on hip strength as a whole rather than targeting a specific muscle.

4.5.4. Limitations

The limitations of this research study may affect the power of the results. Although we used evidence based methods for surface EMG[13], the reliability and precision of EMG during running is unknown[16]. In addition, this study relied on self-reported running data and running related injury information, rather than clinical diagnoses. Due to the high rate of attrition in returning completed running logs, only 21 running logs were able to be analyzed. Future research should continue to use the prospective approach, however, larger sample sizes and longer duration studies should be conducted to form more accurate clinical recommendations for prevention of running related injury.

4.6. Conclusions

Factors associated with running related injury are multifaceted and complex. Based on the results of this study, in conjunction with previous research, it is evident that hip muscle activation plays a role in the rate of running related injury. It is also apparent that there is a larger difference in the hip muscle activation between males and females both in maximal voluntary isometric contraction and while running. This study questions previously held beliefs that females activate their Gluteus Maximus and Gluteus Medius muscles less than males. Thus, future studies should continue with this particular line of research in order to make recommendations to allied health care providers about the role of specific hip musculature in running. Providing evidence-based practice and rehabilitation protocols is crucial to the well-being of future runners.

CHAPTER 5. DISCUSSION

The purpose of this research was to analyze hip muscle activation in relation to running related injury in the following three ways: to analyze hip muscle activation in males and females throughout a one-mile run, to determine if there was a difference in maximal static hip muscle activation when compared to dynamic hip muscle activation, and to determine if there was a difference in hip muscle activation in injured compared to uninjured runners. Due to the growth in the running population[23], an increase in the number of running related injuries has prompted the need for examination of the causative variables of these injuries. Past research has examined the numerous causes that contribute to the incidence rate of running related injuries[1,19,20] ; however, the gaps in the research have left clinicians and runners questioning ways to reduce running related injury occurrence.

Many publishers divide running related injury risk factors into two categories: intrinsic and extrinsic risk factors. Intrinsic factors have been classified as inherited traits of an individual and include gender, age, and genetic alignment such as the quadriceps angle. Extrinsic factors, more commonly known as training variables, are able to be manipulated overtime by runners and include factors such as number of miles ran per week, pace of typical training days, and training surfaces. Although results are still not conclusive, past research has analyzed intrinsic factors in further depth[2-4]. Therefore, in order to advance knowledge of running related injury, the primary goal of the current study was to analyze modifiable, or extrinsic risk factors.

In recent years, researchers have begun to examine the role of the proximal kinetic chain on lower extremity running related injuries. The majority of the available literature that has investigated correlations between hip strength and running related injury have used a retrospective research approach. Therefore, although results suggested that decreased hip strength was strongly correlated with running related injury, the cause and effect relationship was not able to be extrapolated because it is unclear if the hip strength caused the injury or if the musculature weakened due to decreased activity level following the injury. As a result, each of the authors suggested using a prospective research approach in future studies[6,7,9,19].

5.1. Research Findings

As stated previously, there were three primary purposes of this research: to analyze hip muscle activation in males and females throughout a one-mile run, to determine if there was a difference in maximal static hip muscle activation when compared to dynamic hip muscle activation, and to determine if there was a difference in hip muscle activation in injured compared to uninjured runners. Consequently, there were three separate statistical analyses and several major findings associated with this research study.

Dynamic hip strength was analyzed for changes over the four data collection periods throughout the one-mile testing period. Repeated measures ANOVA for within subject comparisons revealed statistical significance in the Gluteus Maximus ($F[3, 115] = 4.47$, $p=.005$, $\eta_p=.104$), Gluteus Medius ($F[3, 115] = 2.573$, $p=.058$, $\eta_p=.063$), and Tensor Fascia Latae ($F[3, 115] = 2.533$, $p=.060$, $\eta_p=.062$). Following initial ANOVA tests, Tukey's honestly significant difference (HSD) revealed statistically significant decreases between the first and fourth dynamic muscle activation measurements in the Gluteus Maximus ($p<0.001$), Gluteus Medius ($p=0.056$) and Tensor Fascia Latae ($p=0.061$). The repeated measures factor was not statistically significant in the Rectus Femoris muscle measurement ($F[3, 115] = 2.06$, $p=.109$).

After an exhaustive review of the current literature, this is the first study to analyze hip muscle fatigue during running gait. Previous research has correlated changes in running kinematics to muscle fatigue; however a fatigue protocol was used to induce muscle fatigue[42]. The current study has revealed significant fatigue that occurs as a natural result of running over a one-mile period. It is possible that the fatigue induced by the protocol in previous research caused different muscle reactions than the natural level of fatigue induced during distance running. Therefore, how the natural fatigue observed in the current study affects running kinematics remains unclear. It is possible that the fatigue observed during this study was caused by a period of gait normalization on the treadmill; however, until future research analyzes both hip muscle activation and running kinematics, the effect of the significant fatigue over the one-mile testing period remains unknown.

Tukey's HSD tests also revealed statistically significant differences between genders. While running, females consistently activated the Gluteus Maximus (F[1, 115] =14.51, p<.001, η_p=.112), Tensor Fascia Latae (F[1, 115] =6.193, p=0.014, η_p=.051), and Rectus Femoris (F [1, 115] =11.41, p<0.001, η_p=.051) at a higher capacity than males. Gluteus Medius gender differences were not statistically significant (F[1, 115] =0.859, p=.356). These results were similar to the conclusions made in past reports.

In 2012, Willson et al.[36] analyzed Gluteus Maximus and Gluteus Medius muscle activation and kinematics during running. They also reported that female runners activated the Gluteus Maximus at higher capacities during running gait. Additionally, they observed no difference in peak or average activation of the Gluteus Medius muscle between healthy male and female runners. One major difference between these two studies is that the current study analyzed muscle contractions while running on a treadmill for one-mile, whereas, Willson et. al. (2012) analyzed running for only 20-meters on a runway[36]. Additionally, Chumanov et al. (2008)[41] analyzed gender differences in muscle activation at a variety of speeds and inclines. Females activated the Gluteus Maximus at higher levels at all six speeds and all three inclines. Again, no statistically significant gender differences were observed in the Gluteus Medius. Interestingly, even with the difference in running distance, surface, and incline, similar gender differences in hip muscle activation were observed in each of these studies. The consistent results that have been reported previously, along with the results from the current study, can assist clinicians in extrapolating results to various running populations. Current rehabilitation protocols emphasize the importance of hip muscle strengthening in female athletes. These results should be incorporated in future protocols to emphasize the importance of dynamic hip strength in males just as much, if not, more than in females.

A second component of this research project analyzed the ratio of dynamic strength in comparison to MVIC. Analyses were conducted at the two extreme points observed in the results: the quarter-mile and one-mile measurements. Paired t-tests were conducted for the overall sample as well as separately for men and women. In general, runners activated their hip muscles at a higher capacity in the first quarter mile of running than their MVIC measurement. As the mile progressed, the ratio of dynamic to static hip strength decreased greatly. At the one mile mark, both men and women activated hip muscles less while running than their MVIC; however, men showed greater difference in ratio of dynamic strength to MVIC than women. These results provide evidence that there is a significant difference between static and dynamic hip muscle strength in recreational runners. In order to conduct a thorough evaluation and provide patients with evidence-based clinical recommendations, both strength measurements should be analyzed. Tables 1 and 2 depict paired t-tests for differences between MVIC and dynamic hip strength at the .25 mile and the 1.0 mile measurements.

Table 6. Paired *t*-tests between MVIC and Dynamic Measurement (0.25 miles)

	Max			Med		
	Diff	p	d	Diff	p	d
Men	-0.133	0.055*	0.615	0.056	0.445	0.218
Women	0.357	0.038**	0.803	0.148	0.08*	0.661
Overall	0.112	0.246	0.302	0.102	0.063*	0.429
	Rec			TFL		
	Diff	p	d	Diff	p	d
Men	-0.176	0.002***	1.022	-0.088	0.097*	0.386
Women	0.025	0.855	0.061	0.157	0.037**	0.766
Overall	-0.075	0.312	0.230	0.035	0.468	0.156

Statistical significance at the 10%, 5%, and 1% levels are represented by *, **, and ***, respectively. The mean difference, *p*-value, and Cohen's *d* are provided for paired t-tests.

Table 7. Paired t-tests between MVIC and Dynamic Measurement (1 mile)

	Max			Med		
	Diff	p	d	Diff	p	d
Men	-0.260	<.001***	1.826	-0.073	0.036**	0.575
Women	-0.018	0.727	0.109	-0.010	0.818	0.087
Overall	-0.139	0.002***	0.855	-0.041	0.126	0.348
	Rec			**TFL**		
	Diff	p	d	Diff	p	d
Men	-0.252	<.001***	1.667	-0.169	0.021**	0.834
Women	-0.181	0.066*	0.628	0.015	0.726	0.113
Overall	-0.216	<.001***	0.942	-0.077	0.077*	0.433

Statistical significance at the 10%, 5%, and 1% levels are represented by *, **, and ***, respectively. The mean difference, *p*-value, and Cohen's *d* are provided for paired t-tests.

As stated previously, this is the first study to analyze hip muscle fatigue while running. Previous reports have drawn conclusions of how gender specific muscle fatigue effects running kinematics. The results of the current study contradict the conclusions that were previously reported. For example, Willson et al. (2012)[36] interpreted results by reporting that the greater peak Gluteus Maximus activation level may predispose females to earlier fatigue and modifications of running gait. As observed in the paired t-tests, after one mile of running, males actually activated a smaller proportion of their MVIC than females. Biomechanic measurements were outside the scope of this study and the relationship between hip muscle fatigue and modifications to running gait remain unknown.

Past research has reported female gender as a positive predictor of running related injury incidence rates[1]. The difference in injury rates between genders has been attributed to differences in running kinematics. In 2003, Ferber et al. reported that female recreational runners exhibited greater peak hip adduction, internal rotation and knee abduction angles compared to men[43]. These differences in joint mechanics during running are thought to be caused by gender specific structural differences. It is possible that the greater hip muscle activation observed in female runners could also contribute to female runners' greater peak joint angles while running. Again, until future research analyses both variables at the same time, conclusions on the relationship between hip muscle activation and running kinematics cannot be drawn.

Finally, average dynamic hip muscle activation was compared between injured and uninjured runners. Prior to discussing results it is important to mention the substantial participant attrition rate that occurred over the three month data collection period. Due to this attrition, only 21 of the 30 participants' running logs were analyzed and only six of the runners experienced at least one running related injury over this timeframe. Although data suggested that Tensor Fascia Latae and Rectus Femoris strength are correlated with a lower injury rate, there were no statistically significant correlations between hip muscle activation of injured runners compared to uninjured runners. Due to the unbalanced nature of this study and the small sample size, this particular test has low statistical power.

Interestingly, the results of the current prospective study contradict conclusions made by past retrospective reports. Fredericson et al. (2000)[6] used a hand-held dynamometer during a manual muscle test to analyze the hip strength of 24 runners diagnosed with Iliotibial (IT) Band syndrome. Results revealed significantly weaker hip abduction in injured limbs when compared to both uninjured runners' limbs and the uninjured limb of the same runner. After initial strength testing, researchers guided each runner through a six-week rehabilitation protocol. All runners returned to running following the six-week protocol and reported no recurrence of IT Band Syndrome in the following six-months. Similarly, Niemuth et al. (2005)[9] also used a hand-held dynamometer to measure 30 injured runners' MVIC. This study observed runners with a single leg overuse injury rather than a group of runners with the same injury. Significantly weaker hip abductors and hip flexors were reported in injured runners when compared to the MVIC of 30 healthy runners. It is evident that there is a relationship between hip strength and running related injury; however, future prospective research with a larger sample size is needed in order to verify the findings in the current study.

5.2. Utilization for Athletic Trainers

As medical practitioners continue to move toward an evidence-based model of medical practice, the findings of this study can help guide clinicians to evaluate runners more effectively. The first outcome of clinical significance is the considerable decrease in both male and female runners' dynamic hip muscle activation over the one-mile testing period. Past researchers have reported that fatigue of hip musculature negatively effects center of pressure and postural stability during landing tasks[34,44]. Higher activation of surrounding musculature is required to maintain lower limb support and proper biomechanics[44]. This compensation of the surrounding musculature may lead to overuse injuries. The level of hip muscle fatigue observed in participants of this study while running should guide clinicians to consider endurance based muscle testing rather than a static MMT.

Additionally, the significant difference between dynamic muscle activation compared to MVIC in males can guide future clinical evaluations. Based on the outcomes of this research, it is evident that males tend to activate hip musculature at lower levels while running when compared to their MVIC. In contrast, females tend to activate their hip muscles at similar capacities both statically and dynamically. Past research has not examined the difference between static and dynamic muscle contractions. These outcomes emphasize the importance of a dynamic strength evaluation, especially in males, to truly understand where weakness may be present in distance runners.

Finally, although the statistical analysis of strength in injured compared to uninjured runners has low statistical power, the trend that was observed does have clinical significance for allied health care providers. Many clinicians focus on strengthening the Gluteus Medius muscle when working with patients on injury prevention protocols. Previous research has concluded that weaker hip abductor and flexor muscle groups are correlated with increased risk of running related injury. The strength testing in previous studies was conducted on already injured patients and therefore, the cause and effect relationship was not truly examined[7,9]. In contrast to these past reports, the current study showed trends of a lower chance of injury with higher activation of the Tensor Fascia Latae and Rectus Femoris muscles. Because research remains inconclusive, injury prevention protocols should include strengthening of musculature surrounding the hip joint rather than focusing on one specific muscle.

In conclusion, the results of this study should guide allied health care providers to complete a comprehensive static and dynamic muscle evaluation to truly understand where runners may be lacking strength. The current study provides evidence that, especially in male runners, there is a significant difference between MVIC and hip muscle activation while running. A thorough strength evaluation may be the key to assisting runners in reducing the rate of running related injury. Although a comprehensive evaluation may be time intensive, using either static or dynamic evaluation, rather than both, may lead to lack of clinical findings where weaknesses may be present.

5.3. Limitations

The limitations of this research study may affect the power of the results. First, there are variables associated with surface EMG that may have caused unpredictable outcomes. EMG has been reported to be a valid and precise tool when used with proper electrode placement and research based parameters[15,16]. Although evidence-based methods were used for placement of surface EMG, muscular anatomy varies slightly between each individual. Therefore, without radiographic imaging to determine precise location of each muscle, slightly different muscle contractions may have been measured in each participant[13]. Furthermore, although the reliability of surface EMG to analyze muscle contractions during physical activity has been supported by past research[15,16], the most accurate method for normalization of dynamic results remains unclear[14,17,18]. The use of MVIC as a normalization method has been supported by past reports[14,17]. MVIC assumes that participants were able to reach their full muscle contraction potential which may not occur each time the MMT is performed[17]. In conclusion, although surface EMG is a precise and reliable tool to measure muscle activation, slight alterations in application can cause drastic changes in results.

Furthermore, muscle activity throughout the one-mile testing period was based solely on EMG data. Without further gait analysis, it was unclear if the significant changes in muscle activation throughout the dynamic testing period were due to muscle fatigue or gait normalization on the treadmill. Until future research analyzes both hip muscle activation and running kinematics, the cause of changes in muscle activation throughout the one-mile run in this study remains unclear.

In addition, this study relied on self-reported running data and running related injury information rather than clinical diagnoses. In an attempt to keep results consistent, the definition of running related injury used for this study resembled definitions used in past research[10,11]. The definition was explained in detail to each participant, but each person may have interpreted when to report an injury in different ways. Therefore, there may have been slight variability in reports of running related injury.

Finally, there was a high rate of attrition in returning completed running logs and only 21 running logs were analyzed. Due to the low number of completed running logs, the number of injuries reported was insufficient to draw strong correlations between injured and uninjured runners. Due to these limitations, clinician discretion should be used when making recommendations based off the evidence provided. These limitations should be considered prior to conducting future research regarding hip strength and running related injury.

5.4. Future Research

Runners tend to be relentless, and will continue to train regardless of the possibility of injury. Therefore, future research is needed to continue exploring the many factors associated with running related injury to help runners prevent future injuries. The limitations of this study, such as very small sample size, as well as limitations from previous reports, should be addressed and modified for future research studies.

The most important aspect of this study that should be considered in future research is the prospective research design. Past research reports have analyzed runners who were being treated for a running related injury and compared injured limb strength to either uninjured limbs or a group of uninjured runners[6,7,9,19]. Each of these reports recommended using a prospective approach to gain a better understanding of this cause-effect relationship. It was not until 2011 that Finnoff et al. conducted a prospectively designed research study to investigate correlations of hip strength and running related injury and reported statistical significance between the two variables in high school runners[8]. Until prospective research designs are used to evaluate hip strength in relation to running related injury in runners of various skill levels, general recommendations regarding how hip strength effects running related injury rates are not able to be made.

Additionally, future research should examine how the significant levels of fatigue during the one-mile testing period in this study effect running kinematics. Past researchers have hypothesized that hip muscle fatigue causes alterations in running gait and increased injury rates[9,36]. However, reports have not supported this hypothesis. Hollman et al. (2012) observed no significant changes in hip or knee kinematics even with a 25% reduction in hip extensor strength during a bilateral limb jump landing task[34]. In contrast, Lee and Powers (2013) reported increase peroneal muscle activation to stabilize the lower limb in a unipedal landing task after hip abductor fatigue was induced[44]. Because it is difficult to extrapolate how these results will effect running gait, the specific relationship between running kinematics and hip muscle fatigue needs to be evaluated.

5.5. Conclusions

Factors associated with running related injury are multifaceted. Based on the results of this study, in conjunction with previous research, it is evident that hip strength evaluation is a complex process that needs to be conducted in a thorough manner to provide accurate recommendations. Various studies have provided evidence on the many intrinsic and extrinsic risk factors associated with running related injuries[2-5]. Due to the complex nature of the activity, research will need to continue in order to provide runners with the most accurate ways to prevent running related injury.

The current research was an important addition to the evidence based evaluation of runners. To date, very few research reports have used a prospective approach to evaluate correlations between hip strength and running related injury. It is apparent that there is a larger difference in the hip muscle activation between males and females both in maximal voluntary isometric contraction and while running. This study provided details on the gender differences in hip muscle activation in recreational runners and created a solid base of information for researchers to build future research questions and studies.

This study questions previously held beliefs that females activate their Gluteus Maximus and Gluteus Medius muscles less than males. Thus, future studies should continue with this particular line of research in order to make recommendations to allied health care providers about the role of specific hip musculature in running. Providing evidence-based practice and rehabilitation protocols is crucial to the well-being of future runners.

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APPENDIX A. NORTH DAKOTA STATE UNIVERSITY INSTITUTIONAL REVIEW BOARD APPROVAL

NDSU NORTH DAKOTA STATE UNIVERSITY

May 4, 2015

Dr. Katie Lyman
Department of Health, Nutrition & Exercise Sciences
BBFH

IRB Approval of Protocol #HE15233, "The Relationship of Static and Dynamic Hip Strength on Running Related Injury Rates in Recreational Runners"
Co-investigator(s) and research team: Abby Reynold, Bryan Christensen

Approval period: 5/4/15 to 5/3/16
Continuing Review Report Due: 4/1/16

Research site(s): NDSU Funding Agency: n/a - Go Far Events to provide incentive
Review Type: Expedited category # 4, 7
IRB approval is based on the original submission, with revised: protocol and consent form (received 5/4/15).

Additional approval is required:
o prior to implementation of any changes to the protocol (Protocol Amendment Request Form).
o for continuation of the project beyond the approval period (Continuing Review/Completion Report Form). A reminder is typically sent 4-6 weeks prior to the expiration date; timely submission of the report is your responsibility. To avoid a lapse in approval, suspension of recruitment, and/or data collection, a report must be received, and the protocol reviewed and approved prior to the expiration date.

A report is required for:
o any research-related injuries, adverse events, or other unanticipated problems involving risks to participants or others within 72 hours of known occurrence (Report of Unanticipated Problem or Serious Adverse Event Form).
o any significant new findings that may affect risks to participants.
o closure of the project (Continuing Review/Completion Report Form).

Research records are subject to random or directed audits at any time to verify compliance with IRB regulations and NDSU policies.

Thank you for cooperating with NDSU IRB procedures, and best wishes for a successful study.

Sincerely,
Kristy Shirley
Kristy Shirley, CIP, Research Compliance Administrator

For more information regarding IRB Office submissions and guidelines, please consult www.ndsu.edu/irb. This Institution has an approved FederalWide Assurance with the Department of Health and Human Services: FWA00002439.

INSTITUTIONAL REVIEW BOARD
NDSU Dept 4000 | PO Box 6050 | Fargo ND 58108-6050 | 701.231.8995 | Fax 701.231.8098 | ndsu.edu/irb

Shipping address: Research 1, 1735 NDSU Research Park Drive, Fargo ND 58102

NDSU is an EO/AA university.

APPENDIX B. INFORMED CONSENT

NDSU North Dakota State University
Health, Nutrition, and Exercise Sciences
PO Box 6050, Dept. 2620
Fargo, ND 58108-6050
(218)443-6446

Title of Research Study: The Relationship of Static and Dynamic Hip Strength on Running Related Injury Rates in Recreational Runners

This study is being conducted by: Principal Investigator- Katie Lyman, HNES, Dept 2620; 231-8208, katie.lyman@ndsu.edu.

Why am I being asked to take part in this research study?
You are being asked to participate in this study because you:

- Are a recreational runner between 25 and 45 years of age.

You should not participate in this study if you:

- Have experienced any items listed below or reported them on your Health History Questionnaire.

- Any current lower extremity injury (including the hip) that has been diagnosed within three months of the data collection period
- Diagnosed Rheumatoid Arthritis and/or other nerve conduction health history including but not limited to: amyotrophic lateral sclerosis (ALS, Lou Gehrig's Disease), Multiple Sclerosis (MS), or Parkinson's Disease.

What is the reason for doing the study? The purpose of this study is to determine if there is a relationship between static and/or dynamic hip strength and running related injury in recreational runners. By determining if there is a relationship between these two variables, we can provide support for strengthening activities for recreational runners to perform in order to decrease the likelihood that they will sustain a running related injury.

What will I be asked to do? OR What Information will be collected about me? You will be asked to visit the Human Performance Laboratory (room 15) in Benston-Bunker Fieldhouse for one testing session that will take approximately one hour. You will be asked to complete a number of forms and provide a few pieces of demographic information.

Preparation for Testing:
After filling out all necessary forms, small electrodes (about the size of a quarter) will be places in specific spots (upper legs/buttocks) to measure the activity of specific

muscles. We may have to shave small portions of these areas to make sure the electrode stick to your skin. Once the electrodes are in place, we will ask you to contract your muscles one by one to ensure the electrodes are on the correct muscles. Each contraction will last about 6 seconds with about a minute rest between each contraction.

Treadmill Testing:
After we record data from each of the four muscles we will have you walk or jog on the treadmill at a pace which you feel comfortable for a warm-up. After the 5-minute warm-up we will have you speed the treadmill up to the pace that you train at during a daily run. We will record muscle activity for short increments while you run on the treadmill just like you would on a normal training day. After the 1-mile testing time, we will allow you as much time as you need to cool down and feel you are ready to step off the treadmill.

Running Log:
When you leave NDSU, we will provide you with a hard copy as well as an electronic copy of the running log. We will not ask you to alter your training in any way however we just ask that you record your daily mileage and the pace you run each day. We will also have you record any alterations made to any aspect of your training regime as a result of a lower extremity injury. At the end of the 3 month period you will hand in the running log.

**Please note: If you are instructed by a health care provider to discontinue your training regime, please do not continue to run for the purpose of this study. Do however, document the injury and missed training days appropriately in your running log.*

Where is the study going to take place, and how long will it take? The face-to-face portion of the study will take place in room 15 (Human Performance Laboratory) in Bentson-Bunker Fieldhouse. The face-to-face testing will take approximately one hour to complete. The rest of the data will be collected while you fill out the provided running log at your home at your own convenience.

What are the risks and discomforts?
It is not possible to identify all potential risks throughout research procedures, but the researchers of this study have taken reasonable safeguards to minimize any known risks to you.

Throughout the muscle contractions you may feel slight discomfort in your muscles however because of your background of recreational runner it is unlikely that these short contractions will cause discomfort.

You may stop activity or withdraw from this research study at any time throughout the data collection period.

What are the benefits to me? You are not expected to get any benefit from being in this research study.

What are the benefits to other people? Beyond the advancement of scientific knowledge, this research may provide data to support specific causes of running related injury. Knowledge of these specific causes will assist recreational runners with a better idea of how to prevent injuries.

Do I have to take part in the study? Your participation in this research is your choice. If you decide to participate in the study, you may change your mind and stop participating at any time without penalty or loss of benefits to which you are already entitled.

What will it cost me to participate? Other than your personal time, there are no costs to participation.

What are the alternatives to being in this research study? Instead of being in this research study, you can choose not to participate.

Who will see the information that I give?

We will keep private all research records that identify you. Your information will be combined with information from other people taking part in the study. When we write about the study, we will write about the combined information that we have gathered. We may publish the results of the study; however, we will keep your name and other identifying information private.

We will make every effort to prevent anyone who is not on the research team from knowing that you gave us information, or what that information is. For example, your name will be kept separate from your research records and these two things will be stored in different places under lock and key.

If you withdraw before the research is over, your information will be removed at your request, and we will not collect additional information about you.

Will I receive any compensation for taking part in this study?
You will receive a $20 Gift Card to Scheel's All Sports Store for your participation in this study.

What happens if I am injured because of this research?
If you receive an injury in the course of taking part in the research, you should contact Katie Lyman at the following phone number 701-231-8208 or Abby Reynolds at 414-750-4882. Treatment for the injury will be available including first aid, emergency treatment and follow-up care as needed. Payment for this treatment must be provided by you and your third party payer (such as health insurance or Medicare). This does

not mean that you are releasing or waiving any legal right you might have against the researcher or NDSU as a result of your participation in this research.

What if I have questions?
Before you decide whether to accept this invitation to take part in the research study, please ask any questions that might come to mind now. Later, if you have any questions about the study, you can contact the researcher, Katie Lyman at 701-231-8208 or Katie.lyman@ndsu.edu.

What are my rights as a research participant?
You have rights as a participant in research. If you have questions about your rights, or complaints about this research, you may talk to the researcher or contact the NDSU Human Research Protection Program by:

- Telephone: 701.231.8908 or toll-free 1-855-800-6717
- Email: ndsu.irb@ndsu.edu
- Mail: NDSU HRPP Office, NDSU Dept. 4000, PO Box 6050, Fargo, ND 58108-6050.

The role of the Human Research Protection Program is to see that your rights are protected in this research; more information about your rights can be found at: www.ndsu.edu/irb .

Documentation of Informed Consent:
You are freely making a decision whether to be in this research study. Signing this form means that

1. you have read and understood this consent form
2. you have had your questions answered, and
3. you have decided to be in the study.

You will be given a copy of this consent form to keep.

____________________________________ _______________
Your signature Date

____
Your printed name

____________________________________ _______________
Signature of researcher explaining study Date

____
Printed name of researcher explaining study

APPENDIX C. PHYSICAL ACTIVITY READINESS QUESTIONNAIRE (PAR-Q)

Physical Activity Readiness Questionnaire (PAR-Q) and You

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:

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 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 to 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.

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: Reprinted from ACSM's Health/Fitness Facility Standards and Guidelines, 1997 by American College of Sports Medicine

APPENDIX D. RUNNING LOG

NDSU Running Research Log

Summer 2015

Please fill out the following running log to the best of your knowledge in order for the results of this research study to be reported accurately. If at any time you wish to withdraw from the study, you may do so with no consequence.

At the end of the data collection period, this running log must be sent via USPS with the envelope provided and the incentive from *Fargo Running Company* will be provided immediately upon researchers receiving this log.

If at any time you have questions regarding any part of this research study including how to report information in this log please contact:

Abby Reynolds, NDSU Graduate Student Conducting this research study
(414)750-4882
ndsurunningresearch@gmail.com

Dr. Katie Lyman, NDSU Health, Nutrition and Exercise Sciences Associate Professor
(701)231-8208
Katie.Lyman@ndsu.edu

NDSU Institutional Review Board
(701)231-895
NDSU.IRB@ndsu.edu

∗ **Running Related Injury:** *Any* musculoskeletal ailment that is attributed to running that causes a restriction of running speed, distance, duration, or frequency.

Date	# of Miles	# of Minutes spent Running	Terrain (i.e. Asphalt, Concrete, Treadmill)	Was run today different than planned? Please Circle Yes or No	If yes to, please describe below. If plan changed due to injury please send email to ndsurunningresearch@gmail.com
Monday, June 1st 2015				Y / N	
Tuesday, June 2nd 2015				Y / N	
Wednesday, June 3rd 2015				Y / N	
Thursday, June 4th 2015				Y / N	
Friday, June 5th 2015				Y / N	
Saturday, June 6th 2015				Y / N	
Sunday, June 7th 2015				Y / N	

✳ **Running Related Injury:** *Any* musculoskeletal ailment that is attributed to running that causes a restriction of running speed, distance, duration, or frequency.