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Investigating the Hip and Trunk Kinematic and Strength Differences Between Those with a History of Exertional Medial Tibial Pain and Healthy Controls

Allison Hocking
University of Wisconsin-Milwaukee

INVESTIGATING HIP AND TRUNK KINEMATIC AND STRENGTH DIFFERENCES BETWEEN THOSE WITH A HISTORY OF EXERTIONAL MEDIAL TIBIAL PAIN AND HEALTHY CONTROLS

by

Allison Hocking

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ABSTRACT

INVESTIGATING HIP AND TRUNK KINEMATIC AND STRENGTH DIFFERENCES BETWEEN THOSE WITH A HISTORY OF EXERTIONAL MEDIAL TIBIAL PAIN AND HEALTHY CONTROLS

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Allison Hocking

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Introduction: Exertional medial tibial pain (EMTP) has been shown to be one of the leading injuries in females who have weakened hip strength. Increased trunk and hip kinematic excursion and decreased hip external rotation and hip abductor strength are related to injury in the athletic population but there is a lack of research in the role of hip strength in the occurrence of exertional medial tibial pain in competitive female runners. **Purpose:** Therefore, the purpose of this study is to investigate differences in hip strength, hip kinematics, and trunk kinematics between those with a previous history of exertional medial tibial pain and healthy controls. **Design:** Cross sectional, case control design. **Participants:** Twenty-one female competitive recreational runners ages 18-45 who were planning on participating in a race within the next 6 months were placed into two groups depending on their past medial history (11- healthy control and 10-EMTP group). **Methods:** Participants completed questionnaires demographics, training history, and views of running. 3D kinematic data were collected with reflective markers attached to the trunk and lower extremity segments during over-ground running trials using a 10-camera motion capture system, force platform, and timing system. Five running trials at 4.0-4.5 m/s were collected and peak angles of hip adduction, internal rotation, and extension and trunk flexion and lateral lean were averaged across the trials. Strength of the hip abductors external rotators, and extensors were collected during 3 maximal voluntary contractions using a handheld dynamometer and stabilization straps. To identify the differences between kinematic and strength variables, an independent t-test was performed to compare between groups with a significance level set at $\alpha<0.05$. **Results:** No significant difference in normalized hip strength were observed between those with a history of EMTP and healthy controls in hip abduction ($p=0.913$), hip external rotation ($p=0.125$), or hip extension ($p=0.308$). No significant difference in hip adduction ROM excursion ($p= 0.711$), hip internal rotation excursion ($p=0.998$), trunk flexion ROM excursion ($p=0.559$) or trunk lateral lean ROM excursion ($p= 0.559$) were observed between those with a history of EMTP and healthy control. The EMTP group found running more enjoyable and were more eager to run. The healthy group showed less remorse for missing a run and ran in more races. **Conclusion:** Hip strength and hip and trunk excursion appear similar between those who have a history of EMTP and those who are healthy and never had a history of EMTP. When looking at the holistic picture of kinesiology, clinicians and researchers have to take into consideration all variables because there are multiple factors that can increase the risk of EMTP.

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Chapter I- Introduction

Statement of Purpose

Recreational running is widely popular in those who are looking for general health benefits. Distance running has increased in the United States with 20% of Americans choosing running as their physical activity and participating in a large number of running events such as marathons (Dudley, R. I., Pamukoff, D. N., Lynn, S. K., Kersey, R. D., & Noffal, G. J. 2017). Participation in competitive running has doubled within the past 30 years because of more involvement from females and the increase in race options (Dudley et al., 2017; van der Worp et al., 2015). However, with the increase in participation comes an increased risk of sustaining a running related injury. Bertelsen et al. (2017) found that injury incidence rates ranges from 2.5 to 33.0 injuries per 1000 hours of running. The high incidence rate leads to an increase risk of sustaining an overuse running related injury. Overuse injuries may lead to a lengthy recovery time and high socioeconomic costs that relate with injury (Bertelsen et al., 2017). Approximately 30% of competitive runners will develop a running related injury (RRI) annually (Dudley et al., 2017). The occurrence of running related injuries can substantially decrease the likelihood of continued activity participation. Since recovery is lengthy and the incidence of reinjury is high, it may lead to a drop out in running involvement, resulting in a sedentary lifestyle (Davis & Futrell, 2016; Kuhman, Paquette, Peel, & Melcher, 2016; Mann et al., 2015; Zadpoor & Nikooyan, 2011). Overuse injuries account for 80% of all running injuries resulting from a mismatch between resilience of the connective and supporting tissue during a running bout (van der Worp et al. 2015). The connective and supporting tissue cannot withstand the load and are not properly and adequately repairing before the next bout of exercise. Poorly perfused tissues, such as ligaments, tendons and cartilage, are particularly at risk because they adapt more slowly than muscles to increased mechanical load (van der Worp et al., 2015).

The most common injuries are tibial stress fractures, patellofemoral pain, muscle strains, medial tibial stress syndrome, knee pain, iliotibial band injuries and Achilles tendinopathies (Daoud et al., 2012; Hamill, Gruber, & Derrick, 2014; Heiderscheit, Chumanov, Michalski, Wille, & Ryan, 2011). The development of RRI has been widely researched and measured in hopes to determine the causal factors so clinicians can prevent the injury before it occurs. There are a multitude of different variables that need to be measured to determine the risk of developing an injury. In addition to the robust literature on running biomechanics and injury, current research (Bertelsen et al., 2017; Davis & Futrell, 2016; Hrelijac, Marshall, & Hume, 2000; Kuhman, Paquette, Peel, & Melcher, 2016; Mann et al., 2015; Zadpoor & Nikooyan, 2011) is also taking into consideration the psychological, physiological, nutritional, and sociological factors of running related injuries. All of these variables have a role in injury risk and interrelate with a person's biomechanics, and thus there is not one sole determinant of running related injuries (Bertelsen et al., 2017; Davis & Futrell, 2016; Hrelijac, Marshall, & Hume, 2000; Kuhman, Paquette, Peel, & Melcher, 2016; Mann et al., 2015; Zadpoor & Nikooyan, 2011). Ideally, research studies should account for multiple factors across these domains. However, this study design quickly becomes overwhelming because there are so many to consider. In order to continue building our understanding of common risk factors, it is important to look at each realm separately. Biomechanics of the lower extremity during running has been found to be related to injury risk; however, there are still gaps in literature that relate to hip strength and trunk and hip control in the occurrence of running related injuries, especially in relation to exertional medial tibial pain (Dudley et al., 2017; van der Worp et al., 2015; Verrelst, De Clercq, Willems, Roosen, & Witrouw, 2014a; Verrelst, De Clercq, Willems, Victor, & Witvrouw, 2014c).

Exertional Medial Tibial Pain (EMTP) is a broad category that includes medial tibial stress syndrome, chronic exertional compartment syndrome, tibial stress fractures, tendon and muscle injuries (Verrelst et al., 2014a; Verrelst et al., 2014b; Verrelst et al., 2014c; Verrelst, 2013). EMTP is characterized as pain along the posterior and medial portion of the lower leg that is caused by activity (Verrelst et al., 2014a; Verrelst et al., 2014c). Current research has found that dynamic joint control, abductor strength, external rotators of the hip, and trunk control play a role in the development of EMTP (Ford, Taylor-Haas, Genthe, & Hugentobler, 2013; Teng & Powers 2015; Verrelst et al., 2014c; Verrelst, 2013). The hip abductors assist to stabilize the hip and the pelvis, especially in single leg movements. Verrelst et al. (2014a; 2014b; 2014c) has done extensive research on EMTP and has investigated the role of biomechanical variables that may lead to the development of pain. The research focused on college aged female physical education students who have no current injury that would affect lower extremity function. Participants were all given a specific workout program with specific environment conditions for 29 weeks and were monitored for the development of EMTP. Significant findings in hip abductor concentric weakness and external rotation weakness showed to be significant predictors of the development in EMTP, especially in women (Verrelst et al., 2014a; Verrelst et al., 2014c; Verrelst, 2013). Decreased hip strength and whole body fatigue can lead to unwanted movement of the trunk and the pelvis, resulting in an increased risk of developing EMTP (Verrelst et al., 2014a; Verrelst et al., 2014c; Verrelst, 2013)

Similar to abductor strength and external rotation strength, lack of trunk motion control has also been shown to increase the risk of developing lower extremity injuries (Ford, Taylor-

Haas, Genthe, & Hugentobler, 2013; Teng & Powers, 2015b). Teng & Powers (2015b) researched the influence of trunk posture on lower extremity energetics during running and found that small changes in trunk position may influence the mechanical demand that is placed on the lower extremities but there cannot be a direct causal relationship determined between trunk posture and injury (Teng & Powers, 2015b). Research has demonstrated that a person who runs with a more extended trunk posture exhibits higher energy absorption and generation of the knee extensors and a lower energy generation of the hip extensors (Teng & Powers, 2015b). A person who runs with a more flexed trunk posture exhibits higher energy generation of the hip extensors and lower energy absorption and generation of the knee extensors (Teng & Powers, 2015b). However, further research is needed to determine the role of trunk posture motion in the development EMTP. Ford et al. (2013) also looked at trunk motion in healthy runners and found that as hip strength increased, thorax and pelvic range of motion (ROM) decreased. Thus, decreasing the trunk and pelvis ROM increases stability, resulting in improved lower extremity mechanics and neuromuscular efficiency (Ford et al. 2013). Ford et al. (2013) also found that females are more at risk of developing lower extremity injuries because they tend to have weaker hip muscle strength. There is still further research that needs to be done to determine if there is a difference in trunk angles in the development of EMTP (Ford et al. 2013). Based on the current research, however, there is evidence supporting the claim that the hip complex does play an important role in overall mechanics and motion control.

There is a gap in the literature that describes hip strength and related hip and trunk motion in runners who have had EMTP. There is also a gap in the literature in looking at EMTP in competitive runners. Since EMTP encompasses a lot of the overuse injuries seen in runners, it is important to measure the hip complex in runners in relation to EMTP. Current research failed to measure strength hip and trunk muscles such as the hip flexors, quadatus lumborum, erector spinae, and the abdominal muscles (Verrelst et al., 2014a; Verrelst, 2013). Verrelst et al. (2014a; 2014b; 2014c) only focused on the hip abductors, hip adductors, and the external rotators. There is also a gap in looking at the occurrence of EMTP in endurance athletes who are continuously performing single leg movements such as in the stance phase of running. Hip strength was found to play a role in improper mechanics in single leg drop jump and increased risk of injury (Steinberg, Dar, Dunlop, & Gaida, 2017; Teng & Powers, 2015; Verrelst, 2013). Due to strength deficits, hip and trunk motion increase during single leg motions, thus reasoning to look at runners because they were continuously performing in the single leg stance.

Purpose

The purpose of this study was to investigate differences in hip strength, hip kinematics, and trunk kinematics between those with a previous history of EMTP and healthy controls. We also examined subjective information as a secondary measure to see if there were trends in demographic, training, psychology, sociology, nutrition, and medical history between groups. It was important to take what we know about EMTP and risk factors of running related injuries and investigate the difference of hip strength and hip and trunk kinematics in runners and the occurrence of EMTP. This study is the next step to further identify the effects of trunk and hip motion and hip strength on lower extremity mechanics and the risk of overuse injuries. With the termination of this research, we have developed a better understanding of the role of proximal mechanics in the kinetic chain and provided future research opportunities towards preventative intervention strategies to reduce the occurrence of running related injuries such as EMTP.

The above objectives were met through the following specific aims:

Specific Aim 1: To determine if there was a difference in isometric hip abduction, extension and external rotation strength in those with a history of EMTP as compared to healthy controls.

Hypothesis 1: Those with a history of EMTP will demonstrate decreased hip strength compared to the healthy controls.

Specific Aim 2: To determine if there was a difference in hip adduction, internal rotation, trunk flexion and lateral lean excursion in those with a history of EMTP compared to healthy controls.

Hypothesis 2: Those with a history of EMTP will demonstrate increased hip adduction, internal rotation, trunk flexion and lateral lean excursion compared to healthy controls.

Specific Aim 3: To explore the nutritional, psychological, sociological, physiological, training, and nutritional factors that may differ between those with a history of EMTP compared to healthy controls.

Delimitations

This study focused on competitive runners because no research could be found that examined those who are running longer distances. The current research only looked at recreational athletes and there was a need to look at competitive runners because, as stated earlier, overuse injuries such as EMTP are predominate in runners. In order to be considered a competitive runner, participants had to run more than 30 miles a week. Because the research was performed on a college campus, access to this age group was readily available; however, since the age requirement was 18-45, some, if not most, of the participants were from the community and surrounding areas. Females were chosen to be included in this investigation because previous research found that females were more likely to have hip strength deficits and were at higher risk of developing EMTP (Verrelst et al., 2014a, Verrelst et al., 2014c). This study included two groups: one who had a previous EMTP defined injury and a control group who never experienced an EMTP injury. Participants needed to be injury free and fully cleared for participate at the time of testing.

<u>Assumptions</u>

It was assumed that the participants in this investigation accurately identified and reported their previous or current injury. It was also assumed that participants truthfully answered questions regarding their training, event logs, and medical history. Shoe type or foot strike pattern were not controlled for in this current investigation because research already found that there was a relation between foot strike patterns and running related injuries (Daoud et al., 2012; Lieberman et al., 2010). We believed that, based on previous research, foot strike pattern would not affect our measurements (Ahn et al., 2014; Daoud et al., 2012; Dudley et al., 2017; Hamill et al., 2014; Lieberman et al., 2010; Zhao et al., 2007); however, we did recognize that foot strike pattern may affect injury risk and may play a role on the occurrence of previous injury. During data collection, we assumed that participants gave their maximal effort during the isometric and strength testing. Finally, we assumed that all lower extremity segments were rigid bodies and the joints were frictionless.

<u>Limitations</u>

Females between the ages of 18-45 used as inclusion/ exclusion criteria, leading to the inability to speculate that the results from the study can be generalized to the entire population within other age groups. Since the study only looked at competitive female runners, the results from the study cannot be generalized to recreational, high school, elite, or male runners. Proper reporting of injuries from participants was also a limitation because we assumed that they were telling the truth. Another limitation was the different type and level of training from the participants based on needs, wants, and race they were training for. The handheld dynamometer was used during strength data collection, leading to the potential that a true MVC was not recorded because of inaccurate placement or inaccurate patient positioning. Another limitation that we could not control was the lab setting. We realized that the lab environment did not accurately replicate the field testing, which may have affected movement patterns and gait of the participants.

Significance of Study

The results from this study provided further knowledge about the characteristics of competitive runners with a history of EMTP. The goal of this research study was to shed a light on causative factors relating to EMTP, which may be used to develop intervention protocols that may reduce the risk of injury in competitive runners. Researchers and clinicians could build a better understanding of the biomechanical risk factors that lead to EMTP. The information received from this study may be carried over into the biomechanical view of running and could help to determine the role of the proximal structures in the kinetic chain.

Chapter II: Literature Review

Introduction

Recreational running is a widely popular mode of aerobic exercise in those who are looking for general health benefits and leisure time activity (Davis & Futrell, 2016; Kuhman et al., 2016; Mann et al., 2015; Zadpoor & Nikooyan, 2011). Furthermore, running is one of the most efficient ways to achieve physical fitness with an average of around 10 million Americans partaking in running related activities (Goss & Gross, 2012; Hespanhol, Luiz, Pena, Leonardo, & Lopes, 2013; Ryan, MacLean, & Taunton, 2006). Nearly 500,000 people in the United States completed a marathon in 2009 and recent estimates report that the running population competes in nearly 30,000 races held annually (Mucha et al., 2016). Unfortunately, with an increase in recreational running, there is an increase in running related injuries. Even though recreational running is considered a health promoting behavior, those who are competitive runners have a 37-70% increased risk of sustaining a musculoskeletal injury (Stephan, Deroche, Brewer, Caudroit, & Le Scanff, 2009). Injury occurrence equates to about 6.8 to 59 injuries per 1,000 hours of running exposure (Williams & Isom, 2012). The high injury occurrence rate becomes problematic for competitive and recreational runners because injury increases mood disturbances, pain, and uncertainty about returning to sport (Hespanhol et al., 2013). The occurrence of running related injuries (RRIs) can substantially decrease the likelihood of continued activity participation and can lead to a drop-out of running involvement and a sedentary lifestyle (Hamill et al., 2014; Hreljac et al., 2000; Mucha, Caldwell, Schlueter, Walters, & Hassen, 2017; Zadpoor & Nikooyan, 2011). Therefore, the purpose of this literature review is to expand on the risk factors or running related injuries, to provide background knowledge about biomechanical risk factors and to expand on a newer development of a running related injury known as exertional medial tibial pain (EMTP).

Running Related Injury

Incidence

Running related injuries (RRIs) may lead to decreased training days to allow for recovery, decreased positive perception of running, increased medical costs due to medical care including physical therapy, and an increased risk of future injuries (Hamill et al., 2014; Hreljac et al., 2000; Mucha et al., 2017; Ryan et al., 2006). Depending on the severity of the injury, RRI may take up to 19 weeks to fully recover. This results in 19 weeks of refraining from running, participating in rehabilitation programs to build strength and endurance, and may lead to cessation of activity all together (Zadpoor and Nikooyan 2011). The most common running related injuries are muscle strains, medial tibial stress syndrome (MTSS), knee pain, IT band injuries, and Achilles tendinopathies, with the shank and the knee being most affected (Daoud et al., 2012; Hamill et al., 2014; Heiderscheit, 2011; Hreljac et al., 2000). The predominant site of leg injuries is the knee, for which the location specific incidence ranged from 7.2% to 50.0%. Running injuries of the lower leg (9.0% to 32%), foot (5.7% to 39.2%), and upper leg (3.4% to 38.1%) are common. Less common sites of running injuries are the ankle (3.9% to 16.6%,), the hip/pelvis/groin (3.3% to 11.5%) and lower back (5.3% to 19.1%) (Hamill et al., 2014; Mann et al., 2015; Milner et al., 2006).

All runners are at a risk of injury. There is no all-encompassing remedy to prevent injuries from happening, which increases the need for further research and replication of studies to reduce the risk of injury (Daoud et al., 2012). Since running is a multifactorial activity, so is the risk of sustaining a RRI, therefore, it is important to not only look at the biomechanical variables, but also look at possible risk factors as a whole (Hreljac et al., 2000). Nutrition, psychological factors, sociological factors, physiological factors, and strength are just some of the predominant elements that need to be taken into consideration in order to accurately determine the reasons and causes of RRIs. The identification of modifiable and non-modifiable risk factors is a necessary step for a better understanding of how to design and deliver injury prevention interventions (Hulme, Nielsen, Timpka, Verhagen, & Finch, 2017). In order to accurately define and measure running related injuries and develop an intervention to reduce the occurrence, it is valuable to continue to examine associated risk factors to build a better understanding of RRI.

Model of Running Related Injuries

In order to accurately develop a study that looks at the multifactorial nature of running related injuries, a conceptual framework should be followed. Since there are many different variables that lead to injury in runners, it is necessary to look at all the different types of exposures that influence the risk of RRIs. Bertelsen and colleagues (2017) built a conceptual framework shown in Figure 1, on the complex nature of running related injuries. This framework provides future prevention studies ways to measure RRI based on exposure by diving deeper into the causation of injuries. The four-part conceptual framework is broken up into structure specific capacity when entering a running session: structure-specific cumulative load per running session; reduction in the structure specific capacity during a running session; and exceeding the structure specific activity (Bertelsen et al., 2017). The structure-specific load capacity when entering a running session is defined as the body’s ability to tolerate the increased load demand without sustaining an injury over time (Bertelsen et al., 2017). The structure specific cumulative load per running session can be defined as the risk of injury depending on the amount of participation in running, which can be viewed as the sum of the exposure to stride specific loads during a running session (Bertelsen et al., 2017). The reduction in the structure specific load capacity during a running session is defined as how much of the load capacity is decreased over a repetitive loading session based on the magnitude of the load and the sensitivity to the applied load (Bertelsen et al., 2017). Exceeding the structure specific load capacity is the relationship between load and load capacity and how long the runner can tolerate the load before it becomes too much (Bertelsen et al., 2017). Running related injuries occur from a combination of factors such as stride, magnitude of load, distribution of load, and load capacity, which is why it is important to include this framework when looking at running related injuries (Bertelsen et al., 2017).

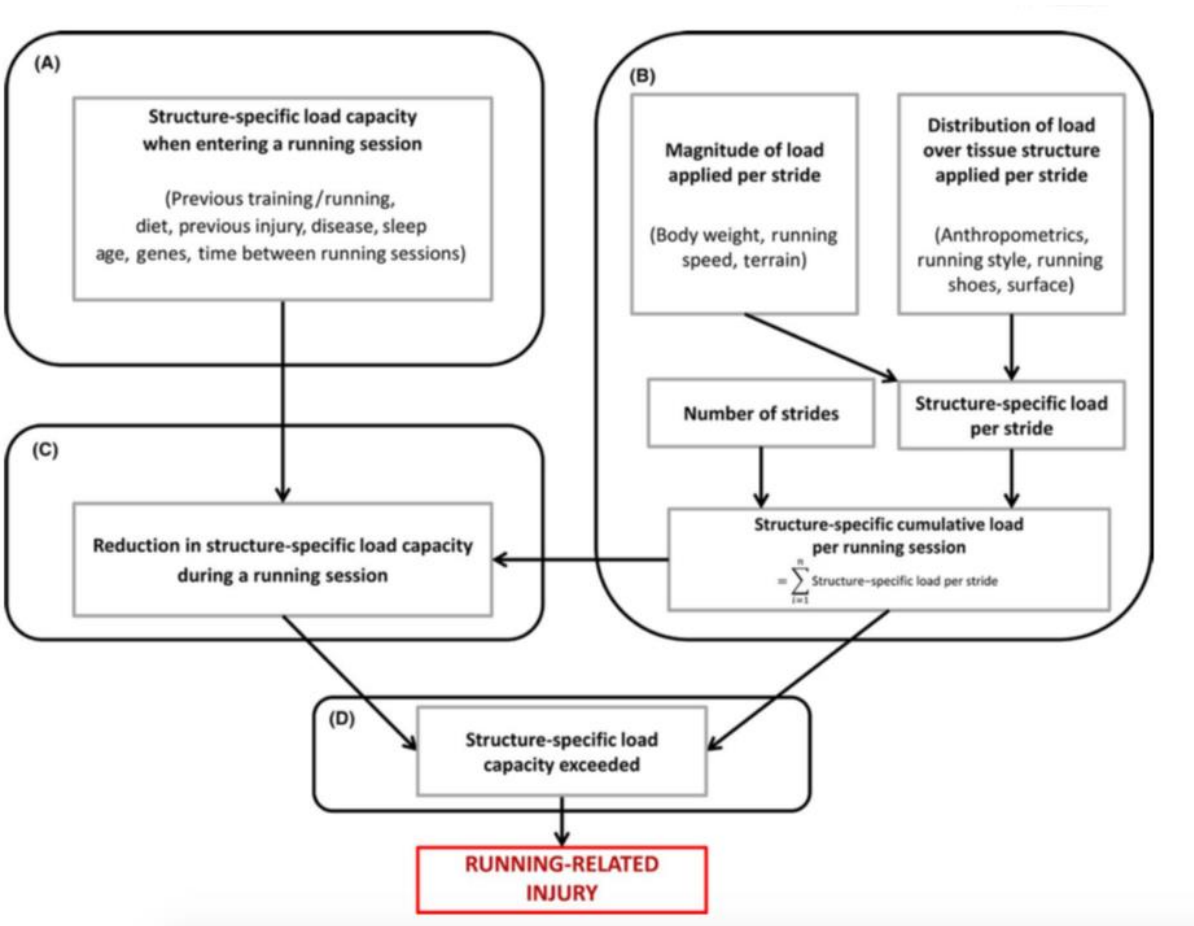

Figure 1: A conceptual framework model for the causal mechanism of running related injuries in a single session of a running bout. Box A represents the structure-specific load capacity of all the variables that can affect the risk of running related injuries outside or prior to a run. Box B represents the structure specific cumulative load per session during the run that can affect the risk of running related injuries. The equation determines the amount of load per stride that can affect injury risk. Box C represents adaptation of continuous running and the reduction of load placed on the body over time. Box D represents the relationship between load and load capacity and what happens when the load capacity exceeds limits.

Holistic Risk Factor Analysis

Adding on to the biomechanical tissue injury model described above, it is important to take into consideration other factors that can ultimately influence the structure specific load capacity, magnitude of the load, and the distribution of the load. Such factors include sociological, psychological, physiological, nutritional, and training factors. Since RRI are multifactorial, there are other variables within these domains that can also affect the risk of sustaining a RRI. The social environment can play a key role in RRI when it comes to environment, scheduling, reasons for training, and family/ friend participation (Masters & Ogles, 1998; Summers, Machin, & Sargent, 1983). A higher positive insight, social involvement, and positive perception of running increases participation in running (Masters & Ogles, 1998; Summers et al., 1983). Those who schedule their life around running and lack the support from close family and friends have a higher risk of sustaining a RRI because their perception in running becomes negative and they begin to train less (Masters & Ogles, 1998; Summers et al., 1983). Psychologically, the motivational level, viewpoint on running and training, and personality type play a role in the development of injury (Carmack & Martens, 1979; Ekenman, Hassmén, Koivula, Rolf, & Felländer-Tsai, 2001; Masters & Ogles, 1998; Summers et al., 1983). Harmoniously passionate individuals present a flexible behavioral commitment and are able to initiate preventative actions because they are willing to discontinue activity until they are healthy again (Stephan et al., 2009). If one has a negative perception of training, it will hinder their desire to train and intensify their perception of pain, resulting in a decrease in running participation (Carmack & Martens, 1979; Masters & Ogles, 1998).

It is important to take into consideration the fitness level and the physiological capacity of runners because low physiological capacity can lead to an increased risk of injury (Bredeweg, Zijlstra, & Buist, 2010; Christina, White, & Gilchrist, 2001; Clansey, Hanlon, Wallace, & Lake, 2012; Dierks & Davis, 2007; Hobara et al., 2010). Training errors, low aerobic capacity, reduced joint coupling and improper co-activation of the lower extremity muscles have been found to increase the risk of RRI (Bertelsen et al., 2017; Malisoux et al., 2015). How a runner takes care of their body, what they put into their body, and what they do to their body may influence injury and help clinicians determine risk factors of injury (Cobb et al., 2007; Hespanhol et al., 2013; Stephan et al., 2009). Female athletes are more susceptible to experience the female athlete triad because they have a high risk of low bone density and bone mineral content (Shaffer et al., 2006; Thein-Nissenbaum et al., 2012). Because of this, it has been found that nutrition plays a predominate role in injury development (Shaffer et al., 2006; Thein-Nissenbaum et al., 2012). Previous injury, oral contraceptives, menstrual irregularity, and eating disorders have been shown to increase the risk of sustaining a RRI, especially in females (Cobb et al., 2007; Shaffer et al., 2006; Thein-Nissenbaum, Rauh, Carr, Loud, & McGuine, 2012). There is a huge debate on what is too much, how far is too far, what is the best terrain to run on, and how much rest one should have between training bouts (Bertelsen et al., 2017; Hespanhol et al., 2013; Malisoux, Nielsen, Urhausen, & Theisen, 2015; Ryan et al., 2006). The form of exercise, type and location of training, shoe type, time between training sessions, and volume of exercise may all play a role in the development of an overuse injury, especially in runners (Bertelsen et al., 2017; Hespanhol et al., 2013; Malisoux et al., 2015).

Common Running Related Injuries

This section will summarize what is known about three of the most common running related injuries, patellofemoral pain, iliotibial band syndrome and exertional medial tibial pain. The etiology, clinical signs and symptoms, and prognosis/ recovery will be discussed.

Patellofemoral Pain

Patellofemoral pain (PFP) is one of the most hindering of running related injuries with 1 in 4 athletes experiencing PFP during activity, leading to activity modifications and extensive prolonged medical treatment. (Murphy, Connolly, & Beynnon, 2003; Stefanyshyn, Stergiou, Lun, Meeuwisse, & Worobets, 2006). PFP is characterized as a chronic, overuse injury with dull, achy pain over the lateral aspect of the patella that is exacerbated during activity (Brewer & Gregory, 2012; Murphy et al., 2003). It is considered an overuse injury because over time, the continuous sliding of the patella over the intercondylar notch of the femur leads to chronic inflammation and pain. Because runners are constantly putting stress on the knee through the continuous and long duration runs, the patellofemoral is more susceptible to overuse injuries (Murphy et al., 2003).

Studies have found that frontal plane loading, knee abduction moments, hip abduction, and hip external rotation are the most common biomechanical risk factors presented in those who are experiencing PFP (Murphy et al., 2003; Stefanyshyn et al., 2006). These variables increase patellar tracking and increase the load and force on the patella over the femur, leading to chronic inflammation (Stefanyshyn et al., 2006). Those who have higher knee abduction moments, higher hip abduction and higher hip external rotation increase the stress and load on the knee. Over time, this may also lead to increased risk of osteoarthritis, preventing future activity and possible complete cessation of physical activity (Brewer & Gregory, 2012; Stefanyshyn et al., 2006).

Iliotibial Band Syndrome

Iliotibial Band Syndrome (ITBS) is a common overuse injury, causing lateral knee pain in runners resulting in repetitive friction of the Iliotibial Band (ITB) jumping over the lateral femoral epicondyle because of increased tightness in the ITB (Brewer & Gregory, 2012; Gallo, Plakke, & Silvis, 2012). Like any other injury, the casual pathway of ITBS is multifactorial but investigations have found biomechanical causative factors that lead to the development of ITBS (Murphy et al., 2003). When the knee is flexed to 30^{o}, the ITB is impinged, increasing the tightness of the ITB, resulting in chronic inflammation and increased pain (Chuter & Janse de Jonge, 2012).

Common risk factors that are found in ITBS are weakness of the hip muscles leading to decreased control of the pelvis and increased tightness in other muscles to compensate for the weakness (Chuter & Janse de Jonge, 2012; Murphy et al., 2003). When the hip muscles fail to fire properly throughout the support phase of the running cycle, there is a decreased ability to control eccentric hip abduction, leading to compensation throughout the kinetic chain (Brewer & Gregory, 2012; Gallo et al., 2012). Increases in peak hip adduction moments increase the risk of developing ITBS due to hip weakness (Chuter & Janse de Jonge, 2012; Gallo et al., 2012). The increased hip adduction increases the tension of the ITBS because there is more eccentric demand from the gluteal muscles leading to excessive soft tissue tightness and myofascial restrictions (Brewer & Gregory, 2012; Gallo et al., 2012).

Exertional Medial Tibial Pain

The tibial area is one of the most common locations for overuse injuries in physically active individuals (Verrelst, 2014a). Exertional medial tibial pain (EMTP) is a common overuse injury that is often due to the repetitive loading of the tissue during a bout of exercise (Verrelst et al., 2014a; Verrelst et al., 2014b; Verrelst et al., 2014c; Verrelst, 2013). EMTP is associated with tibial stress fractures, medial tibial stress syndrome, chronic exertional compartment syndrome, muscle strains, and tendon sprains to the lower extremity with individuals usually experiencing pain inferior to the knee and superior to the ankle joint on the medial side of the leg (Verrelst et al., 2014b; Verrelst et al., 2014c). The diagnosis of EMTP is given when the individual experiences pain during weight bearing activities that prevent them from exercising or having to refrain from certain activities because of the pain (Verrelst et al., 2014a; Verrelst et al., 2014b). EMTP has been found to be more prominent in females compared to their male counterparts because females tend to have weaker hips, lower bone density, and higher risk of stress fractures (Verrelst et al., 2014c). Since EMTP is a repetitive overuse injury, the most common individuals that experience the pain are runners and those who perform jumping tasks such as basketball or volleyball (Steinberg et al., 2017; Teng & Powers, 2015; Verrelst, 2013).

There are multiple different risk factors that that affect EMTP and can be categorized into two different domains: intrinsic and extrinsic (Verrelst et al., 2014b; Verrelst, 2013). Intrinsic risk factors are factors that are within the body that can cause injury such as gender, age, body structure, and previous history of injury. Extrinsic risk factors are factors that are external to the body that can cause injury such as training surface, type of training, shoe type, training load (Verrelst et al., 2014a; Verrelst et al., 2014c; Verrelst, 2013). The human body is considered a dynamic model that requires coordination, activation, and synchrony throughout the entire body known as a kinetic chain (Steinberg et al., 2017; Teng & Powers, 2015; Yagi et al., 2013). A deficit in one area leads to compensation or changes in movement in another area, possibly leading to injury. For example, prolonged or excessive foot pronation and hip abduction strength have been found to be a risk factor for EMTP (Verrelst et al., 2014a; Verrelst et al., 2014c). There has been extensive research on the distal parameters of RRI but there has been limited research on the proximal parameters such has pelvis and trunk position, strength, and instability (Verrelst et al., 2014b).

Tibial stress fractures are characterized by tenderness or edema in the lower leg during increased activity or repeated activity with limited rest (Brewer & Gregory, 2012; Chuter & Janse de Jonge, 2012). The limited rest leads to an acceleration of normal bone remodeling, producing micro fractures and the creation of a bone stress fracture (Chuter & Janse de Jonge, 2012; Gallo et al., 2012). Medial tibial stress syndrome (MTSS), commonly known as shin splints, is one of the most common causes of exertional leg pain in athletes (Brewer & Gregory, 2012; Gallo et al., 2012). The cause of MTSS usually involved training errors, excessive load on the tibia, weakness or dysfunction in the tibialis posterior, tibialis anterior, and soleus muscles leading to increased tibial loading (Chuter & Janse de Jonge, 2012; Murphy et al., 2003). The increased tibial loading puts more force on the tibia, leading to undesired bending and abnormal strain of the tibia (Murphy et al., 2003). Over time and without proper recovery and care, pain and discomfort will develop because the tibia is unable to remodel itself efficiently to fix the increased load (Gallo et al., 2012).

Chronic exertional compartment syndrome (CECS) is caused by increased intra-compartmental pressure of the fascial space in the lower leg (Murphy et al., 2003; Tucker, 2010). Common risk factors associated with CECS are increased loading on the tibia, muscle type composition, and muscle tightness (Murphy et al., 2003; Tucker, 2010). CECS is usually characterized by pain and tightness in the compartment during exercise because the muscle volume increases to about 20% in size during exercise. As the muscle volume increases, the pressure in the fascia increases and there is less blood flow to the tissues. This leads to cell hypoxia, increased dependence on anaerobic metabolism, production of lactate and possibly cell death (Tucker, 2010).

Strains and sprains are also common injuries categorized as EMTP but are usually related to acute injury (Gallo et al., 2012; Murphy et al., 2003). Excessive load increases the risk of sustaining tendon strains or a ligament sprains because the desired load and force needed to match the task exceeds the capability of the structure. Muscle strains may also occur because of the muscle weakness or tightness. Muscle weakness reduces the amount of force produced, resulting in an increased risk of straining the muscle when the load is too great, whereas, muscle tightness reduces the range of motion available by the muscle, resulting in increased risk of straining the muscle (Chuter & Janse de Jonge, 2012; Murphy et al., 2003). All of these injuries are related to EMTP because of their mechanism of action, location of injury, and causative factors (Verrelst et al., 2014b). Due to their mechanism of action, location of injury, and causative factors, all of these injuries are categorized as EMTP and all of them are considered overuse injuries. Therefore, it is important to understand the risk factors, causative factors, and etiology of all injuries in order to properly care for EMTP in runners.

Biomechanical Factors

For the remainder of this review, I will focus on the literature related to risk factors for EMTP specifically. EMPT was identified to be the injuries that there is the least amount of research about, therefore the focus of the proposed project.

Based on the conceptual framework by Bertelsen et al. (2017), RRIs occur when the loading on a tissue exceeds the capacity of the tissue to withstand that load. This can occur from a sudden onset load of large magnitude, or, more commonly, from repetitive loading of lower magnitude but without adequate time for recovery. One method of examining the load placed on the tissue is to evaluate the lower extremity kinetics. Some of the most common and identified variables related to RRI's are ankle eversion angle at loading response, angle eversion moment at loading response, knee vertical stiffness, knee adduction moment, max knee flexion, loading rate, and varus moment at loading rate (Butler, Ferber, & Davis, 2003; Dudley et al., 2017; Hamill et al., 2014; Hreljac et al., 2000; Kuhman et al., 2016; Milner et al., 2006; Zhao et al., 2007). Kinetic measures play a critical role in the development of running related injuries. Kinematics is the branch of mechanics that is concerned with the motion of the body without regard to the forces that produce the motion (Heiderscheit et al., 2011; Ryan et al., 2006). Some of the common variables that were found to be related to running related injuries were step width and foot strike pattern (Hafer, Brown, deMille, Hillstrom, & Garber, 2015; Heiderscheit et al., 2011; Meardon & Derrick, 2014; Radzak, Putnam, Tamura, Hetzler, & Stickley, 2017). Taken together, the altered kinematics and greater medial-lateral GRFs, torsional loads, and frontal plane joint moments have the potential to increase the stress applied to the tibia during running, increasing the risk of RRIs (Meardon & Derrick, 2014). Even though these variables are the most common, there is still a lot of gray area associated with each, which is why they cannot be said to be a sole determination and risk factor for RRI.

Biomechanically, we know that injuries in general occur because there is an imbalance between the loading characteristics and the tissue. During a bout of running, the tibia experiences a bending load that is the biggest contributor to injury (Chuter et al., 2012; Goss et al., 2012; Hamill et al., 2014; Hulme et al., 2017; Ryan et al., 2006). If the bending load becomes too high, fractures may occur because of the lack of energy absorption and ability to withstand the motion (Hulme et al., 2017; Ryan et al., 2006). EMTP occurs in a specific site, which is the distal 1/3 medial portion of the tibia. Based on the Bertelsen et al. (2017) model, if there is an imbalance between the load that is placed on the tissue and the tissue's ability to withstand the load, an injury will occur. If there is balance between the load and the tissue, there will be no injury

(Bertelsen et al., 2017). However, there are other factors that may influence running mechanics such as hip weakness, hip and trunk motion control, nutrition, physiological characteristics, and psychological perspective of running. These factors may influence the mechanics of running but do not cause the injury to occur. Injury occurrence is due to the biomechanical deficit between the load applied and the tissues inability to match the load demand and repair the damage (Bertelsen et al., 2017).

Peak Impact Force

Peak impact force is one of the major risk factors of RRI such as tibial stress fractures, medial tibial stress syndromes and patellofemoral pain. The initial impact peak occurs when the foot comes into contact with the ground and results in 2.5-2.8 times the body weight (Hreljac et al., 2000; Milner et al., 2006; Ryan et al., 2006). This compressive loading creates a greater bending moment on the tibia, leading to more susceptibility to injury over time (Ryan et al., 2006; Zadpoor & Nikooyan 2011). Having a higher peak impact force reduces the ability to absorb the force, placing more pressure on the lower extremities (Hreljac et al., 2000; Milner et al., 2006; Ryan et al., 2006). Over time, the constant load and high impact peak forces, may result in increased risk of RRI (Milner et al., 2006).

Impact peak is important in the study of EMTP because EMTP may be caused by the increased peak impact. There is less hip and knee flexion excursions in the controlled landings, resulting in instability and more load placed on the extremities (Verrelst et al., 2014a; R. Verrelst, 2013). Since the body works as a kinetic chain, instability in one joint will affect the instability and function of other joints, leading to the snowball effect of overuse injury (Butler et al., 2003; Ryan et al., 2006). Peak impact force may be an important factor in the cause of overuse injuries because of the cumulative effect of the higher impacts and not enough recovery or rest (Hreljac et al., 2000; Milner et al., 2006).

Foot Strike Pattern

The importance of considering foot strike pattern in this study is due to the fact that foot strike pattern has become a common and widely researched variable because of the rise of barefoot running and minimalist shoes (Lieberman et al., 2010). Runners can be categorized into forefoot strikers (FFS) or rearfoot strikers (RFS), and occasionally midfoot strikers (MFS). These classifications are based on the landing strategy at the impact of initial ground contact (Daoud et al., 2012; Lieberman et al., 2010). FFS make initial contact with the ball of their foot portraying a toe-heel-toe running style and rearfoot strikers make contact with the heel initially at contact demonstrating a heel-toe running style (Daoud et al., 2012; Lieberman et al., 2010). FFS decrease the frontal and sagittal moment at the knee with a softer footfall; however, they increase the load placed on the metatarsal heads resulting in an increased risk of MT stress fractures (Goss & Gross, 2012). RFS decrease the load placed on the ankle joint but increases the load on the knee and then tibia due to the higher impact peak force (Goss & Gross, 2012). Because of this, it has been determined that FFS and RFS both have incidences of injuries but depending on the style of running preferred and trained will determine the risk of injuries to certain lower extremities joints (Kulmala et al., 2013). There is no style of running that will eliminate all risk of RRI but FFS has shown to decrease the more common RRI's (Goss & Gross, 2012). Therefore, it is important to understand the gait mechanics and associated risk factors in both types of runners. Since this study is going to focus on the running mechanics, it will be imperative to control for foot strike patterns to determine if there is a role in the occurrence of EMTP.

Loading Rate

The loading rate simply represents how quickly the impact force is applied with a steeper slope meaning a more rapid collision and a gentler slope indicating the force spread over a longer period of time (Davis & Futrell, 2016; Hreljac et al., 2000; Milner et al., 2006; Ryan et al., 2006). Those with a history of tibial stress fractures, which is a classification within EMTP, exhibit greater impact GRF, vertical impact GRF, vertical loading rate, and peak tibial acceleration than uninjured runners (Hreljac et al., 2000; Milner et al., 2006; Ryan et al., 2006; Zadpoor & Nikooyan, 2011). Higher rates and magnitudes of loading have been shown by some studies to correlate significantly among rearfoot runners with lower limb stress fractures, plantar fasciitis, and other injuries such as hip pain, knee pain, lower back pain, medial tibial stress syndrome, and patellofemoral pain syndrome, which are all associated with EMTP (Daoud et al., 2012; Goss & Gross, 2012; Kulmala et al., 2013).

Trunk Position

The role of trunk posture has recently been suggested to affect the moment distribution among the lower extremity joints during weight bearing activities with small changes of trunk orientation increasing the demand on the lower extremities (Ford et al., 2013; Teng & Powers, 2015; Verrelst et al., 2014b). The role of the trunk affects the actions of the lower extremity through the concept of the kinetic chain (Ford et al., 2013; Teng & Powers, 2015; Verrelst et al., 2014b). Increasing trunk flexion lowers the energy absorption of the knee extensors and higher generation of the hip extensors resulting in more load placed on the knee and lower extremities (Ford et al., 2013; Teng & Powers, 2015). Over time, the increased load demand, leads to the development of EMTP, which is commonly associated with overuse injuries.

Core has been found to control the movement of the distal segments, therefore, the role of core control and injury development may be associated (Ford et al., 2013; Teng & Powers, 2015; Verrelst et al., 2014a). Impaired function at the trunk and the core increases uncontrolled movement throughout the lower extremity kinetic chain, in turn, increasing the ground reaction force and strain of the lower extremities, resulting in overuse pathologies (Ford et al., 2013). The accessory movements in the trunk reduces the control of the hip region, leading to lesser load distribution of the lower extremities, compensation patterns, and more eccentric activity of the lower extremity muscles that increase the risk of EMTP (Ford et al., 2013; Teng & Powers, 2015; Verrelst et al., 2014a). On the other hand, there is still a gap in the knowledge of trunk control and motion in the occurrence of EMTP. Since the trunk does have a role in overuse injuries, it is important to measure its kinematic effect on the risk of EMTP.

Hip Mechanics

Hip mechanics have been found to play a role in the development of EMTP (R. Verrelst, 2013), PFP (Stefanyshyn et al., 2006), and ITBS (Chuter & Janse de Jonge, 2012). Excessive hip internal rotation and adduction have been found to increase the risk of developing PFP and EMTP because hip adduction contributes to dynamic valgus of the lower extremity, placing more load and strain on the tibia (Ford et al., 2013; Mucha et al., 2017; R. Verrelst, 2013). Consequently, altered hip biomechanics are likely due to weakness in the hip external rotators and hip abductors, leading to the inability to eccentrically control single leg stance during running (Mucha et al., 2017; Verrelst, 2013). This weakness results in an inability to stabilize the hip and the trunk, leading to compensation patterns and increased load on the distal segments (Ford et al., 2013; Verrelst, 2013). Over time, these compensations and load changes may lead to overuse injuries such as EMTP (Verrelst, 2013). The movement and control of the hip influence the location of the total body center of gravity, ground reaction forces, and energetics during running, meaning that increased hip adduction and internal rotation increase the ground reaction force and energetics (Mucha et al., 2017; Verrelst, 2013). For example, it has been found that the increased adduction and internal rotation resulted in increased maximum knee abduction angle and knee abduction angle at initial contact and toe off during running (Ford et al., 2013). The alterations in hip muscle performance or weakness in the stabilizing muscles during running may result in pelvic drop, collapsed posture of the lower extremity, foot placement errors, or excessive subtalar inversion moments (Ford et al., 2013; Yagi et al., 2013).

A decrease in hip abduction and extension isometric torque have also been shown to increase the risk of injury in runners (Yagi et al., 2013). The gluteus maximus is the primary contributor to hip extension and abduction, therefore, weakness in the gluteus maximus will reduce the isometric torque and reduce the control of the hip complex during single leg stance activities (Yagi et al., 2013). The weakness in hip abduction and extension results in compensation by employing a lateral trunk lean, decreasing the demand on the stance limb abductors and shifting the center of mass over the hip joint center (Ford et al., 2013; Yagi et al., 2013). The recent research has indicated that it cannot be determined if poor hip performance plays a role in the development of EMTP or if the hip muscle weakness and dysfunction develop after the onset of the injury as a result of decreased activity levels secondary to pain (Ford et al., 2013; Verrelst, 2013). There is a gap in the literature on the effect of hip muscle mechanics and its role in the occurrence of EMTP, resulting in the need for more research on this topic.

Knee Mechanics

Peak knee adduction moment (KAM) has been proposed as a relative measure for medial compartment load during gait, and has been related to knee injury (Zhao et al., 2007). The adduction torque results in a larger muscle force estimate and more co-contraction, placing more repetitive loading on the medial portion of the knee, increasing the risk of EMTP (Zhao et al., 2007). Varus alignment during running increases the forces on the knee, leading a higher risk of overuse injuries. Tibial torsional loading is linked to running injuries because the excessive internal rotation of the knee interferes with the normal knee-muscle force vectors and shifts the patella laterally with respect to the knee joint center. This causes increased compressive forces to act on the knee joint (Lilley et al., 2011; Williams & Isom, 2012) resulting in the development of patellofemoral pain (Stefanyshyn et al., 2006), ITBS (Murphy et al., 2003), and EMTP (Verrelst et al., 2014a).

Ankle and Foot Mechanics

Rearfoot eversion is one of the most investigated joint motions related to running mechanics in the foot (Dierks & Davis, 2007). Eversion is the motion that begins at initial contact and continues through loading response as the stance leg transitions from dorsiflexion to plantarflexion (Kuhman et al., 2016). Excessive eversion can result in excessive tibial internal rotation, which can, in turn, influence knee mechanics and hip mechanics (Hamill et al., 2014; Kuhman et al., 2016). A greater range of eversion motion at loading response exposes the tissues of the foot to more stress and strain (Kuhman et al., 2016). Conversely, limited eversion might load the leg with impact and body weight forces too quickly, subjecting tissue to high forces over a short time, and possibly leading to injuries such as a lateral ankle sprain, stress fracture, or iliotibial band syndrome (Valenzuela et al., 2016). It creates a brief window during each gait cycle in which the tibia and femur are out of sync, resulting in the knee experiencing excessive stress and strain forces (Hamill et al., 2014; Kuhman et al., 2016; Milner, Hamill, & Davis, 2007; Tiberio, 1987). Alternatively, this could result in a compensation at the hip and knee that negatively influences lower extremity mechanics. Relationships between rearfoot eversion and knee mechanics have been found in both patellofemoral pain (Valenzuela et al., 2016), knee osteoarthritis (Kuhman et al., 2016), and EMTP (Verrelst et al., 2014b).

Biomechanically, we know that injuries in general occur because there is an imbalance between the loading characteristics and the tissue. During a bout of running, the tibia experiences a bending load that is the biggest contributor to injury (Chuter et al., 2012; Goss et al., 2012; Hamill et al., 2014; Hulme et al., 2017; Ryan et al., 2006). If the bending load becomes too high, fractures may occur because of the lack of energy absorption and ability to withstand the motion (Hulme et al., 2017; Ryan et al., 2006). EMTP occurs in a specific site, which is the distal 1/3 medial portion of the tibia. Based on the Bertelsen et al. (2017) model, if there is an imbalance between the load that is placed on the tissue and the tissue's ability to withstand the load, an injury will occur. If there is balance between the load and the tissue, there will be no injury (Bertelsen et al., 2017). However, there are other factors that may influence running mechanics such as hip weakness, hip and trunk motion control, nutrition, physiological characteristics, and psychological perspective of running. These factors may influence the mechanics of running but do not cause the injury to occur. Injury occurrence is due to the biomechanical deficit between the load applied and the tissues inability to match the load demand and repair the damage (Bertelsen et al., 2017).

Muscular Strength and Endurance Factors

Strength is the ability to perform a movement for longer durations at high intensities (Dierks et al., 2008; Ferber & Pohl, 2011; Madeley, Munteanu, & Bonanno, 2007; Ryan et al., 2006). Adequate muscle strength and endurance of the leg muscles has been hypothesized as being necessary to absorb biomechanical force and protect the tibia from excessive shock during athletic activities (Ferber & Pohl, 2011; Madeley et al., 2007). For endurance runners, strength is needed to be able to push off the ground, maintain pace, and control muscles concentrically and eccentrically (Christina et al., 2001; Madeley et al., 2007; Rosager et al., 2002). Strength in the lower extremity muscles allow for increased mileage without reaching exhaustion, the capability to control muscles and load distribution across the joints and structures (Hobara et al., 2010; Madeley et al., 2007; Ryan et al., 2006). The gastrocnemius-soleus complex (G-S complex), tibialis anterior, tibialis posterior, and hip adductors/abductors have an effect on the biomechanics and injury risk of endurance runners (Dierks et al., 2008; Ferber & Pohl, 2011; Madeley et al., 2007; Rosager et al., 2002).

Trunk Muscle Function

The trunk and hip motion during running occurs in a coupling fashion (Teng & Powers, 2015) . If there is excessive motion at the trunk and the pelvis, the femoral internal rotation and adduction increases during the stance phase, increasing the load of the lower extremity, leading to EMTP over time (Verrelst et al., 2014c; Verrelst, 2013). Trunk weakness reduces the ability to control the hip and trunk, making runners more vulnerable to large external forces on the lower extremities (Ford et al., 2013; Teng & Powers, 2015). This may lead to excessive motion in the hip or trunk, permitting the entire kinetic chain to move into positions frequently associated with overuse injuries such as femoral adduction and internal rotation (Ford et al., 2013; Teng & Powers, 2015).

The trunk muscle function can affect the moment distribution among the lower extremity joints during weight bearing activities and constitutes about 50% of the total body mass (Ford et al. 2013; Teng & Powers 2015). Weakness in the core and the trunk muscles increases the accessory movement if the thorax and the hips, which could be caused by impaired neuromuscular control (Ford et al., 2013; Teng & Powers 2015). If this occurs, the ability to control the lower extremity motions during single leg stance movements, especially in running, will decrease, leading to excessive load placed on the tibia, resulting in EMTP (Teng & Powers 2015). Improving the lower extremity mechanics will improve the ground reaction force stabilization, increasing the gluteus maximus and gluteus medius neuromuscular efficiency during a single-leg movement, which leads to the importance of measuring and studying the relationship between hip and trunk control (Ford et al., 2013;Verrelst et al., 2014a; Verrelst, 2013).

Hip Muscle Function

The proximal segments compromise of approximately 60% of the total body mass (Teng & Powers, 2015; Verrelst et al., 2014b; Verrelst, 2013). The movement and the control of the pelvis and thorax influence the location of the total body center of gravity, ground reaction forces and energetics during running (Ford et al., 2013; Teng & Powers, 2015; Verrelst et al., 2014c). Proximal muscle weakness in the hip has been found to increase the risk of EMTP in athletes in both the transverse and frontal plane (Verrelst et al., 2014a; Verrelst, 2013). Hip abductors play an important role in the alignment of then femur thus the entire kinetic chain because they stabilize the hip and prevent excessive movement during single leg stance (Ford et al., 2013; Steinberg et al., 2017; Verrelst, 2013). Weakness in the hip abductors and hip extensors cause increased trunk and pelvis instability, increased movement, and increased load on the lower extremity (Ford et al., 2013; Teng & Powers, 2015; Verrelst, 2013). This weakness increases the external forces on the hip and the trunk, leading to increased loading on the lower extremity. The deficit in the hip abductor, extensor and external rotator strength increases the external load on the lower extremity structures during running and compromises the ability to protect the bone against the excessive loads. Continuous, excessive loads increases the risk of EMTP over time (Verrelst et al., 2014a; Verrelst et al., 2014b; Verrelst et al., 2014c; Verrelst, 2013).

Dynamic joint control can be defined as the ability of the joint to maintain position during a particular movement (Teng & Powers, 2015; Verrelst et al., 2014a). Without the proper function and control of the joint, there is increased accessory movement that may result in altered proximal-to-distal movement in the lower extremities, placing more load on the lower leg (Ford et al., 2013; Steinberg et al., 2017; Teng & Powers, 2015). EMTP is associated with instability and improper function of the lower leg muscles due to compensation through excessive eccentric activity (Verrelst et al., 2014c; Verrelst, 2013). The excessive hip movement and motion is linked to hip strength because the muscles cannot withstand the load and force during a single leg stance (Teng & Powers, 2015; Verrelst et al., 2014a). The decreased function of the hip muscles results in higher vertical ground reaction forces during single leg landings, especially in running (Ford et al., 2013; Steinberg et al., 2017; Verrelst et al., 2014b; Yagi et al., 2013). The impaired function of the hip complex increases the accessory movements throughout the lower extremity kinetic chain, leading to impaired neuromuscular control, and impaired ability to control trunk and hip motion, leading to the development of EMTP (Ford et al., 2013; Teng & Powers, 2015; Verrelst et al., 2014b; Verrelst, 2013). Without the proper function of the hip abductors, the entire kinetic chain modifies their action and motions to compensate for the deficit, resulting in increased risk of overuse injuries (Ford et al., 2013; Verrelst et al., 2014b; Yagi et al., 2013).

Knowledge Gap

Even though there has been a strong breakthrough in the literature of EMTP, there are still gaps that need to be filled (Verrelst et al., 2014a; Verrelst et al., 2014b; Verrelst et al., 2014c; Verrelst, 2013). The area that has been selected for this study is the relationship between hip strength and trunk and hip angular kinematics in runners who have a history of EMTP (Teng & Powers, 2015; Verrelst et al., 2014a; Verrelst et al., 2014b; Verrelst et al., 2014c; Verrelst, 2013). Another gap in literature relating to EMTP is the population of the participants that have been studied. There is limited research on competitive runners or those who are training for races. Because of this, it is important to determine the risk of competitive runners and the occurrence of EMTP. In order to continue to answer the gaps presented in previous research, the next step is to measure the hip and trunk motion, hip strength, and hip angular excursion in competitive runners between those who have sustained a RRI such as EMTP to those who have not sustained an injury to see if there are significant differences.

Chapter III: Methods

Design and Setting

This research used a cross sectional case control design to identify any differences in kinematic and kinetic measures between competitive runners with a history of EMTP and healthy controls. All of the data collection was performed at the University of Wisconsin-Milwaukee Musculoskeletal Injury Biomechanics Research Laboratory.

Instrumentation

Hip abduction, hip external rotation, and hip extension strength were assessed with a handheld dynamometer (Lafayette's model 01165). The device recorded the peak force and the time required to achieve maximal muscle contraction providing reliable, accurate, and stable muscle strength measurements (Bazett-Jones, Cobb, Cashin, & Earl-Boehm, 2011). Stabilization straps were used for stability, maintaining body position, and allowing for maximal force to be achieved. A standard treadmill (Precor) was used for proper warm up and cool down. The three-dimensional marker trajectories were collected using Cortex (Motion Analysis Corporation, Santa Rosa, Ca) motion analysis system with 10 digital cameras (Eagle cameras; Motion Analysis Corporation). The video was collected at the standard 200 Hz and the calibration based on the manufacturer's recommendation and previous studies in the lab. Ground reaction force data was obtained at a rate of 1000 Hz using a single force plate (AMTI, Newton MA). Marker and ground reaction force data were further processed and analyzed using the Visual 3-D software (Visual 3D, C-Motion, Germantown, MD).

Participants

Participants were placed in two different groups depending on their past medical history. The EMTP group were those who had a history of EMTP and the control group were those who are not-injured and had never experienced EMTP. The participants were recruited from local races, running clubs, local fitness centers, and the university by direct contact with the study personnel or via flyers outlining the study.

The participants in the study were female competitive runners between the ages of 18-45 because the most common age of participants in races were within this age group (Kuhman et. al. 2016; Mann et. al. 2015). The age was determined based on practicality of where to get participants since the research was done on a college campus. Only females were studied because of the higher incidence of EMTP in females compared to males (Butler et. al. 2003; Zadpoor & Nikooyan 2011). Individuals over the age of 45 were excluded from the study to control for the possible effects of overt degenerative joint disease. Competitive, female, long distance runners were chosen for the study because there was a gap in research when looking at this group and EMTP. Competitive runners were considered those who were training for a race whether it is a marathon, half marathon, 10k race, triathlon related races, Tough Mudder, an ultramarathon or any related races. All participants were training for one of the selected races and planned on running the race within 6 months.

To be included in the study for the EMTP group, participants had a history of either medial tibial stress syndrome, tibial stress fracture, or chronic exertional compartment syndrome within the past 24 months. The symptoms relating to EMTP lasted a minimum of 3 weeks; however, they were pain free at the time of testing. The EMTP group was cleared by a Physician or self-cleared to participate in running and were currently training for a 10k, half marathon, full marathon, triathlon, ultramarathon, tough mudder, or spartan race. Exclusion from the study included currently experiencing another musculoskeletal or neurological condition affecting the lower extremity or having a history of patellofemoral pain or iliotibial band syndrome. Those who were not currently fully cleared to participate in regular training or currently experiencing pain during running were also excluded from the study. Participants were also excluded from the study if they had a previous lower extremity fracture or surgery and if they were currently pregnant.

To be included in the study for the control group, participants did not have any history of EMTP and were free of any pain during testing. They did not have any medical history of patellofemoral pain or iliotibial band syndrome. The control group did not have any acute, insidious, or non-running related injury or back injuries or disorders such as scoliosis, spondylitis, spondylosis, or a herniated disk. Exclusion criteria included musculoskeletal or neurological conditions that affected the lower extremity, not fully cleared to participate in regular running, had a previous lower extremity fracture or surgery, currently experiencing pain during running, or if they were currently pregnant. All participants were pre-screened through a phone interview performed by a certified athletic trainer to determine if they were eligible for participation. After all participants were asked whether they had experienced EMTP or not, further follow up was performed by the certified athletic trainer. Identification of injury was determined by the certified athletic trainer based on her experience and knowledge in injury diagnosis. On the first day of testing, participation eligibility was assessed again to ensure all requirements were met.

Table 1: Exertional Medial Tibial Pain Group Inclusion/ Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
• Female Sex (Self- Identified) • 18-45 years old • Competitive Runners (Training for a 10K, Half Marathon, Full Marathon, Triathlon, or any other distance running event. • Training to Compete in an event within the upcoming 6 months • History of Exertional Medial Tibial Pain (e.g. medial tibial stress syndrome, “shin splints,” tibial stress fracture, chronic exertional compartment syndrome) • Symptoms lasted a minimum of 3 weeks • Symptoms occurred within the last 24 months • Currently pain free during running and having no training restrictions	• Currently experiencing another musculoskeletal or neurological condition affecting the lower extremity • History of patellofemoral pain or iliotibial band syndrome • Currently not fully cleared to participate in regular training • Previous lower extremity fracture or surgery • Currently experiencing pain during running • Pregnancy

Table 2: Control Group Inclusion/ Exclusion Criteria

Inclusion Criteria	Exclusion Criteria
• Female Sex (Self- Identified) • 18-45 years old • Competitive Runners (Training for a 10K, Half Marathon, Full Marathon, Triathlon, or any other distance running event. • Training to Compete in an event within the upcoming 6 months • No medical history of Exertional Medial Tibial Pain, patellofemoral pain, or iliotibial band syndrome.	• Currently experiencing a musculoskeletal or neurological condition affecting the lower extremity • Currently not fully cleared to participate in regular training • Previous lower extremity fracture or surgery • Currently experiencing pain during running • Pregnancy

A statistical power analysis was performed to determine the sample size needed to measure all variables (Ford et al. 2013; Hobara et al., 2010; Kulmala et al., 2013; Lilley et al., 2011; Teng & Powers 2014 Lilley et al., 2011). The power analysis was based on the angles and strength results from previous studies (Ford et al. 2013; Hobara et al., 2010; Kulmala et al., 2013; Lilley et al., 2011; Teng & Powers 2014 Lilley et al., 2011). Based on the effect sizes of all variables being measured in the current study, power of 0.80 and alpha of 0.05, the sample size for this study was a total of N= 20 participants (GPower 3.1). This put 10 in the EMTP group and 10 in the control group. The total sample size of N>20 was recruited to allow for possible attrition with +1 for the control group in case of inaccurate data collected. For the demographic and perspective of running questionnaires, no power analysis was performed because the results were used for secondary measures to find trends.

Protocol

Prior to data collection, the participants came into the lab and were informed about the study, any possible risks, benefits they obtained, and understanding that they could withdraw from the study at any time. Informed consent was obtained from each participant in writing in accordance with the protocol approved by the Institutional Review Board.

Demographic Data

After the participants signed the informed consent, they completed demographic questionnaires. All questions used in the demographic questionnaire were taken from other scales that were used in previous studies (Carmack et al. 1979; Cobb et. al. 2007; Jelvegard et al. 2016; Masters & Ogles, 1998; Nieves et. al. 2010; Stephan et al. 2009; Summers et al. 1983; Thein-Nissenbaum et al. 2012). The information collected about the demographic of the participants were used as a secondary aim during the data analysis to explain the results found during data collection.

The participants filled out a Commitment to Running Scale-11 and Running Addiction Scale-8 that determined the commitment towards and the dependence upon running (Zarauz & Ruiz-Juan, 2011). The Commitment to Running Scale contained 11 items for measuring commitment. Responses were collected through a Likert scale from 1 (completely disagreed) to 5 (completely agreed) with a minimum score of 11 and a maximum score of 55. The higher the score, the more committed to running the participant showed (Zarauz & Ruiz-Juan, 2011). The Running Addiction Scale-8 contained 8 items for measuring negative addiction to running. The results from the scale were collected with a Likert scale from 1 (completely disagreed) to 7 (completely agreed) with a minimum score of 11 and a maximum score of 56. The higher the score, the more negative addiction to running the participant experienced (Zarauz & Ruiz-Juan 2011).

Hip Strength

Following completion of the questionnaires, participants performed a 5-minute warm up run on the treadmill at a self-selected speed. Foot strike pattern were determined by 2-D video analysis during the warm-up period on the treadmill. Foot strike was observed and recorded by the tester who was a certified athletic trainer and had experience and knowledge about gait analysis by slowing the video down and looking at the strike pattern. After the warm up, strength testing with the handheld dynamometer was performed. Strength testing used handheld dynamometry (HHD) has previously demonstrated excellent reliability (Bazett-Jones et al., 2011; Thorborg, Petersen, Magnusson, and Hölmich 2010). Hip abductor strength was assessed in the side-lying position while being strapped to the treatment table for more stability. Hip external rotation was assessed in the prone position with the knee flexed to 90 degrees and the strap facing outwards with resistance held by the examiner. Hip extension was assessed with the participant prone while the strap was placed around the gluteus complex to prevent the hip from rising off the table. Participants were instructed to contract maximally for three to seven seconds and were given standardized verbal encouragement to reach maximal contractions (Thorborg et al., 2010). Participants were given one practice trial and 3 reps to reduce a possible learning effect. The highest value of the 3 consecutive measures and the mean of the three highest values were recorded. The participants were given a one-minute rest interval between each test and between each muscle group to avoid a decline in strength across the trials due to fatigue (Thorborg et al., 2010).

Running

After the strength testing was performed, markers and clusters were placed on the participant. To obtain a standing model, reflective markers were placed on the trunk (right and left AC joint, sternum, cervical spine, and thoracic spine), pelvis (ASIS, PSIS, right and left iliac crest), femur (left and right greater trochanter and medial and lateral femoral epicondyle), right and left malleoli, and the 1st and 5th metatarsal heads bilaterally. Clusters were placed on the heel, thigh and shank (Bazett-Jones et al., 2013). The reflective markers were used to calculate three-dimensional kinematic variables relative to the global coordinate system during the running protocol. After calibration was set, the R/L iliac crest, R/L greater trochanter, M/L femoral epicondyle, M/L malleoli, and the 1st and 5th metatarsal markers were removed to allow for proper running gait (Bazett-Jones et al., 2013).

The participant ran across the platform at a 4.0-4.5 m/s pace while making contact with the force plate for 5-8 successful trials (Bazett-Jones et al., 2013). Speed was monitored with photocells that were placed 3.7 m and 2.1 m before and after the force plate (Model 2T35; Radio Shack Corporation, Fort Worth, TX). To calculate the preferred running speed, a custom program (LabView; National Instruments Corp., Austin, TX) was used to determine if preferred running speed was achieved (Bazett-Jones et al., 2013). Before the data was collected, the participant established the proper running distance so contact with the force plate occurred every time. The participant was encouraged to run without changing gait during every trial (Bazett-Jones et al., 2013). After 3-5 consecutive practice trials were successful, the starting location was marked, for reference, and data collection began. A successful trial occurred when the symptomatic leg struck the force plate with the entire foot within normal strides for the EMTP group and the non-dominate leg struck the force plate with the entire foot within normal strides for the control group. The non-dominate leg was considered the leg that the participant would plant with when kicking a ball. The reason for choosing the non-dominate leg was because of the possibility that it was the weaker of the two and possibly had a higher effect on the kinematic and kinetic variables. After 5-8 successful trials were performed, the clusters and the markers were removed and the participant performed a 5-minute recovery run on the treadmill at a self-selected speed (Bazett-Jones et al., 2013).

Data Analysis

The kinematic and kinetic data were processed and analyzed using Visual 3D software. Marker trajectories were filtered at a cutoff frequency of 12 Hz, low-pass fourth order Butterworth filter. When the GRF signal rose above 20 N, it was defined as heel strike. When the GRF signal dropped below 20 N, it was defined as toe off. Stance phase was defined as the time between heel strike and toe off, when the foot was in full contact with the force plate (Earl and Hoch 2010). Calculation of hip, knee, and ankle joint angles were done using a joint coordinate system approach (Grood & Suntay, 1983). Joint kinematics were calculated using Cardan angles and the local coordinate systems of the trunk, pelvis, thigh, shank, and foot segments were derived from the standing calibration trial taken before the running session. Joint angles of the hip and knee were determined by the relative position of the pelvis, thigh, and shank segments, respectively. Trunk angle was determined relative to the global reference frame. Angular excursion were calculated by finding the difference between the maximal and minimal joint angle during the stance phase in all three planes. Angular excursion was used over peak angles because it allowed us to obtain an average range of motion throughout the entire running cycle instead of an instant point. The kinematic measures were extracted for each trial were hip adduction and internal rotation excursion, and trunk flexion and lateral lean excursion. The average of all three running trials for the angular excursions throughout the stance phase were used for analysis.

Statistical Analysis

The SPSS software was used to analyze the data and determine if there was statistical significance. The independent variables were the two groups: EMTP and control. The dependent variables were kinematics: hip internal rotation and adduction excursion, trunk flexion and lateral lean excursion, and hip extension, abduction and external rotation strength. A t-test was used to analyze the data and determine if there was statistical significance. Participants were matched for age, mileage, training factors, and weight between the EMTP group and the control group during statistical analysis. An alpha level of 0.05 was used to determine statistical significance.

Chapter IV: Results

Participant Characteristics

Based on the effect sizes of all variables being measured in the current study, power of 0.80 and alpha of 0.05, the sample size for this study was a total of N= 20 participants (GPower 3.1). This put 10 in the EMTP group and 10 in the control group. A t-test was performed to confirm that there was no difference in age (p=0.698), training mileage (p=0.821), height (p=0.399), and weight (p=0.718) between groups. Details of the analysis are located in Table 3.

Table 3: Participant Characteristics Statistical Analysis

	Mean and Standard Deviation		t	df	p
	EMTP	CON			
Age (yrs.)	27.3 ± 7.2	28.4 ± 5.5	0.4	19	0.7
Training Mileage (mi/wk.)	19.8	20.8	0.2	19	0.8
Weight (kg)	65.4 ± 5.1	63.9 ± 10.8	-0.4	19	0.7
Height (cm)	173.1 ± 7.6	170.2 ± 7.1	-0.9	19	0.4

Hip Strength

The results from this study show that there was no significant differences between those with a history of EMTP and healthy controls in hip abduction (p=0.913), hip external rotation (p=0.125), and hip extension (p=0.308). Details of the analysis are located in Table 4.

Table 4: Hip Strength Statistical Analysis

	Mean and Standard Deviation		t	df	p
	EMTP	CON			
Hip Abduction	36.2 ± 10.8	36.7 ± 8.3	0.1	19	0.9
Hip Extension	42.4 ± 14.0	37.1 ± 7.7	-1.1	19	0.3
Hip External Rotation	10.8 ± 2.2	9.5 ± 1.0	-1.6	19	0.1

Hip and Trunk Excursion

Likewise, there were no significant differences in hip adduction ROM excursion (p= 0.711), hip internal rotation excursion (p=0.998) and trunk flexion ROM excursion (p=0.559) and trunk lateral lean ROM excursion (p= 0.559) between those with a history of EMTP and healthy control. Details of the analysis are located in Table 5.

Table 5: Hip and Trunk Kinematic Data Analysis

	Mean and Standard Deviation		t	df	p
	EMTP	CON			
Hip Adduction ROM	12.7° ± 6.9°	11.8° ± 3.6°	-0.4	19	0.7
Hip Internal Rotation ROM	7.2° ± 3.4°	7.2° ± 4.3°	-0.003	19	0.9
Trunk Flexion ROM	3.3° ± 1.7°	2.8° ± 1.8°	-0.8	19	0.6
Trunk Lateral Lean ROM	2.9° ± 1.6°	2.3° ± 1.7°	0.9	19	0.5

Demographic Questionnaire

Details of the results of the demographic questionnaire can be found in Tables 6-10, and key information is highlighted in this paragraph. Based on the demographic background questionnaire, more of the participants with a history of EMTP were training for a full marathon (40%), whereas more of those in the healthy control group were training for a half marathon (45.5%) (Table 7). The EMTP group found running more enjoyable and were more eager to run (50%) compared to the healthy control group (27.3%) (Table 10). In the EMTP group, the reason for starting to run was because they had more of a desire to run a race. Those who were in the EMTP group also showed an irregular menstruation (80%) with a large portion of them taking birth control to control their irregular menstruation (70%) compared to the control group who have a regular menstruation (90.9%.) and less likely to take birth control (36.4%) (Table 8). The healthy control group stated that they were more willing to go a day without running when they were asked “If there were another way to maintain my current fitness level, I would never run again”, and “ I have stopped running for at least a week for other reasons than having an injury” compared to the EMTP group. The healthy control also showed not having any remorse for missing a run (72.8%) compared to the EMTP group (40%) when asked “To go a day without running is a relief for me” (Table 10). The healthy control group reported participating in more races and had more experience in how to train for races compared to the EMTP group. The healthy control were involved in more years of running with 45.5% of them running for more than 5 years compared to the EMTP group where 20% had been running for more than 5 years (Table 7). The healthy control ran in more races with 45.5% of the them participating in more than 10 races whereas the EMTP group the majority of them (60%) had only participated in less than 5 races (Table 7).

Table 6: Medical History of EMTP Group	
Question	EMTP
When did your leg pain occur?	0-3 Months- 30% 4-6 Months- 10% 7-9 Months- 10% 19-21 Months-10% 22-24 Months-40%
Did you see a medical provider for your shin pain?	Yes- 30% No-70%
What was your diagnosis?	Shin Splints- 4 Stress Fracture-2 Not Stated/ Undiagnosed- 4
How long were you limited in your running or training?	1-3 Weeks- 50% 4-6 Weeks- 30% >12 Weeks- 10% Not At All- 10%
Did you receive any treatment for injury? - Selected Choice	Ice/ Heat- 8 Medications- 4 Rehabilitation- 1
How long did symptoms persist?	<1 Month- 50% 1-3 Months-20% 4-6 Months- 10% >12 Months- 10%

Table 7: Self-Reported Training and Exercise Data		
Question	EMTP	CONTROL
What kind of running event are you training for?	Full Marathon- 40% Half Marathon- 30% Triathlon-20% 10K-10%	Half Marathon 45.5% 10K-27.3% Full Marathon-18.2% Triathlon- 9.1%
How many miles/ weeks do you run on average?	18.6	20.8
How many days/ week do you run on average?	4.1	4.2
How many years have you been involved in running?	1-5 Years- 80% >5 Years- 20% < 1 Year-0.0%	1-5 Years- 54.5% >5 Years- 45.5% < 1 Year-0.0%
What made you start running? (Multiple Select)	Desire to Run a Race- 7 Physical Fitness- 6 Feel Better- 6 Feeling of Achievement-5 Provide a Challenge- 5 Enjoyment- 5 Mental Health- 1 Retired T/F Athlete-1	Physical Fitness- 7 Feeling of Achievement-5 Feel Better- 5 Enjoyment- 3 Desire to Run a Race- 3 Provide a Challenge- 2 Weight Control- 1
Where do you spend most of your time running? (Multiple Select)	Asphalt- 9 Trail- 6 Treadmill- 3 Track-1	Asphalt- 9 Trail- 2 Treadmill-3 Soccer Field-1
How many races have you participated in?	< 5 Races-60% 5-10 Races- 20% > 10 Races-20%	5-10 Races- 54.5% > 10 Races-45.5% < 5 Races- 0.0%
Do you participate in any other forms of exercise? (Multiple Select)	Strength Training-7 Yoga- 5 Cycling- 4 Stair Stepper- 4 Cross Fit- 2 Elliptical-2 Swimming- 1 Pilates-1	Cycling- 7 Strength Training-7 Swimming- 4 Yoga- 4 Pilates-1 Stair Stepper- 1 Soccer- 1 Elliptical-1 Body Pump-1
Do you run/ train with anyone else or do you train by yourself? (Multiple Select)	Self- 9 Friend- 4 Family Member- 3 Co-Worker- 2 Recreational Running Club- 1	Self- 9 Friend- 6 Significant Other- 3 Family Member- 1 Recreational Running Club- 1
Are you a member of any running clubs/ groups?	Yes- 50% No- 50%	Yes-45.5% No- 54.4%
Running Style	Rearfoot-100% Forefoot-0.0% Midfoot-0.0%	Rearfoot-63.6% Forefoot-27.2% Midfoot-9.1%

Table 8: Self-Reported Nutritional and Hormonal Data								
Question	EMTP				CONTROL			
	Yes	No			Yes	No		
Do you have regular, monthly menstruation?	20.0%	80.0%			90.9%	9.1%		
Are you taking birth control?	70%	30.0%			36.4%	63.6%		
Do you take any supplements such as vitamins or protein powder?	60.0%	40.0%			45.5%	54.5%		
	Always	Sometimes	Never	I Don’t Know	Always	Sometimes	Never	I Don’t Know
Do you pay close attention to what food you are putting in your body and/ or restrict yourself from certain foods because of training/ running?	20%	70%	10%	0.0%	0.00%	90.9%	18.2%	0.00%
Do you consume enough calories for the number of miles you put in every day?	70.0%	30.0%	0.0%	0.0%	45.5%	54.5%	0.00%	18.2%

Table 9: Self-Reported Sociological Data								
	EMTP				CONTROL			
	Never	Sometimes	Always	I Don’t Know	Never	Sometimes	Always	I Don't Know
Has running put any strain on relationships?	90%	10%	0.0%	0.0%	90.9%	18.2%	0.0%	0.0%
Do family members and friends support your races/ training?	0.00%	0.0%	100%	0.0%	0.0%	18.2%	90.9%	0.0%

Table 10: Commitment to Running and Addiction to Running Results for EMTP and Control Group		
	EMTP	CONTROL
Commitment to Running (CR)	35.3 ± 4.5	35.2 ± 3.8
Addiction to Running (RAS)	31.8 ± 5.5	32.1 ± 4.0

Chapter V: Manuscript

Investigating Hip and Trunk Kinematic and Strength Differences Between Those with a History of Exertional Medial Tibial Pain and Healthy Controls

Hocking, A.H., Ericksen, H.M., O'Connor, K.M., Earl-Boehm, J.E.

Introduction

Running has become a highly popular form of physical activity in the general population because it is easily accessible, requires little to no equipment, and is very cost effective (Dudley, R. I., Pamukoff, D. N., Lynn, S. K., Kersey, R. D., & Noffal, G. J. 2017). Even though running is considered a health promoting behavior, those who are competitive runners have a 37-70% increased risk of sustaining an injury (Stephan et al., 2009) and 80% of those injuries are said to be overuse injuries (van der Worp et al. 2015). Over the past couple of years, participation in recreational and competitive running, resulting in an increased risk of sustaining a running related injury (Dudley et al., 2017; van der Worp et al., 2015). Running related injuries (RRI) have been found to occur with relatively high frequency among competitive recreational runners with 30% of competitive runners developing a RRI annually (Hamill et al., 2014; Hreljac et al., 2000; Mucha et al., 2017; Ryan et al., 2006). Females have been found to be at the greatest risk of sustaining a running related injury because of factors such as anatomical structure and biomechanics, and that females are more likely to participate in running activities (Hamill et al., 2014; Hreljac et al., 2000; Mucha et al., 2017; Ryan et al., 2006). Injury occurrence is about 6.8 to 59 injuries per 1,000 hours of running exposure, making it problematic for those who are training for a long distance race such as a half marathon, full marathon or ultramarathon (Hespanhol et al., 2013). The increased occurrence becomes problematic because it can lead to lead to a decrease of continued activity, increased mood disturbances and uncertainty, and possible drop out of participation all together (Hamill et al., 2014; Hespanhol et al., 2013;

Hreljac et al., 2000; Mucha, Caldwell, Schlueter, Walters, & Hassen, 2017; Zadpoor & Nikooyan, 2011).

Running related injuries are considered overuse injuries that occur after repetitive bouts of continuous exposure to mechanical loading and impact force to the bone, tissue, and ligaments (Daoud et al., 2012; Hamill, Gruber, & Derrick, 2014; Heiderscheit, Chumanov, Michalski, Wille, & Ryan, 2011). Progressively, the biomechanical stress placed on the musculoskeletal system becomes too high and with limited recovery time, the musculoskeletal system cannot adapt and repair the damage, resulting in injury (Daoud et al., 2012; Hamill et al., 2014; Heiderscheit, 2011; Hreljac et al., 2000). In order to accurately examine the multifactorial nature of running related injuries, a conceptual framework describing the interrelationships between biomechanical loading and the factors that influence that loading has been developed by Bertelsen and colleagues. (Bertelsen et al., 2017) (Figure 2).

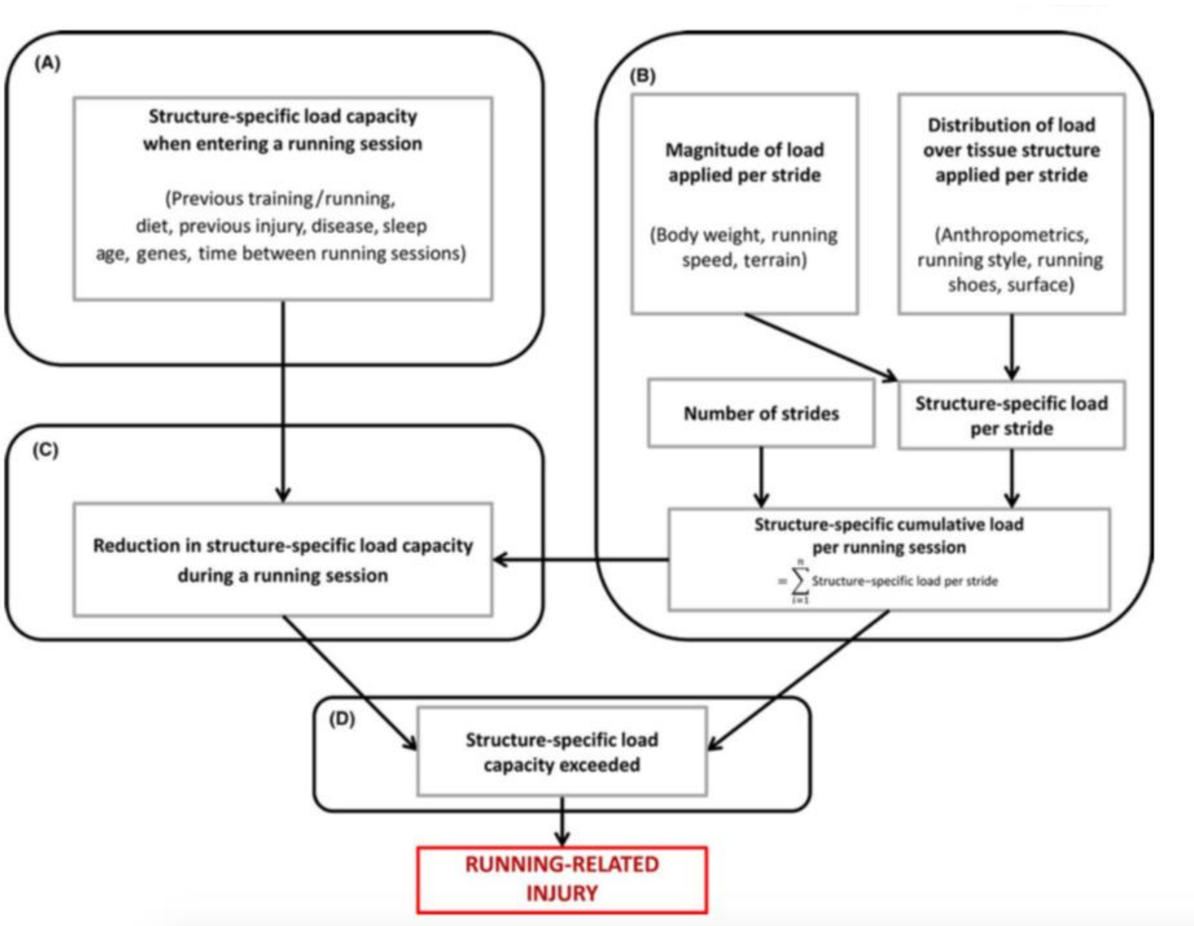

Figure 2: A conceptual framework model for the causal mechanism of running related injuries in a single session of a running bout. Box A represents the structure-specific load capacity of all the variables that can affect the risk of running related injuries outside or prior to a run. Box B represents the structure specific cumulative load per session during the run that can affect the risk of running related injuries. The equation determines the amount of load per stride that can affect injury risk. Box C represents adaptation of continuous running and the reduction of load placed on the body over time. Box D represents the relationship between load and load capacity and what happens when the load capacity exceeds limits.

The four-part conceptual framework is broken up into: 1) structure specific capacity when entering a running session, 2) structure-specific cumulative load per running session, 3) reduction in the structure specific capacity during a running session and how injury results when the structure specific activity is exceeded (Bertelsen et al., 2017). Running related injuries occur from a combination of not only biomechanical factors such as stride, magnitude of load, distribution of load, and load capacity, but also other factors which directly or indirectly influence the biomechanical factors. Thus in additional to exploring the biomechanics of runners who are injured, it is important to explore other factors that may have influenced their susceptibility to ultimately sustain tissue damage.

Exertional Medial Tibial Pain (EMTP) is a broad category that exclusively characterizes overuse injuries that are seen in runners (Verrelst et al., 2014a; Verrelst et al., 2014b; Verrelst et al., 2014c; Verrelst, 2013). EMTP is characterized as pain along the posterior and medial portion of the lower leg that is caused by activity which can be considered stress fractures, medial tibial stress syndrome, chronic exertional compartment syndrome, and muscular and tendon injuries (Verrelst et al., 2014a; Verrelst et al., 2014b). Recent prospective studies have found that dynamic joint control, abductor strength, external rotation of the hip, and trunk control all play a role in the development of EMTP (Verrelst et al., 2014a; Verrelst et al., 2014b; Verrelst et al., 2014c; Verrelst, 2013). Verrelst et al. (2014a; 2014b; 2014c) found that hip abductor concentric weakness and external rotation weakness is a significant predictor of the development of EMTP (Verrelst et al., 2014a; Verrelst et al., 2014b; Verrelst et al., 2014c; Verrelst, 2013). The hip abductors assist to stabilize the hip and the pelvis, especially in single leg movements. Decreased hip strength and whole-body fatigue can lead to unwanted movement of the trunk and the pelvis, resulting in an increased risk of developing EMTP (Verrelst et al., 2014a; Verrelst et al., 2014c; Verrelst, 2013). Teng and Powers (2015) found that small changes in trunk position may influence the mechanical demand that is placed on the lower extremities but there cannot be a direct causal relationship determined between trunk posture and injury (Teng & Powers, 2015b). Ford et al. (2013) found that hip strength decreases thorax and pelvic motion increases, resulting in poor lower extremity biomechanics and neuromuscular efficiency.

While there has been some investigation into the effects of hip strength and trunk motion, there is currently no study that looks at the role of hip and trunk range of motion excursion simultaneously and within competitive runners. There is also limited information on hip strength in female competitive runners. To ultimately reduce the risk of sustaining an overuse injury such as EMTP, it is vital to measure hip strength and running kinematics, but also explore other factors which may influence the loading (e.g. sociological, psychological, physiological, training, and nutrition) and their relationship with EMTP in competitive females. Therefore, the purpose of this study was to investigate differences in hip strength, hip kinematics and trunk kinematics during running between female competitive runners with a previous history of EMTP and healthy controls, and to explore the nutritional, psychological, sociological, physiological and training, nutritional factors that may differ between those with a history of EMTP compared to healthy.

Methods

Twenty-one competitive female runners who were training for a mid-distance race (10K, half marathon, full marathon or triathlon) participated in the study and were placed in two different groups depending on their past medical history: EMTP or control. The EMTP group (N= 10) were those who had a history of EMTP (N= 10, age= 27.2± 6.8 yrs., weight= 65.8± 5.01kg, height= 173.2± 7.2 cm, and training mileage= 19.8±9.5 mi/wk.). Participants were free of pain with no training restrictions and had to have experienced shin splints, chronic compartment syndrome, medial tibial stress syndrome, or stress fractures within the past 2 years for a length of at least 3 weeks. The control group (N=11) were not-injured and had never experienced EMTP (N=11, age= 28.5±5.5 yrs., weight= 63.9±10.8 kg, height= 170.2±7.1 cm, and training mileage=20.8±10.1 mi/wk.). Control group participants were pain free, and had no medical history of EMTP, surgery or fracture, patellofemoral pain, or iliotibial band syndrome.

Instrumentation

Hip abductor, external rotation, and extension strength were measured with a handheld dynamometer (Lafayette's model 01165) and stabilization straps were used to maintain body position and provide stability. A standard treadmill (Precor) was used for proper warm up and cool down before data collection. The motion analysis data was collected using Cortex (Motion Analysis Corporation, Santa Rosa, Ca) motion analysis system with 10 digital cameras (Eagle cameras; Motion Analysis Corporation) at the standard 200 Hz and the system was calibrated based on the manufacturer's recommendation. Running trial data was collected and synchronized using a motion capturing software (Visual 3D, C-Motion, Germantown, MD). Ground reaction force data was obtained at a rate of 1000 Hz using a single force plate (AMTI, Newton MA).

Procedure

Participants reported to the biomechanics lab for one testing session. After consenting to participate, the participants filled out a demographic questionnaire, Commitment to Running Scale-11 (Zarauz-Sancho & Ruiz-Juan, 2011), and Running Addiction Scale-8 (Zarauz-Sancho & Ruiz-Juan, 2011). These questionnaires were used to explore various sociological and psychological factors of the participants. Participants then warmed up on the treadmill at a self-selected speed for 5 minutes while the researcher recorded foot strike pattern using Hudl Technique application (Hudl Incorporation, Des Moines, IA). Following proper warm up, the demographic data such as height (cm), weight (kg), and age (yrs.) was recorded. All participants were asked if they were experiencing pain before testing occurred. If any participant was experiencing pain during the time of testing, data collection was terminated. For the EMTP group, the most painful leg at the time of injury was used as the test leg, and for the control group, the test leg was the leg that they would stand on to kick a soccer ball.

Hip abductor, external rotation, and extension strength was recorded using a handheld dynamometer following the protocol of Lee & Powers (2013). Two warm up trials of 50% and 75% effort were performed followed by three trials of maximal effort (Lee & Powers, 2013). Hip abductor strength was assessed in the side-lying position while being strapped to the treatment table for more stability (Lee & Powers, 2013). Hip external rotation was assessed in the prone position with the knee flexed to 90 degrees and the strap facing outwards with resistance held by the examiner (Lee & Powers, 2013). Hip extension was assessed with the participant prone while the strap was placed around the gluteus complex to prevent the hip from rising off the table. Participants were given one practice trial and 3 reps to reduce a possible learning effect (Lee & Powers, 2013). The highest value of the 3 consecutive measures and the mean of the three highest values were recorded. The participants were given a one-minute rest interval between each test and between each muscle group to avoid a decline in strength across the trials due to fatigue (Lee & Powers, 2013).

Following the strength testing, individual reflective markers and rigid clusters were placed on the participant for 3-D kinematic data collection. A standing trial was recorded with reflective markers placed on the trunk (right and left acromioclavicular joint, sternum, cervical spine, and thoracic spine), pelvis (anterior superior iliac spine (ASIS), posterior superior iliac spine (PSIS), right and left iliac crest), femur (left and right greater trochanter and medial and lateral femoral epicondyle), right and left malleoli, and the 1st and 5th metatarsal heads. Clusters were placed on the heel, thigh and shank. After recording the standing trial, the right and left iliac crest, right and left greater trochanter, medial and lateral femoral epicondyle, medial and lateral malleoli, and the 1st and 5th metatarsal markers were removed to allow for proper running gait. The participants were asked to run across the platform at a 4.0-4.5 m/s pace. The participant performed 3-5 practice trials followed by 3 successful trials determined by full contact of the identified leg on the force plate without changing gait pattern. Following collection of the successful trials, the clusters and the markers were removed and the participant performed a 5-minute recovery run on the treadmill at a self-selected speed.

Data Analysis

The strength data (kg) were normalized to the participants body weight for all motions and expressed as percent body weight (%BW). The kinematic data was processed and analyzed using Visual 3D software (Visual 3D, C-Motion, Germantown, MD). Marker trajectories were filtered at a cutoff frequency of 12 Hz, low-pass fourth order Butterworth filter. When the GRF signal rose above 20 N, it was defined as heel strike. When the GRF signal dropped below 20 N, it was defined as toe off. Stance phase was defined as the time between heel strike and toe off, when the foot was in full contact with the force plate (Earl and Hoch 2010). Calculation of hip, knee, and ankle joint angles were done using a joint coordinate system approach (Grood & Suntay, 1983). Joint kinematics were calculated using Cardan angles and the local coordinate systems of the trunk, pelvis, thigh, shank, and foot segments were derived from the standing calibration trial taken before the running session. Joint angles of the hip and knee were determined by the relative position of the pelvis, thigh, and shank segments, respectively. Trunk angle was determined as a segment angle relative to the global reference frame. Angular excursion was calculated by finding the difference between the maximal and minimal joint angle during the stance phase in all three planes. The kinematic measures were extracted for each trial were hip adduction and internal rotation excursion, and trunk flexion and lateral lean excursion. The average of all three running trials for the angular excursions throughout the stance phase were used for analysis. All demographic and questionnaire data were used to explored to provide insight into other factors that led to the occurrence of EMTP.

Statistical Analysis

The International Business Machine (IBM) Statistical Package for the Social Science (SPSS) (Armonk, New York) software was used to analyze the data for statistical significance. The independent variables were the two groups: EMTP and control. The dependent variables were *kinematics*: hip internal rotation, hip adduction, trunk flexion and lateral lean excursion, and *strength*: hip extension, abduction and external rotation. A t-test was used to analyze the data, and the alpha level set at 0.05 to determine statistical significance.

Results

Participant Characteristics

There were no differences in age (p=0.698), training mileage (p=0.821), height (p=0.399), and weight (p=0.718) between groups (Table 3).

Table 3: Participant Characteristics					
	Mean and Standard Deviation		t	df	p
	EMTP	CON			
Age (yrs.)	27.3 ± 7.2	28.6 ± 5.5	0.4	19	0.7
Training Mileage (mi/wk.)	19.7±10.1	20.8±10.1	0.2	19	0.8
Weight (kg)	65.4 ± 5.16	63.9 ± 10.8	-0.4	19	0.7
Height (cm)	173.1± 7.6	170.2 ± 7.1	-0.9	19	0.4

<u>Hip Strength</u>

The results showed no significant differences in normalized hip strength between those with a history of EMTP and healthy controls in hip abduction (p=0.913), hip external rotation (p=0.125), and hip extension (p=0.308) (Table 4).

Table 4: Hip Strength					
	Mean and Standard Deviation		t	df	p
	EMTP	CON			
Hip Abduction	36.2 ± 10.8	36.7 ± 8.4	0.1	19	0.9
Hip Extension	42.5 ± 14.0	37.2 ± 7.7	-1.1	19	0.3
Hip External Rotation	10.8± 2.2	9.6 ± 1.1	-1.6	19	0.1

<u>Hip and Trunk Excursion</u>

Likewise, there were no significant differences in hip adduction ROM excursion (p= 0.711), hip internal rotation excursion (p=0.998) and trunk flexion ROM excursion (p=0.559) and trunk lateral lean ROM excursion (p= 0.559) between those with a history of EMTP and healthy control (Table 5).

Table 5: Hip and Trunk Kinematic

	Mean and Standard Deviation		t	df	p
	EMTP	CON			
Hip Adduction ROM	12.7° ± 6.9°	11.8° ± 3.6°	-0.3	19	0.7
Hip Internal Rotation ROM	7.2° ± 3.3°	7.2° ± 4.3°	-0.003	19	0.9
Trunk Flexion ROM	3.3° ± 1.7°	2.8° ± 1.8°	-0.8	19	0.6
Trunk Lateral Lean ROM	2.9° ± 1.6°	2.3° ± 1.7°	0.9	19	0.5

Demographic Questionnaire

Based on the demographic background questionnaire, more of the participants with a history of EMTP were training more for a full marathon (40%), whereas more of those in the healthy control group were training for a half marathon (45.5%) (Table 7). The EMTP group found running more enjoyable and were more eager to run (50%) compared to the healthy control group (27.3%) (Table 10). In the EMTP group, the reason for starting to run was because they had more of a desire to run a race. Those who were in the EMTP group also showed an irregular menstruation (80%) with a large portion of them taking birth control to control their irregular menstruation (70%) compared to the control group who have a regular menstruation (90.9%.) and take birth control (36.4%) (Table 8). In the healthy control, 72% showed no remorse for missing a run compared to 40% in the EMTP group when asked “To go a day without running is a relief for me” (Table 10). The healthy control group reported participating in more races and had more experience in how to train for races compared to the EMTP group. The healthy control were involved in more years of running with 45.5% of them running for more than 5 years compared to the EMTP group where 20% had been running for more than 5 years (Table 7). The healthy control ran in more races with 45.5% of them participating in more than 10 races whereas the 60% of the EMTP group participated in less than 5 races (Table 7). Finally, the two groups scores appeared similar on both the Commitment to Running Scale and the Running Addiction Questionnaire.

Table 6: Medical History of EMTP Group	
Question	EMTP
When did your leg pain occur?	0-3 Months- 30% 4-6 Months- 10% 7-9 Months- 10% 19-21 Months-10% 22-24 Months-40%
Did you see a medical provider for your shin pain?	Yes- 30% No-70%
What was your diagnosis?	Shin Splints- 4 Stress Fracture-2 Not Stated/ Undiagnosed- 4
How long were you limited in your running or training?	1-3 Weeks- 50% 4-6 Weeks- 30% >12 Weeks- 10% Not At All- 10%
Did you receive any treatment for injury? - Selected Choice	Ice/ Heat- 8 Medications- 4 Rehabilitation- 1
How long did symptoms persist?	<1 Month- 50% 1-3 Months-20% 4-6 Months- 10% >12 Months- 10%

Table 7: Self-Reported Training and Exercise Data		
Question	EMTP	CONTROL
What kind of running event are you training for?	Full Marathon- 40% Half Marathon- 30% Triathlon-20% 10K-10%	Half Marathon 45.5% 10K-27.3% Full Marathon-18.2% Triathlon- 9.1%
How many miles/ week do you run on average?	18.6	20.8
How many days/ week do you run on average?	4.1	4.2
How many years have you been involved in running?	1-5 Years- 80% >5 Years- 20% < 1 Year-0.0%	1-5 Years- 54.5% >5 Years- 45.5% < 1 Year-0.0%
What made you start running? (Multiple Select)	Desire to Run a Race- 7 Physical Fitness- 6 Feel Better- 6 Feeling of Achievement-5 Provide a Challenge- 5 Enjoyment- 5 Mental Health- 1 Retired T/F Athlete-1	Physical Fitness- 7 Feeling of Achievement-5 Feel Better- 5 Enjoyment- 3 Desire to Run a Race- 3 Provide a Challenge- 2 Weight Control- 1
Where do you spend most of your time running? (Multiple Select)	Asphalt- 9 Trail- 6 Treadmill- 3 Track-1	Asphalt- 9 Trail- 2 Treadmill-3 Soccer Field-1
How many races have you participated in?	< 5 Races-60% 5-10 Races- 20% > 10 Races-20%	5-10 Races- 54.5% > 10 Races-45.5% < 5 Races- 0.0%
Do you participate in any other forms of exercise? (Multiple Select)	Strength Training-7 Yoga- 5 Cycling- 4 Stair Stepper- 4 Cross Fit- 2 Elliptical-2 Swimming- 1 Pilates-1	Cycling- 7 Strength Training-7 Swimming- 4 Yoga- 4 Pilates-1 Stair Stepper- 1 Soccer- 1 Elliptical-1 Body Pump-1
Do you run/ train with anyone else or do you train by yourself? (Multiple Select)	Self- 9 Friend- 4 Family Member- 3 Co-Worker- 2 Recreational Running Club- 1	Self- 9 Friend- 6 Significant Other- 3 Family Member- 1 Recreational Running Club- 1
Are you a member of any running clubs/ groups?	Yes- 50% No- 50%	Yes-45.5% No- 54.4%
Running Style	Rearfoot-100% Forefoot-0.0% Midfoot-0.0%	Rearfoot-63.6% Forefoot-27.2% Midfoot-9.1%

Table 8: Self-Reported Nutritional and Hormonal Data								
Question	EMTP				CONTROL			
	Yes	No			Yes	No		
Do you have regular, monthly menstruation?	20.0%	80.0%			90.9%	9.1%		
Are you taking birth control?	70%	30.0%			36.4%	63.6%		
Do you take any supplements such as vitamins or protein powder?	60.0%	40.0%			45.5%	54.5%		
	Always	Sometimes	Never	I Don't Know	Always	Sometimes	Never	I Don't Know
Do you pay close attention to what food you are putting in your body and/ or restrict yourself from certain foods because of training/ running?	20%	70%	10%	0.0%	0.00%	90.9%	18.2%	0.00%
Do you consume enough calories for the number of miles you put in every day?	70.0%	30.0%	0.0%	0.0%	45.5%	54.5%	0.00%	18.2%

Table 9: Self-Reported Sociological Data								
	EMTP				CONTROL			
	Never	Sometimes	Always	I Don't Know	Never	Sometimes	Always	I Don't Know
Has running put any strain on relationships?	90%	10%	0.0%	0.0%	90.9%	18.2%	0.0%	0.0%
Do family members and friends support your races/ training?	0.00%	0.0%	100%	0.0%	0.0%	18.2%	90.9%	0.0%

Table 10: Commitment to Running and Addiction to Running Results for EMTP and Control Group		
	EMTP	CONTROL
Commitment to Running (CR)	35.27 ± 4.54	35.27 ± 3.82
Addiction to Running (RAS)	31.83 ± 5.53	32.09 ± 4.01

Discussion

The purpose of this study was to determine if there was a difference in hip strength and hip and trunk excursion between those who have a history of EMTP and those who have never had a history of EMTP. It was hypothesized that hip strength would be weaker in those who have a history of EMTP and hip and trunk excursion would be greater in those who have a history of EMTP. Results indicate that in this group of competitive female runners there were no biomechanical differences observed between those with a history of EMTP and healthy control in either hip strength or hip and trunk motion.

Our findings do not support our hypothesis that hip and trunk kinematics and hip strength would be different between those who have a history of EMTP and those have no history of EMTP. There are multiple possibilities as to why the hypotheses were not supported and there were no significant differences found between the groups. One reason that should be noted is that one cannot look at the running mechanics alone but should also include factors that directly or indirectly influence running mechanics and tissue loading. For example, two people may have the same running mechanics, yet one may have different training and recovery habits, nutritional intake, and psychological characteristics such as their viewpoint on running, and these factors place one person at higher risk. As described in the Bertelsen model, many factors contribute to the load capacity of the tissue and the magnitude of the load that is being applied. While ultimately it is a mechanical failure of the musculoskeletal tissue that causes the injury, there are many underlying factors that may have contributed to the development of overuse injury such as EMTP. This idea is supported by the Bertelsen et al. (2017) when he explains the multifactorial nature of running related injury etiology and the importance of looking at the injury as a whole.

Secondly, broad inclusion criteria of type of EMTP injury and time since occurrence (2 years) created a very heterogeneous sample. Two years was the cut off frequency because we wanted them to be fully back to their training state they were at prior to the injury and had no pain at the time of testing. Based on previous research, the two year criteria showed adequate time for recovery and allowed for enough time to return back to their training level they were at before the injury occurred Verrelst et al. (2014a, 2014b, 2014c). Verrelst et al. (2014a, 2014b, 2014c) used the same cut off criteria to prevent current injuries from affecting the results and potentially changing the outcome.

When sustaining an injury, most athletes will change their training habits to reduce re-injury (Meeuwisse & Derrick 2014). It is possible that they changed their gait pattern, training regime, and physiological characteristics since the last injury occurred either subconsciously or consciously. It is possible, in order to prevent the injury again, their gait pattern changed, resulting in no reoccurrence of injury. Meeuwisse & Derrick (2014) found that those who performed more cross-training routines and changed their training habits to allow for the bone remodeling to occur, had lower risk of developing an overuse injury. Likewise, they may have changed their training habits and regime because they had an injury before so they may have reduced their mileage, changed the terrain they were running on, changed their shoe style, or even changed their strength training and cross training routines to prevent the injury from relapsing. Since the occurrence of injury was over two years, it is possible that the participants became stronger and focused on strength training, which may have affected the results.

During the demographic questionnaire, the participants were asked what other training, outside of running, they participated in, which showed that many of the participants incorporated strength training into their training regime. This may have included hip strength, core strength, and high intensity or endurance training. It is possible that the type of resistance training they were participating in and the amount of resistance training incorporated into overall training may have affected the results of the current study. When looking at Table 7, many of the participants in the EMTP group did participate in some form of cross-training whether it was strength training, yoga, elliptical, swimming, or other sporting events. Incorporating different training styles decreases the risk of overuse injuries because other body parts and muscles are used, allowing for proper recovery (Meeuwisse & Derrick 2014). It is important to note that only one participant performed rehabilitation for her injury and only three participants sought medical care for their injury. This allowed for proper injury diagnosis and ensured that the participants were truly experiencing EMTP since most injuries reported were self-diagnosis with no medical diagnosis by a Physician.

The lack of significant differences between those with a history of EMTP and healthy controls in hip external rotation strength and abduction strength contradicts the findings of previous prospective studies on EMTP risk factors in college aged females (Ford et al., 2013; Mann et al., 2015; Verrelst et al., 2014a; 2014b, 2014c). Verrelst et al. (2014a), Verrelst et al. (2014b), and Verrelst et al. (2014b) found that weaker hip extension, abduction, and external rotation led to greater movement in the lumbopelvic complex, placing more stress on the tibia, thus increasing the load. Verrelst et al. (2014a), Verrelst et al. (2014b), Verrelst et al. (2014b) performed a prospective study on the role of EMTP and injury while looking at recreational college aged females. There was a wide range of training experience between the participants ranging from no training experience to high intensity training. All participants were given the same standard training regime to follow over the course of the study and EMTP was observed over the course of a 12-24 training regime period. This is a key difference to the current study as training history and current training was not controlled. The inclusion and exclusion criteria were similar in the current study whereas participants were not experiencing any pain during the time of testing, had no neurological or previous musculoskeletal injuries, no previous surgery or fracture to the lower extremity and experienced pain along the medial distal two-thirds of the tibia within the past 2 years. The differences in study designs may have led to the difference in results between the current study and the studies performed by Verrelst et al. (2014a, 2014b, 2014c). The key difference is that the current study used a retrospective design to look at relationships between hip strength and motion after injury recovery had occurred, and the Verrelst et al papers looked prospectively at risk factors.

The current study reported no differences in hip strength between the two groups, which contradicts the findings by Ford et al. (2013). This discrepancy may be due to differences in the experimental methods in that they measured strength isokinetically, and their participants were healthy, uninjured male and female collegiate cross-country runners. They found that the strength of the hip musculature is correlated to the motion of the pelvis during dynamic tasks, leading to hip strength influencing the amount of thorax motion which was different from the findings of the current study due to the difference in protocols and participant criteria. The reason to use HHD in the current study over isokinetic testing was due to other studies that found that the HHD was a valid and reliable tool to use to measure strength, which is different than the study performed by Ford et al. (2013). The differences in methods between the two studies may have led to the differences in results between the current study and the study performed by Ford et al. (2013) (Bazett-Jones et al., 2011; Thorborg et al., 2010). These studies found that using a handheld dynamometer and normalizing the force and the torque to body weight is the most effective method of removing the body-mass dependence and establishes normal weight and strength distribution across different body sizes which is why this current study opted to use handheld dynamometry testing (Bazett-Jones et al., 2011; Thorborg et al., 2010). In the current study, during visual analysis, relationship between hip strength and motion did not exist, which may indicate the difference in results.

Increased motion of the thorax may lead to speculation that the increased motion has a relation to EMTP because it increases the load on the lower extremity (Ford et al., 2013). Over time, this increased load over repetitive bouts of exercise and improper recovery may lead to the occurrence of chronic injuries such as EMTP. Hip abductors play a very important role in the lower extremity alignment in both the frontal and transverse planes and they assist in stabilizing the pelvis and the hip (Ford et al., 2013, Teng & Powers 2015). Verrelst et al. (2013;2014a; 2014b; 2014c) found that females with weak hip abductors are more vulnerable to large external forces, reducing the ability to stabilize the lumbopelvic complex and increasing the load. Ford et al. (2013) found that decreased strength increases the motion in the frontal and transverse planes, leading to greater load placed on the tibia. The results from this study do not support the prospective idea that weak abductors are different between females who have a history of EMTP and those who have no history of EMTP. The lack of support may be due to the differences in training regimes between participants, differences in the protocol, and the biological and physiological changes through adaptation over the two-year span. Hip strength has been found to increase the risk of injury should not be considered a risk factor in isolation, rather considered amongst the other holistic factors that contribute to tissue load capacity and repetitive loading and recovery (Ford et al., 2013). The results from this study support the claim that it should be implemented into a holistic intervention protocol since gluteal strength deficits should to have a potential causal relationship in overall injury (Ford et al., 2013). However, it is still beneficial to strengthen the hip external rotators and the hip abductors to prevent excessive motion of the lower extremity and trunk. In turn, this may decrease the load on the tibia and reduce the risk of EMTP.

The current hip abduction strength measures showing no significant difference between groups do align with the findings of a systematic review by Mucha et al. (2016). He found that many previous studies on hip abductor strength and lower extremity injury did not yield significant relationships. however only 2 studies had been conducted with the EMTP populations (Mucha et al., 2016). Mucha et al., (2016) found wide differences between testing methodology, population characteristics and study design with diverse findings signifying a need for future studies to examine hip abductor strength more inclusively and consistently. The role of hip abductor strength on the development of EMTP and other injuries cannot be fully determined because of the variability in the measurement of the lower extremity strength; therefore, in order to gain more insight on the role of abductor strength on injury, a more consistent method warrants further investigation. Both the current study and the study done by Mucha et al. (2016) establish the need for more research with more heterogenous sample sizes, better matched criteria, and a more valid form of measurement, lack of maximal contraction from the participants, and limited true maximal voluntary contraction being reached and measured. There is still a lack of research in the validity between testing instruments when looking at the lower extremity (Mucha et al., 2016). Therefore, further research showed head towards validating the handheld dynamometer testing in the lower extremity musculature compared to other forms of testing.

There is no difference between hip and trunk excursion between those with a history of EMTP and healthy controls. It has been claimed that the more hip adduction excursion and internal rotation excursion increases the risk of EMTP because more load is placed on the medial side of the knee, resulting in increased load on the lower extremities (Teng & Powers 2015; Yagi et al., 2013). Over time, this increased maximum knee abduction angle and knee abduction angle at initial intact and toe-off increases the load on the tibia. The increased load during a repetitive bout of exercise such as running increases the micro damage resulting in EMTP pathologies (Yagi et al., 2013). Yagi et al. (2013) found that limited internal rotation of the hip increased the risk of lower extremity injuries in both males and females. However, there was no difference in hip internal rotation excursion between groups in the current study. The difference between the results of the two studies may be due to the fact that Yagi et al. (2013) measured hip internal rotation range of motion in high school runners with only moderate training levels and the current study focused on recreational competitive female runners who are training for a race, and measured hip rotation in the transverse plane during running. Since high school athletes are still maturing and in the development stage, the risk of injury and incidence of injury is different. High school athletes are still developing their bones, going through bone absorption and remodeling, and are experiencing hormonal imbalance, resulting in a higher risk of developing an overuse injury (Lilley et al., 2011).

An interesting finding that should be noted is that all EMTP participants presented a rearfoot strike pattern whereas those in the control group had a wider variation of foot strike pattern. It has been hypothesized in previous studies that those who have more of a rearfoot strike pattern have a higher risk for developing overuse injuries such as MTSS or stress fractures because more load is placed on the tibia and progressively, the increased load, increases the risk of injury (Hafer et al., 2015; Hamill et al., 2014, Kulmala et al., 2013, Lieberman et al., 2010). The increased impact peak force and loading rate over repetitive bouts of foot strikes, along with other factors, may increase the risk of the occurrence of injury (Hafer et al., 2015; Hamill et al., 2014, Kulmala et al., 2013, Lieberman et al., 2010).

The exploratory portion of the study evaluating the demographic and other factors from the questionnaires yielded information that support the idea that nutritional, psychological, sociological, physiological, and training factors all may be related to EMTP and are worthy of further investigation. Those who have a history of EMTP felt more remorse if they missed a run or had to go a day without running. They also enjoyed running more and were more eager to go for a run. These results coincide with previous studies that found that one's viewpoint on running and their personality type play a role in the occurrence of EMTP (Carmack & Martens, 1979; Ekenman et al., 2001; Masters & Ogles, 1998; Summers et al., 1983). Those who place running as a high priority and use running as a tool for mental, emotional and physical health will have the feeling of needing to run every day in order to control their health status. Those who place running as a high priority lack the flexibility in their training and have a more controlling behavior, resulting in the need to have to run and maintain their training habits every day, even if they are experiencing an injury (Carmack & Martens, 1979; Ekenman et al., 2001; Masters & Ogles, 1998; Summers et al., 1983). The need for having for having to run even if they are experiencing pain or discomfort may have led to the occurrence of EMTP. Those with a history of EMTP may have continued to run even though they were experiencing pain because they felt like they needed to run and continue with their training. They were less willing to take a day off to rest, resulting in inadequate recovery time to the injured area. The constant need to run and the lack of time to allow the body to recover may have relation to EMTP, especially those who have lower bone density. While the two groups were similar in their weekly training mileage, we did not ask about specific details about their recovery or training schedules. These speculations should be considered with caution as this portion of the study was exploratory.

The EMTP group recorded training for a full marathon at 40% and the control group recorded training for a half marathon at 45.5%. Typically, in order to train for a full marathon runners have to incorporate longer duration and longer distance runs into their training, increasing the risk of overuse injuries. The control group were more likely to train for half marathons, reducing the need to run high mileages and longer durations (Dierks et al., 2008; Hobara et al., 2010; Hulme et al., 2017; Ryan et al., 2006). However, the training mileage that was reported by each group was not different. It is possible that the EMTP group experienced injury because of training factors associated with the desire to run race. Training errors such as excessive distance, sudden changes in training routine, etc. are the cause of 60-70% of all running injuries (Hreljac et al, 2001). There is a possibility that the EMTP group incorporated too much training for the chosen race, resulting in the injury since they were new to running and new to training habits.

Contraceptive intake has been found to influence injury risk in female athletes (Cobb et al., 2007). It is interesting to note the results found from contraceptives and those who are taking contraceptives have irregular menstrual cycles. It has been found in previous studies that females with amenorrhea or oligomenorrhea have reduced bone mineral density (Cobb et al., 2007; Thein-Nissenbaum et al., 2012). This is, in part, due to bone loss because of low estrogen levels and low caloric intake based on activity level (Cobb et al., 2007). The irregular menstrual cycles may be a cause of improper nutritional intake and decreased bone mineral density. A higher percentage of EMTP participants used contraceptives compared to the healthy control group, leading to speculation that the EMTP may have had biological deficits resulting in injury. This is due to a possibility that with a lower bone density, the bone is unable to adapt to the forces applied to the lower extremity, resulting in an increased risk of injury. The constant, repetitive load placed on the lower extremity during a long duration run, can increase the risk of injury, especially overuse injury. The results regarding the higher rate of participants in the EMTP group that experience irregular menstruation support the findings in Thein-Nissenbaum et al. (2012) in that those who have menstrual irregularities have a higher risk of injury. Decreased menstruations lead to low energy availability, which can cause alterations in the maintenance, growth, and thermoregulation, resulting in an increased risk of injury (Thein-Nissenbaum et al., 2012). The EMTP group were more likely using birth to control their irregular menstruation patterns. When asked about reasoning as to why they were taking birth control, the participants stated that it was due to their irregular menstruation patterns. As one can see, based on the results from the questionnaires, physiological factors, psychological factors, nutritional factors, sociological factors, and training factors may be interrelated and influencing the biomechanical loading of the bones and soft tissue result in the increased risk of EMTP. There is no one sole variable that play a substantial role on the occurrence of EMTP, increasing the need in understanding all factors present when trying to build an intervention and prevention protocol.

Practical Application

Even though the results do not support the hypotheses stated early in regards to hip strength and hip and trunk excursion, the lack of significant findings in only running mechanic measures support the theoretical framework because it shows that other variables affect the occurrence of EMTP. The results from this study bring insight to the fact that running related injuries occur because of multiple factors. There are multiple factors that may influence the biomechanics of injury and all factors link together to cause injury. For example, a compulsive runner will run too much, increasing the load on the tissue, resulting in an overuse injury if proper recovery is not achieved. The lack of significant findings in the role of hip strength and the occurrence of EMTP reinforces the idea that biomechanics at the injury site may be the predictive factor. The site where the injury occurs may be enough to explain the occurrence of EMTP. Biomechanically, the load capacity is exceeded because there is not enough or adequate repair at the site of the injury. The bone cannot repair the damage quick enough or sufficiently, leading to EMTP pathologies. Hip strength may increase the risk but it cannot be one of the sole reasons as to why EMTP occurs in female competitive runners. The same idea can be made with motion control of the hip and the trunk. The lack of motion control may increase the risk but may not be a major contributor in relation to EMTP. At the site of injury, there is a biomechanics deficit that affects injury prevention and bone remodeling.

The role of nutrition, social environment, psychological perspective, physiological characteristics, and training habits must be considered when developing an intervention study to reduce the risk and hopefully prevent the occurrence of EMTP. All areas need to first be considered when looking at injury risk and prevention strategies before building an intervention protocol. The results coincide with the golden standard of rehabilitation, in which, clinicians need to treat the patient and not the injury. Every patient, injury, rehabilitation, and protocol are going to be different because of all the factors that need to be considered. As healthcare continues to grow, new treatments are developed, and new technology is created, it is important for researchers to take caution in implementing these new ideas without taking into account all factors associated with an injury.

Limitations

The limitations from this study were the heterogeneity in the sample size, the possibility of inaccurate self-reported information given by the participants on identification of injury, and tester and participant errors. Because some of the participants gave self-diagnosis of their injury, we have to take into consideration of the information given. There is a possibility that inaccurate information was given during the medical history screening because many of the participants did not seek a medical provider for their injury and self-reported their injury based on own knowledge. It may be possible that the participants simply diagnosed their injury based on what they know about injuries such as shin splints, MTSS, or stress fracture without actually seeking medical care for clinical diagnosis. The study is limited by the device that was used to measure strength in possible tester errors in placement of the device or errors resulting from participants failing to put forth maximal effort, leading to inaccurate results when using the hand-held dynamometer. Finally, participants were not asked about their running or training speed.

It has also been found that running speed plays a role in the development of overuse injuries. (Mann et al., 2015). Running related injuries are at a higher risk for those who have a lower running speed because the loading rate is higher and the impact force is greater (Mann et al., 2015). The selected speed may have played a factor in the difference of results between this study and the current study (Mann et al., 2015). It has been found in previous literature that running speed is a risk factor in injury occurrence (Chumanov et al., 2012; Goss et al., 2012; Hafer et al., 2015; Heiderscheit et al., 2011; Zadpoor & Nikooyan 2011). Reducing the running speed, decreases the impact forces and dissipates the load throughout the lower extremity (Chumanov et al., 2012; Goss et al., 2012; Hafer et al., 2015). Increasing the speed results in larger impact forces and less time for energy absorption, leading to increased risk of injury (Davis & Futrell 2016; Goss et al., 2012; Hafer et al., 2015). By slowing down the speed, it may increase the ability to dissipate the load throughout the tibia, leading to lower impact forces (Davis & Futrell 2016; Heiderscheit et al., 2011; Ryan et al., 2006). Running speed was not assessed or asked during the questionnaire, which would have been a beneficial measure to include in the data collection.

Future Research

Future research should include a larger sample size to determine if with more participants to attempt to gain a more homogeneous sample. Another direction to go is to develop intervention protocols for those who have had a history of EMTP including hip strengthening, gait training, and other factors that may have caused the injury and do a cross sectional study to see if the intervention prevents a reoccurrence of EMTP. Another direction to start looking into both biomechanical factors along with the psychological mindset of runners such as their need to run and why those who are runners have a more controlling personality. Finally, another direction to take is to look at other levels of runners such a recreational runners, collegiate athletes, or high school athletes. Performing the same study on different populations may help establish a better understanding of causative factors in EMTP if differences arise in those populations.

Conclusion

Hip strength and hip and trunk excursion were not different in this sample of those who have a history of EMTP and those who are healthy and never had a history of EMTP.. Due to the wide timeframe for the occurrence of EMTP, and broad definition of EMTP our sample was very heterogenous. Future research should control for the large gap to reduce the heterogeneity of the results. Better control of the time table between injuries may show different results and may show significant differences between groups. While this study didn’t support the theory that hip strength biomechanics are different in those with a history of EMTP, future research should continue to examine these factors, perhaps in combination with other factors that could influence lower extremity loading.

There are differences in the mindset, training, nutritional intake between the two groups showing that there are multiple factors that play a role in the occurrence of EMTP. Researchers cannot confidently say that the biomechanical factors that have been found to increase the risk of injury are the only causative factors in EMTP. When looking at the holistic picture of kinesiology, clinicians and researchers have to take into consideration all variables due to the fact that there are multiple factors that can increase the risk of EMTP. It is vital for clinicians to treat the patient or athlete and not treat the injury because everyone is different. There is not going to be one gold standard protocol that will reduce the risk of EMTP because the etiology of injury is different across athletes or patients. Clinicians should build the protocol intervention around the athlete based on their needs.

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APPENDICES

APPENDIX A: RECRUITMENT FLYER

Have you had “shin splints” or other lower leg pain? Are you a runner?

Here is a research study for you!

University of Wisconsin – Milwaukee
Neuromechanics Laboratory, END 132

Title: Investigating Hip and Trunk Kinematic and Strength Differences Between Those with a History of Exertional Medial Tibial Pain and Healthy Controls

Purpose: Exertional medial tibial pain (EMTP) has been shown to be one of the leading injuries in females who have weakened hip strength. Increased trunk and hip kinematic excursion and decreased hip external rotation and hip abductor strength are related to injury in the athletic population but there is a lack of research in the role of hip strength in the development of exertional medial tibial pain in competitive female runners. The purpose of this study is to investigate the differences in hip strength, hip kinematics and trunk kinematics between those with a previous history of exertional medial tibial pain and healthy controls.

Participant requirements?

Control Group

- ✓ Female Sex (Self-Identified)
- ✓ Between the age of 18-45
- ✓ Competitive runners (Training for a 10k, Half Marathon, Full Marathon, Triathlon, or any other distance running events)
- ✓ Training to compete in an event within the next 6 months
- ✓ No medical history of Exertional Medial Tibial Pain

Exertional Medial Tibial Pain Group

- ✓ Female Sex (Self-Identified)
- ✓ Between the age of 18-45
- ✓ Competitive runners (Training for a 10k, Half Marathon, Full Marathon, Triathlon, or any other distance running events)
- ✓ Training to compete in an event within the next 6 months
- ✓ History of EMTP injury (medial tibial stress syndrome, lower leg stress fracture, chronic exertional compartment syndrome, tendon or ligament injury) that occurred due to running resulting in at least 3 weeks in pain and occurred within the last 24 months
- ✓ Currently Pain Free during running and have no training restrictions

What will I do?

Screening & Warm-Up	**Testing**
Complete Consent Forms and get more information about the study Complete a 5-minute walk/run warm-up Complete a few questionnaires about your medical history and running experience and training	Complete strength testing of your hip muscles using a small device called a dynamometer Have a 3-D analysis of your running biomechanics completed. To do this we will place small reflective makers placed on your legs and pelvis

Questions? Please contact **Allison Hocking** at **ahocking@uwm.edu** or at (262) 492-2503

This research project has been approved by the University of Wisconsin-Milwaukee Institutional Review Board for the Protection of Human Subjects (IRB Protocol Number18.202 approved on 03-16-2018)

APPENDIX B: EMAIL ANNOUNCEMENT SCRIPT

My name is Allison Hocking and I am a Masters' student at University of Wisconsin-Milwaukee. I am currently working on my thesis project and am looking for participants for my study. The title of the study is *Investigating Hip and Trunk Kinematic and Strength Differences Between Those with a History of Exertional Medial Tibial Pain (EMTP) and Healthy Controls.* Participation is completely voluntary. If you agree to participate now, you can always change your mind later. There are no negative consequences in whatever you decide. This study has been approved by the University of Wisconsin-Milwaukee Institutional Review Board (______).

What is the Purpose of this Study:

Exertional medial tibial pain (EMTP) has been shown to be one of the leading injuries in females who have weakened hip strength. Increased trunk and hip kinematic excursion and decreased hip external rotation and hip abductor strength are related to injury in the athletic population but there is a lack of research in the role of hip strength in the development of exertional medial tibial pain in competitive female runners. The purpose of this study is to investigate the differences in hip strength, hip kinematics and trunk kinematics between those with a previous history of exertional medial tibial pain and healthy controls.

Who can Participate?

I am looking for two different groups of runners. Those who are healthy with no injury and those who have experienced EMTP. Below are the following criteria for both groups:

Control Group

- ✓ Female Sex (Self-Identified)
- ✓ Between the age of 18-45
- ✓ Competitive runners (Training for a 10k, Half Marathon, Full Marathon, Triathlon, or any other distance running events)
- ✓ Training to compete in an event within the next 6 months
- ✓ No medical history of Exertional Medial Tibial Pain

Exertional Medial Tibial Pain Group

- ✓ Female Sex (Self-Identified)
- ✓ Between the age of 18-45
- ✓ Competitive runners (Training for a 10k, Half Marathon, Full Marathon, Triathlon, or any other distance running events)
- ✓ Training to compete in an event within the next 6 months
- ✓ History of EMTP injury (medial tibial stress syndrome, lower leg stress fracture, chronic exertional compartment syndrome, tendon or ligament injury) that occurred due to running resulting in at least 3 weeks in pain and occurred within the last 24 months
- ✓ Currently Pain Free during running and have no training restrictions
- ✓ Come into the Biomechanics lab on the University of Milwaukee Campus for 1 session

What Would I Have to Do?

- ✓ Answer a background questionnaire (15 minutes)
- ✓ Perform 3 different strength exercises (25-30 minutes)
- ✓ Perform 5 trials of over-ground running (25-30 minutes)

What are my Benefits?

- ✓ Learn about the risk of Exertional Medial Tibial Pain
- ✓ Understand the role of hip strength and hip and trunk mechanics and injury

For more information, or to volunteer to participate please contact

Allison Hocking LAT, ATC
Master of Science- Kinesiology Integrative Human Performance
University of Wisconsin-Milwaukee
AHocking@uwm.edu
(262) 492-2503

APPENDIX C: PHONE SCREEN SCRIPT

<u>Phone Screening & Medical History Questionnaire</u>

(To be read by research assistant) To make sure that you are eligible for this study, I need to ask you several questions about your past medical lower extremity history. Is this okay with you? Please listen carefully and answer to the best of your ability. If you don't understand a question please ask. This information will not be recorded or used for research purposes unless you are eligible, and consent to be in the study.

Which group are you interested in being a part of, the EMTP or pain free group? ☐ EMTP
☐ Control

1. General Screening Criteria <u>All Potential Participants</u>
First, I'm going to ask you some general questions about you, your health, and your physical activity level.

☐ Yes ☐ No	Are you female?
☐ Yes ☐ No	Are you between the ages of 18 and 45 years old?
☐ Yes ☐ No	Are you currently training to run a 10K, half-marathon, full marathon, triathlon, or any other distance running event within the next 6 months.
☐ Yes ☐ No	Are you fully cleared to participate in regular training?

If answer is "Yes" to all above, continue to section 2.
If answer is "No" to any, continue to section 5.

2. **Medical History Screening Criteria** <u>All Potential Participants</u>
I'm going to ask you some specific questions about your medical history. If you need further explanation in order to answer the question, please ask.

☐ Yes ☐ No	Are you currently experiencing a musculoskeletal or neurological condition affecting the lower extremity?
☐ Yes ☐ No	Do you have a history of any lower extremity surgery or fracture?
☐ Yes ☐ No	Are you currently experiencing any pain during running?
☐ Yes ☐ No	Are you pregnant or do you have reason to believe that you may be pregnant?

If answer is "No" to all above, continue to section 3 for CONTROL and section 4 for EMTP group.
If answer is "Yes" to any, continue to section 5.

3. **CONTROL Screening Criteria** <u>For Potential Control Participants Only</u>
I'm now going to ask you some questions about your injury history to make sure you qualify for the pain free, control group.

☐ Yes ☐ No	Have you had Exertional Medial Tibial Pain in the past or currently experiencing Exertional Medial Tibial Pain (i.e. stress fracture, "shin splints," chronic compartment syndrome, pain in the lower leg)?

If answer is "No" to all above, continue to section 6.
If answer is "Yes" to any, continue to section 5.

4. **EMTP Screening Criteria** For Potential EMTP Participants Only

I'm now going to ask you some questions about your lower extremity pain.

☐ Yes ☐ No Do you have a history of exertional medial tibial pain (e.g. medial tibial stress syndrome, "shin splints", tibial stress fracture, chronic exertional compartment syndrome)?

☐ Yes ☐ No Has your pain been persistent for at least 3 weeks?

☐ Yes ☐ No Have your symptoms occurred within the last 24 months?

☐ Yes ☐ No Are you currently pain free during running and have no training restrictions?

(Above answers must be yes to continue)

☐ Yes ☐ No Are you currently experiencing pain during running?

☐ Yes ☐ No Do you have a history of patellofemoral pain or iliotibial band syndrome?

(Above answers must be NO to continue)

If answers YES, then NO continue to section 6.
If not, continue to section 5.

5. Screening Failures

I am sorry to inform you that you do not qualify for our study. We thank you for your time and interest in this study. Do you have any further questions?

6. Screening Successes

I am pleased to inform you that you may qualify for our study. If you are still interested in participating, we will now need to schedule you for a testing session. This session will take approximately an hour to an hour and a half during which time your final eligibility will be determined and data collection will be obtained. During this session, you will be asked to perform some strength testing and you will be asked to perform running tasks while a camera system tracks your movement. All of the procedures of this study are outlined in the consent form. Would you like me to e-mail you a copy of it?

If "Yes", record e-mail address here: ____
If "No", proceed to next section.

Are you still interested in participating in this study?
If "Yes", schedule participant for testing and ask if they would like a confirmation email.
If "No", thank the person for their time and end call.

Schedule for Testing:

Date: _________________ Time: ___________ AM / PM

Do you have any other questions about the study?

Explain the directions to campus.
Explain what clothes to wear.

Thank you for participating in our study. We look forward to seeing you on __INSERT DATE & TIME__.

APPENDIX D: CONSENT FORM

Study title	Investigating Hip and Trunk Kinematic and Strength Differences Between Those with a History of Exertional Medial Tibial Pain and Healthy Controls
Researcher[s]	Jennifer Earl Boehm, PhD, ATC and Allison Hocking. University of Wisconsin- Milwaukee. Department of Kinesiology- Integrated Health Care and Performance.

We're inviting you to participate in a research study. Participation is completely voluntary. If you agree to participate now, you can always change your mind later. There are no negative consequences, whatever you decide.

What is the purpose of this study?
The purpose of this study is to investigate the differences in hip strength and running biomechanics between those with a previous history of exertional medial tibial pain and healthy controls.

What will I do?

- In our lab:
  - You'll complete a survey about your past medical history, how often you exercise, what you are training for, and what you do for your training. You will also be asked questions regarding your nutrition, psychology, sociology, physiology, and form of running. You will also complete a Commitment to Running Questionnaire and a Running Addiction Questionnaire (10 minutes)
  - We'll measure your hip muscle strength through the use of a hand-held dynamometer, a small device that measures force. (20-30 minutes)
  - We'll place reflective markers and reflective clusters onto your legs and hips to build a 3-D video of your running (5 minutes)
  - We'll measure and record your over-ground running on the platform that is in the middle of the lab. 5 successful trials of contact with the force plate will be recorded (15-20 minutes).

Risks

Possible risks	**How we're minimizing these risks**
Some questions may be very personal or upsetting	You can skip any questions you don't want to answer.
Reoccurrence of injury or new injury occurs during the testing process	We will allow for proper and adequate warm up before any of the testing begins along with proper cool down after the study is done. You can stop at any time or if the injury occurs. You will also be given referrals to local clinics in case medical advice/ attention is needed.
Breach of confidentiality (your data being seen by someone who shouldn't have access to it)	• All identifying information is removed and replaced with a study ID. • We'll remove all identifiers after 10 years following the completion of the study for the purpose of having comparisons for future studies. • We'll store all electronic data on a password-protected,

	encrypted computer. • We'll store all paper data in locked room (END 132) separate from any the participant key and informed consent containing identifiable information. • We'll keep your identifying information separate from your research data, but we'll be able to link it to you by using a study ID. We will destroy this link after we finish collecting and analyzing the data.

There may be risks we don't know about yet. Throughout the study, we'll tell you if we learn anything that might affect your decision to participate.

Other Study Information

Possible benefits	• Better understanding of injury • Possible injury prevention protocols • Better understanding of training habits and running gait
Estimated number of participants	12 participants who have injury 12 participants who do not have injury
How long will it take?	Approximately an hour to an hour and a half
Costs	None
Compensation	None
Future research	De-identified (all identifying information removed) Your data won't be used or shared for any future research studies.
Recordings / Photographs	Standard video cameras will be used to record the side view of the participants feet during running. This will only be used to determine if the individual is a rearfoot or forefoot strike runner. The videos will only be used during the screening and will not be saved.
Removal from the study	If you do not feel comfortable being recorded you will be removed from the study due to the need of the recording. If you give the wrong or misguided information about your past medical history, you will be removed from the study.

What if I am harmed because I was in this study?
If you're harmed from being in this study, let us know. If it's an emergency, get help from 911 or your doctor right away and tell us afterward. We can help you find resources if you need psychological help. You or your insurance will have to pay for all costs of any treatment you need.

Confidentiality and Data Security
We'll collect the following identifying information for the research: Signature of Consent Form This information is necessary to allow us to perform the study and have evidence that you agreed to all of the risks, benefits, knowledge of the study, and participation of the study. **We will keep a copy of your signed consent form and you will receive a copy of the full consent form with**

signatures for your referral of the study and contact information if you have any questions after the study is performed.

Where will data be stored?	• Data obtained during the 3-D video will be stored on safe and controlled file in Enderis 132 lab computer. • Data recorded on paper will be stored in safe, locked file that is located in Enderis 132 separate from collected data.
How long will it be kept?	**10 Years**

Who can see my data?	**Why?**	**Type of data**
The researchers	To analyze the data and conduct the study	The questionnaire, strength and measures and kinematic measures will be collected. You will be given a Study ID that will prevent any of the information from being associated with you and your name will be removed from all of the information collected.
The IRB (Institutional Review Board) at UWM The Office for Human Research Protections (OHRP) or other federal agencies	To ensure we're following laws and ethical guidelines	The questionnaire, strength measures and kinematic measures will be collected. You will be given a Study ID that will prevent any of the information from being associated with you and your name will be removed from all of the information collected.
Anyone (public)	If we share our findings in publications or presentations	All of your measures, results, and questionnaire answers will be used during the presentation of publication of the study but they will be associated with the study ID given. Your name will not be used in any of the information. All information will be aggregated together for results.

Contact information:

For questions about the research	Allison Hocking Dr. Jennifer Earl-Boehm	(262) 492-2503 AHocking@uwm.edu Pavilion 378 (414) 229-3227 jearl@uwm.edu Pavilion 367
For questions about your rights as a research participant	IRB (Institutional Review Board; provides ethics oversight)	414-229-3173 / irbinfo@uwm.edu

For complaints or problems	Allison Hocking Dr. Jennifer Earl-Boehm	(262) 492-2503 AHocking@uwm.edu Pavilion 378 (414) 229-3227 jearl@uwm.edu Pavilion 367
	IRB	414-229-3173 / irbinfo@uwm.edu

Signatures
If you have had all your questions answered and would like to participate in this study, sign on the lines below. Remember, your participation is completely voluntary, and you're free to withdraw from the study at any time.

____
Name of Participant (print)

____ ________________
Signature of Participant Date

____
Name of Researcher obtaining consent (print)

____ ________________
Signature of Researcher obtaining consent Date

APPENDIX E: BACKGROUND QUESTIONNAIRE

Start of Block: EMTP Group (If CONTROL group, SKIP to question 8)

Q1 When did your leg pain occur?

- ○ 0-3 months ago (1)
- ○ 4-6 months ago (2)
- ○ 7-9 months ago (3)
- ○ 10-12 months ago (4)
- ○ 13-15 months ago (5)
- ○ 16-18 months ago (6)
- ○ 19-21 months ago (7)
- ○ 22-24 months ago (8)

Q2 Did you see a medical provider for your shin pain?

- ○ Yes (1)
- ○ No (2)

Q4 What was your diagnosis?

- ○ Shin Splints (1)
- ○ Medial Tibial Stress Syndrome (2)
- ○ Stress Fracture (3)
- ○ Chronic Compartment Syndrome (4)
- ○ I Don't Know (5)

Q5 How long were you limited in your running or training?

- ◯ Not At All (1)
- ◯ 1-3 weeks (2)
- ◯ 4-6 weeks (3)
- ◯ 7-9 weeks (4)
- ◯ 10-12 weeks (5)
- ◯ >12 weeks (6)

Q6 Did you receive any treatment for injury?

- ◯ Exercise/ Rehabilitation (1)
- ◯ Gait (Running Form) Training (2)
- ◯ Medications like NSAIDS (Ibuprofen, Advil, Aleve) (3)
- ◯ Ice/ Heat (4)
- ◯ Other (5) ____

Q7 How long did symptoms persist?

- ◯ <1 month (1)
- ◯ 1-3 months (2)
- ◯ 4-6 months (3)
- ◯ 7-9 months (4)
- ◯ 10-12 months (5)
- ◯ >12 months (6)

End of Block: EMTP Group (If CONTROL group, SKIP to question 8)

Start of Block: Background Questions

Q9 What kind of running event are you training for?

- ○ 10K (1)
- ○ Half Marathon (2)
- ○ Full Marathon (3)
- ○ Triathlon (4)
- ○ Tough Mudder (5)
- ○ Spartan Race (6)
- ○ Other (7) ____

Q10 How many miles/ weeks do you run on average?

____

Q11 How many days/ weeks do you run on average?

____

Q12 How many years have you been involved in running?

- ○ <1 year (1)
- ○ 1-5 years (2)
- ○ >5 years (3)

Q13 What made you start running? (Select all that apply)

- ☐ Physical Fitness (1)
- ☐ Feeling of Achievement (2)
- ☐ Provide a Challenge (3)
- ☐ Feel Better (4)
- ☐ Enjoyment (5)
- ☐ Desire to Run a Race (6)
- ☐ Other (7) ____

Q14 Where do you spend most of your time running? (Select all that apply)

- ☐ Treadmill (1)
- ☐ Track (2)
- ☐ Trails (3)
- ☐ Asphalt (4)
- ☐ Other (5) ____

Q15 How many races have you participated in?

- ○ <5 races (1)
- ○ 5-10 races (2)
- ○ >10 races (3)

Q16 Do you participate in any other forms of exercise? (Select all that apply)

- ▢ Yoga (1)
- ▢ Pilates (2)
- ▢ Strength Training (3)
- ▢ Cycling (4)
- ▢ Elliptical (5)
- ▢ Stair Stepper (6)
- ▢ CrossFit (7)
- ▢ Swimming (8)
- ▢ Other (9) ____

Q17 Do you run/ train with anyone else or do you train by yourself? (Select all that apply)

- ▢ Self (1)
- ▢ Friend (2)
- ▢ Family Member (3)
- ▢ Co-worker (4)
- ▢ Significant Other (5)
- ▢ Coach (6)
- ▢ Other (7) ____

Q18 Are you a member of any running clubs/ groups?

- ○ Yes (1)
- ○ No (2)

Q19 Has running put any strain on relationships?

- ○ Never (1)
- ○ Sometimes (2)
- ○ Always (3)

Q20 Do family members and friends support your races/ training?

- ○ Never (1)
- ○ Sometimes (2)
- ○ Always (3)

Q21 Do you have regular, monthly menstruation?

- ○ Yes (1)
- ○ No (2)

Q22 If not, how many months do you go without your period?

____

Q23 Are you taking birth control?

- ○ Yes (1)
- ○ No (2)

Q24 Do you take any supplements such as vitamins or protein powder?

- ○ Yes (1)
- ○ No (2)

Q25 If yes, please list what you are taking?

____

Q26 Do you pay close attention to what food you are putting in your body and/ or restrict yourself from certain foods because of training/ running?

○ Never (1)

○ Sometimes (2)

○ Always (3)

○ I Don't Know (4)

Q27 Do you consume enough calories for the number of miles you put in every day?

○ Never (1)

○ Sometimes (2)

○ Always (3)

○ I Don't Know (4)

End of Block: Background Questions

Start of Block: Commitment to Running Scale-11 (1- Completely Disagree, 5- Completely Agree)

Q28 I am eager to run

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)
1 (1)	○	○	○	○	○

Q29 Running is enjoyable

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)
1 (1)	○	○	○	○	○

Q30 I don't enjoy running (R)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)
1 (1)	○	○	○	○	○

Q31 Running is of vital importance to me

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)
1 (1)	○	○	○	○	○

Q32 My life is much more fulfilled because I run

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)
1 (1)	○	○	○	○	○

Q33 Running is pleasant

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)
1 (1)	○	○	○	○	○

Q34 The idea of running terrifies me (R)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)
1 (1)	○	○	○	○	○

Q35 I would reorganize or change my timetable in order to satisfy my need to run

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)
1 (1)	○	○	○	○	○

Q36 I have to force myself to run (R)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)
1 (1)	○	○	○	○	○

Q37 To go a day without running is a relief for me (R)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)
1 (1)	○	○	○	○	○

Q38 Running is a climatic point of my day

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)
1 (1)	○	○	○	○	○

End of Block: Commitment to Running Scale-11 (1- Completely Disagree, 5- Completely Agree)

Start of Block: Running Addiction Scale- 8 (1- Completely Disagree, 7- Completely Agree)

Q39 If the weather is too cold, hot or windy, I choose not to run (R)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
1 (1)	○	○	○	○	○	○	○

Q40 I would not change plans with friends so that I could go running (R)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
1 (1)	○	○	○	○	○	○	○

Q41 I have stopped running for at least a week for other reasons than having an injury (R)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
1 (1)	○	○	○	○	○	○	○

Q42 If there were another way to maintain my current fitness level, I would never run again (R)

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
1 (1)	○	○	○	○	○	○	○

Q43 After running, I feel better

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
1 (1)	○	○	○	○	○	○	○

Q44 I would continue running while recovering from an injury

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
1 (1)	○	○	○	○	○	○	○

Q45 Some days I run even if I don't feel like it

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
1 (1)	○	○	○	○	○	○	○

Q46 I feel that I need to run at least once every day

	1 (1)	2 (2)	3 (3)	4 (4)	5 (5)	6 (6)	7 (7)
1 (1)	○	○	○	○	○	○	○

End of Block: Running Addiction Scale- 8 (1- Completely Disagree, 7- Completely Agree)

APPENDIX F: DATA COLLECTION FORM

Date : ___________________ **Participant Code :** EMTP________

Group: Control EMTP

Age: _____

Ht: ______cm **Wt:** ______kg

Do you have pain today? YES NO

EMTP group: Which leg was injured (or worse)? Right______ Left________

CONTROL group: Which leg do you stand on when you kick a ball? Right _____Left______

Foot Strike Pattern: Rearfoot __________ Forefoot____________ Midfoot __________

HHD Strength Testing

	Leg tested:__________				
	Trial 1	**Trial 2**	**Trial 3**	**Trial 4**	**Mean**
Hip ABD (kg)					
Hip Ext Rot (kg)					

Hip Ext (kg)					

Biomechanical Data Collection

Recorded	**Notes**	**Collected**	**Tracking**	**Exported**
Stand	Leg tested: RIGHT__________ LEFT_________			
Run 1	Time:			
Run 2	Time:			
Run 3	Time:			
Run 4	Time:			
Run 5	Time:			

APPENDIX G: PARTICIPANT ID TABLE

EMTP Group		
Participant Name	Participant Group	Participant ID
1)	EMTP	001
2)	EMTP	002
3)	EMTP	003
4)	EMTP	004
5)	EMTP	005
6)	EMTP	006
7)	EMTP	007
8)	EMTP	008
9)	EMTP	009

10)	EMTP	010
11)	EMTP	011
12)	EMTP	012

CONTROL Group		
Participant Name	Participant Group	Participant ID
1)	CON	001
2)	CON	002
3)	CON	003
4)	CON	004
5)	CON	005
6)	CON	006
7)	CON	007
8)	CON	008
9)	CON	009

10)	CON	010
11)	CON	011
12)	CON	012

APPENDIX H: DATA PROTOCOL FORM

Screening

Pre-Data Collection

Phone Screening
○ Obtain Initial Phone Screening to determine eligibility to participate in to study and possible group the individual may be placed in (Control vs EMTP)
○ Ask if they are still interested in the study
○ Send confirmation email with time and date for data collection
    ○ Include driving directions to the campus and where to park
    ○ Send directions to Enderis Lab

Before Participant Arrival

DAY 1
Print forms

Set up equipment
• Equipment:
    ○ Hand Held Dynamometer and Charging Cord
    ○ Treadmill
    ○ 3-D Cortex Calibration (Prepare Clusters and Makers for the Participant)
    ○ Individual and Cluster Markers
    ○ 2-D Video Recording through iPad using Technique software

3-D Cortex Calibration

- 10 cameras with camera angles and zoom in desired position.
  - 35 mm
  - Floor Camera at lowest height
  - Vertical Camera 8= 17 degrees, 9= 15 degrees, and 10= 24 degrees below horizontal
- Cortex
  - Set Participant folder as working folder
  - Live Mode
  - Load Setup
  - Turn on Cameras
  - Adjust settings
    - Brightness%: 100
    - Minimum Horizontal Lines: 2
    - Maximum Horizontal Lines: 50
  - Calibrate
    - Select Initial Calibration
    - Check cameras and mask unwanted markers
    - Place L-Frame in the corner of the force plate with the X towards the right and the Y towards direction of motion
    - Click run and check that all cameras see all four markers on the L-Frame.
    - Wand
      - # of frame: <100
      - Wand length: ~500.00
      - SD: <0.5
      - Duration: 60 seconds
  - Save Set Up

After Participant Arrival

DAY 1
Consent Form • Review Consent Form with the participant. ○ Ask that they read over the Consent Form, sign and date it. See if they have any questions or concerns regarding the research study and protocol. ○ Participant will keep the copy that was sent in the email and researcher will print out scanned copy and keep on file.
Background Questionnaire • Give the participant the iPad with the questionnaire loaded.
Measure Strength 5 minutes of warm up on the treadmill at slow speed (below self-selected speed). • One practice trial at 50% of maximal ability and 1 unrecorded practice trial at 75% of maximal ability to familiarize the participant with the motion and reduce the risk of soreness. • 3 trials at 100% ability will be recorded. • Hip Abduction ○ Side-lying Position • Hip External Rotation

    - Prone Position
  - Core
    - Front Plank
    - Side Plank
  - Back Extensors
    - Superman Position

One minute rest interval between each test and between each muscle group

Preparation and Calibration

- Place Markers and Clusters on the participant
  - R/L Acromioclavicular joint
  - Sternum
  - Cervical
  - R/L ASIS
  - R/L PSIS
  - R/L Iliac Crest
  - R/L Greater Trochanter
  - M/L Femoral Epicondyle
  - M/L Malleolus
  - 1^{st} and 5^{th} Metatarsal Heads
  - Heel Cluster
  - Thigh Cluster
  - Shank Cluster
- Add standing marker set
- Check for all 32 visible markers
- Calibrate the 3-D anatomical structure of patient for 3-D video. Make sure every marker can be seen and there are no other factors in the view.
- After Calibration, remove some of the clusters to allow for normal running
- Explain running session and answer any questions about study. Explain that they can stop at any time.

Remove Markers

- R/L Iliac Crest
- R/L Greater Trochanter
- M/L Femoral Epicondyle
- M/L Malleolus
- 1^{st} and 5^{th} Metatarsal Head

Running Session

- Establish running distance where participant makes contact with the force plate with entire foot.
- Encourage participant to run at a self-selected speed without changing gait during trial.
- Mark the location where they should start
- Allow for 3-5 practice trials before recording or until constant foot strike on the force plate occurs or the participant is comfortable with the over-ground running gait
- Start recording the 3-D video

Running Session Data Collection

- Record 5 successful trials of over ground run

<table>
<tr><td>

The symptomatic leg strikes the force plate with the entire foot within normal strides in the EMTP group
The dominate/ desired leg strikes the force plate with the entire foot within normal strides in the control group
Record Kinematic and Kinetic measures

Loading Rate
Peak Impact
Impact Forces
Pelvis

Tilt
Obliquity
Rotation

Trunk

Flexion
Lateral Lean
Rotation

Hip

Angle
Rotation

</td></tr>
<tr><td>Post Running Session</td></tr>
<tr><td>

Remove clusters and markers from participant
5 minutes of recovery on the treadmill at slow speed
All kinetic and kinematic variables will be compared between the two groups. They will also be correlated between trunk stability, hip strength, and the development of EMTP.

</td></tr>
</table>

APPENDIX I: RAW DATA COLLECTION

Participant Questionnaire Master Data Sheet

Group	#	Q1	Q2	Q4	Q5	Q6	Q7	Q9	Q10	Q11	Q12	Q13_7_TEXT
		When did your leg pain occur?	Did you see a medical provider for your shin pain?	What was your diagnosis?	How long were you limited in your running or training?	Did you receive any treatment for injury? - Selected Choice	How long did symptoms persist?	What kind of running event are you training for? - Selected Choice	How many miles/ week do you run on average?	How many days/ week do you run on average?	How many years have you been involved in running?	What made you start running? (Select all that apply) - Other - Text
CON	001	[redacted]						Triathlon	22	4	1-5 years	Physical Fitness, Desire to Run a Race
CON	002	[redacted]						Half Marathon	27.5	7	>5 years	Enjoyment
CON	003	[redacted]						Half Marathon	11	3	1-5 years	Physical Fitness, Feeling of Achievement, Feel Better, Desire to Run a Race
CON	004	[redacted]						10K	10	4	>5 years	Physical Fitness
CON	005	[redacted]						10K	10	3	1-5 years	Physical Fitness, Feeling of Achievement, Provide a Challenge
CON	006	[redacted]						Half Marathon	36	6	1-5 years	Physical Fitness, Feeling of Achievement, Feel Better, Weight Control
CON	007	[redacted]						10K	10	3	1-5 years	Physical Fitness
CON	008	[redacted]						Full Marathon	35	4	1-5 years	Feel Better
CON	009	[redacted]						Half Marathon	20	4	>5 years	Feeling of Achievement
CON	010	[redacted]						Half Marathon	17.5	3-4	>5 years	Physical Fitness, Feeling of Achievement, Provide a Challenge, Feel Better, Enjoyment
CON	011	[redacted]						Full Marathon	30	5	1-5 years	Physical Fitness, Feeling of Achievement, Provide a Challenge, Feel Better, Enjoyment, Desire to Run a Race
EMTP	001	0-3 months ago	No	Shin Splints	1-3 weeks	Ice/ Heat	<1 month	10K	12	3	1-5 years	Physical Fitness
EMTP	002	7-9 months ago	Yes		4-6 weeks	Ice/ Heat	4-6 months	Half Marathon	20	4	1-5 years	Feeling of Achievement, Feel Better, Desire to Run a Race
EMTP	003	19-21 months ago	No		4-6 weeks	Ice/ Heat	1-3 months	Full Marathon	17.5	4	>5 years	Physical Fitness, Feeling of Achievement, Provide a Challenge, Feel Better, Enjoyment
EMTP	004	22-24 months ago	No	Shin Splints	1-3 weeks	Medications, Ice, Heat	<1 month	10K	8.5	3-4	1-5 years	Physical Fitness, Feeling of Achievement, Provide a Challenge, Feel Better, Enjoyment, Desire to Run a Race, Mental Health
EMTP	005	0-3 months ago	No		4-6 weeks	Ice/ Heat	1-3 months	Half Marathon	10	3	1-5 years	Physical Fitness, Feeling of Achievement, Provide a Challenge, Feel Better, Enjoyment, Desire to Run a Race
EMTP	006	22-24 months ago	Yes	Shin Splints	Not At All	Ice/ Heat	>12 months	Full Marathon	22	3	1-5 years	Provide a Challenge, Desire to Run a Race
EMTP	007	0-3 months ago	No		1-3 weeks	Ice/ Heat	<1 month	Half Marathon	18	3-4	1-5 years	Physical Fitness, Feel Better, Enjoyment
EMTP	008	22-24 months ago	Yes	Stress Fracture	>12 weeks	Rehabilitation, Medications, RICE	>12 months	Triathlon	40	7	>5 years	Physical Fitness, Feeling of Achievement, Provide a Challenge, Feel Better, Enjoyment, Desire to Run a Race, Retried T/F Athlete
EMTP	009	4-6 months ago	No	Stress Fracture	1-3 weeks	Medications like NSAIDS (Ibuprofen, Advil, Aleve)	<1 month	Full Marathon	30	5	1-5 years	Desire to Run a Race
EMTP	010	22-24 months ago	No	Shin Splints	1-3 weeks	Medications like NSAIDS (Ibuprofen, Advil, Aleve)	<1 month	Full Marathon	20	5	1-5 years	Desire to Run a Race

Q14	Q15	Q16	Q17	Q18	Q19	Q20	Q21	Q22	Q23	Q24	Q25	Q26	Q27
Where do you spend most of your time running? (Select all that apply) - Selected Choice	How many races have you participated in?	Do you participate in any other forms of exercise? (Select all that apply) - Selected Choice	Do you run/ train with anyone else or do you train by yourself? (Select all that apply) - Selected Choice	Are you a member of any running clubs/ groups?	Has running put any strain on relationships?	Do family members and friends support your races/ training?	Do you have regular, monthly menstruation?	If not, how many months do you go without your period?	Are you taking birth control?	Do you take any supplements such as vitamins or protein powder?	If yes, please list what you are taking?	Do you pay close attention to what food you are putting in your body and/ or restrict yourself from certain foods because of training/ running?	Do you consume enough calories for the number of miles you put in every day?
Trails,Asphalt	5-10 races	Cycling, Swimming, Other	Self, Significant Other	No	Sometimes	Always	Yes		No	Yes	Protein Isolate, Fish Oil, Daily Vitamin, Essential Enzymes, BCAA, Biotin	Sometimes	Sometimes
Treadmill, Trails, Asphalt, Soccer Field	>10 races	Yoga,Strength Training,Swimming	Self	Yes	Never	Always	Yes		No	No		Sometimes	I Don't Know
Asphalt	5-10 races	Strength Training	Friend, Recreational Running Club	Yes	Never	Always	No	2-3	No	No		Sometimes	Always
Treadmill	5-10 races	Cycling, Swimming	Self	No	Never	Always	Yes		No	No		Sometimes	Sometimes
Asphalt	>10 races		Self, Friend	No	Never	Sometimes	Yes		No	Yes	Vitamin B, D and C	Sometimes	Sometimes
Asphalt	>10 races	Strength Training, Cycling, Elliptical, Body Pump	Self, Friend	Yes	Sometimes	Always	Yes		Yes	Yes	Women's One-A-Day	Sometimes	Sometimes
Asphalt	5-10 races	Yoga, Strength Training, Cycling	Self	No	Never	Always	Yes		No	No		Never	Always
Asphalt	>10 races	Yoga, Pilates, Cycling	Friend, Family Member	Yes	Never	Sometimes	Yes		Yes	No		Sometimes	Always
Asphalt	5-10 races	Yoga, Strength Training, Cycling, Stair Stepper, Soccer	Self	No	Never	Always	Yes		Yes	Yes	First Phorm Protein	Sometimes	Sometimes
Asphalt	5-10 races	Strength Training, Cycling, Swimming	Self, Friend, Significant Other	No	Never	Always	Yes		No	No		Never	Always
Treadmill	>10 races	Strength Training	Self, Friend, Significant Other	Yes	Never	Always	Yes		Yes	Yes	Women's One-A-Day, Pre-workout for energy if necessary	Sometimes	I Don't Know
Treadmill, Asphalt	<5 races	Elliptical, Stair Stepper	Self	No	Never	Always	Yes		Yes	No		Sometimes	Always
Treadmill, Asphalt	<5 races	Pilates, Strength Training, Stair Stepper	Self, Family Member	No	Never	Always	Yes		Yes	Yes	B12, Iron, Zinc, Chllorella, Probiotic	Sometimes	Sometimes
Treadmill, Asphalt	>10 races	Strength Training, Cycling, Stair Stepper	Self	Yes	Never	Always	Yes		Yes	Yes	Vitamin D, Iron	Sometimes	Always
Trails, Asphalt	5-10 races	CrossFit	Self, Friend, Family Member, Co-worker	Yes	Never	Always	Yes		No	No		Always	Always
Trails, Asphalt	>10 races	Yoga, Strength Training, Cycling	Self, Friend	Yes	Never	Always	Yes		Yes	Yes	Whey Protein Shakes	Sometimes	Always
Trails, Asphalt	<5 races	Yoga, Strength Training, Cycling	Self, Friend	No	Never	Always	No	30	Yes	No	Daily Vitamin	Sometimes	Always
Trails, Asphalt	<5 races	Yoga	Running Club	Yes	Never	Always	Yes		No	No		Never	Always
Track, Trails	<5 races	Yoga, Strength Training, Cycling, Stair Stepper, Swimming	Self, Friend, Family Member, Co-Worker	No	Sometimes	Always	Yes		Yes	Yes	Vitamin D, Glucosamine Chondrotin, Multi-Vitamin	Sometimes	Sometimes
Trails, Asphalt	5-10 races	Yoga, Strength Training	Self	Yes	Never	Always	Yes		Yes	Yes	Ideal Fit Protein Powder	Sometimes	Always
Asphalt	<5 races	Strength Training, Elliptical, CrossFit	Self	No	Never	Always	No	2-3	No	Yes	Whey Protein	Always	Sometimes

Q28_1	Q29_1	Q30_1	Q31_1	Q32_1	Q33_1	Q34_1	Q35_1	Q36_1	Q37_1	Q38_1
I am eager to run - 1	Running is enjoyable - 1	I don't enjoy running (R) - 1	Running is of vital importance to me - 1	My life is much more fulfilled because I run - 1	Running is pleasant - 1	The idea of running terrifies me (R) - 1	I would reorganize or change my timetable in order to satisfy my need to run - 1	I have to force myself to run (R) - 1	To go a day without running is a relief for me (R) - 1	Running is a climatic point of my day - 1
4	4	2	4	4	4	1	5	3	2	3
5	5	1	5	5	5	1	4	1	1	4
4	4	2	4	4	4	1	4	3	2	4
4	4	2	2	2	4	1	3	2	1	3
3	4	2	2	3	4	1	2	4	3	3
4	4	2	4	4	3	1	4	3	3	3
4	4	2	2	3	4	3	2	4	3	2
4	5	1	5	5	4	1	5	2	2	5
3	4	2	4	3	4	3	3	2	1	4
5	5	2	5	5	5	1	4	3	2	4
5	5	1	5	5	5	1	5	1	1	5
3	3	4	2	3	3	3	3	3	2	4
5	5	1	4	4	5	1	4	1	2	3
5	5	1	5	5	5	1	5	4	2	5
5	5	1	4	5	5	1	5	1	3	4
5	5	2	3	4	4	1	3	3	3	4
4	4	2	3	3	4	1	5	2	3	2
3	4	1	2	3	3	1	4	1	3	3
3	4	2	3	4	3	1	4	2	4	3
5	5	1	5	5	5	1	4	3	2	4
3	3	2	3	2	3	2	4	2	4	3

Q39_1	Q40_1	Q41_1	Q42_1	Q43_1	Q44_1	Q45_1	Q46_1
If the weather is too cold, hot or windy, I choose not to run (R) - 1	I would not change plans with friends so that I could go running (R) - 1	I have stopped running for at least a week for other reasons than having an injury (R) - 1	If there were another way to maintain my current fitness level, I would never run again (R) - 1	After running, I feel better - 1	I would continue running while recovering from an injury - 1	Some days I run even if I don't feel like it - 1	I feel that I need to run at least once every day - 1
2	2	2	1	6	4	6	1
6	4	1	1	7	5	7	6
5	5	5	1	7	4	6	1
3	6	4	3	5	2	4	3
3	6	7	2	6	2	5	2
1	2	2	2	6	5	7	6
6	4	7	4	6	3	5	1
6	6	4	2	7	4	5	3
2	3	4	1	7	4	4	3
2	5	5	2	7	4	5	3
2	3	1	1	7	4	6	6
5	6	7	4	4	3	4	2
6	5	5	3	7	3	5	5
3	4	6	1	7	5	4	3
2	5	6	1	7	5	5	2
2	2	6	2	7	6	6	3
2	2	2	1	7	4	3	2
1	3	2	2	5	3	3	2
3	5	5	2	5	5	5	5
1	3	2	4	7	6	5	4
6	3	3	3	6	4	5	3

Master Participant Data

Subject	Foot Strike Pattern	Leg Tested	Age	Height (cm)	Weight (kg)	Hip ABD					Hip EX ROT					Hip EXT					HADD_ROM	HIR_ROM	TRFL_ROM	TRLL_ROM	Training Mileage
						Trial 1	Trial 2	Trial 3	Mean	Normalized Force to BW (%)	Trial 1	Trial 2	Trial 3	Mean	Normalized Force to BW (%)	Trial 1	Trial 2	Trial 3	Mean	Normalized Force to BW (%)					
CON 001	Rearfoot	Left	29	174	74.5	31.6	32.4	29	31	41.61073826	5.7	6	6.4	6.03333333	8.098434004	37.3	37.2	35.3	36.6	49.12751678	4.152779	5.500393	0.574176	2.07204	22
CON 002	Forefoot	Left	18	162	57.4	29.6	26.4	26.5	27.5	47.90940767	4.4	4.9	4.9	4.73333333	8.246225319	26.3	26.4	25.6	26.1	45.47038328	15.697345	3.511791	3.852542	1.658165	27.5
CON 003	Forefoot	Left	28	163	52.3	19.1	16.9	18.7	18.2333333	34.86297004	6	5.6	4.8	5.46666667	10.45251753	20.1	20.2	21.7	20.6666667	39.51561504	11.749878	4.788109	1.843181	4.078239	11
CON 004	Rearfoot	Left	24	170.5	64.3	26.1	24.4	24.9	25.1333333	39.08761016	5.7	6.4	5.6	5.9	9.175738725	23.3	22.1	23.3	22.9	35.61430793	10.903126	11.810711	2.958509	3.876147	10
CON 005	Rearfoot	Left	37	174.1	59.7	30.9	29.6	33.1	31.2	52.26130653	5.1	5.6	6	5.56666667	9.324399777	20	20.9	21.1	20.6666667	34.6175321	9.833021	6.284264	3.485588	1.320682	10
CON 006	Rearfoot	Left	38	181.7	81.8	18.3	17.9	19.6	18.6	22.73838631	8	7.2	7.4	7.53333333	9.209453953	19.7	20.8	19.5	20	24.44987775	11.297873	12.263727	3.019727	0.781029	36
CON 007	Forefoot	Left	28	166.8	57.3	21.8	20	21.3	21.0333333	36.70738802	5.7	6.1	5.6	5.8	10.12216405	18.3	19.1	19.7	19.0333333	33.21698662	14.42959	5.984457	2.55476	1.387257	10
CON 008	Rearfoot	Left	27	174.1	64.2	21	20.1	19.1	20.0666667	31.25649013	6.8	7.2	7	7	10.90342679	30.2	27.6	28.8	28.8666667	44.96365524	17.703604	6.272556	0.586278	1.849414	35
CON 009	Rearfoot	Left	26	163.2	79.6	28.7	29.3	28.4	28.8	36.18090452	7.7	7.7	7.4	7.6	9.547738693	19	21.7	21.4	20.7	26.00502513	10.46106	2.242575	1.019944	6.310094	20
CON 010	Rearfoot	Left	29	180	64.2	18.4	20.1	20.3	19.6	30.52959502	5.6	6.1	5.3	5.66666667	8.826583593	25.3	26.2	24.7	25.4	39.56386293	9.546154	16.129982	5.946542	0.705646	17.5
CON 011	Midfoot	Left	29	163	48.4	14.8	13.5	16.2	14.8333333	30.64738292	4.9	6.5	5.1	5.5	11.36363636	17.2	16.6	19.1	17.6333333	36.43250689	13.914505	4.536077	5.048328	1.749185	30
EMTP 001	Rearfoot	Right	23	183	71.8	15.9	15.9	15.8	15.8666667	22.09842154	6	5.7	5.1	5.6	7.799442897	23.4	23	22	22.8	31.75487465	8.781015	4.972752	1.624382	1.195714	12
EMTP 002	Rearfoot	Left	20	171.5	71.1	25.9	28.4	27.1	27.1333333	38.16221285	7.2	7.4	6.6	7.06666667	9.939052977	17.2	18	15.9	17.0333333	23.95686826	11.7665	10.876356	3.262019	1.312585	20
EMTP 003	Rearfoot	Left	20	162	58.2	28.7	31.5	29.3	29.8333333	51.26002291	8.8	8	6.8	7.86666667	13.51660939	33.1	34.5	33.6	33.7333333	57.96105384	1.311359	10.874428	2.547044	0.891424	17.5
EMTP 004	Rearfoot	Left	36	162.6	66.6	27.7	27.7	29.1	28.1666667	42.29229229	10.2	8.7	9.7	9.53333333	14.31431431	38.9	39.5	38.9	39.1	58.70870871	16.295996	5.645289	1.792638	4.906793	8.5
EMTP 005	Rearfoot	Right	23	173.1	62.7	31.1	32.9	33.5	32.5	51.83413078	6.3	6.6	7.1	6.66666667	10.63264221	35.5	32.9	34.3	34.2333333	54.59861776	13.370649	7.071264	2.554081	1.580135	22
EMTP 006	Rearfoot	Right	41	174	62.4	18.2	21.2	20.3	19.9	31.89102564	6.8	5.8	6.8	6.46666667	10.36324786	19.7	20.9	20.8	20.4666667	32.7991453	5.408759	2.451115	4.321877	4.413202	10
EMTP 007	Rearfoot	Right	29	169.8	58.5	21.4	18.8	22.6	20.9333333	35.78347578	6	6.7	6.5	6.4	10.94017094	32.7	31.4	32.2	32.1	54.87179487	13.135588	6.567228	1.602808	3.086744	18
EMTP 008	Rearfoot	Left	25	181.6	69.1	28.2	27.4	28.8	28.1333333	40.71394115	8.5	9.7	9.1	9.1	13.16931983	34.8	35.1	34.2	34.7	50.2170767	15.320412	11.451395	7.130725	2.780918	40
EMTP 009	Rearfoot	Right	29	180	68.3	18.3	17.9	19.8	18.6666667	27.33040508	6.4	6.6	6	6.33333333	9.272816008	17	17.1	17.7	17.2666667	25.28062469	27.48172	9.716843	3.29336	4.83572	30
EMTP 010	Rearfoot	Left	26	174	69.3	15.4	14.2	14	14.5333333	20.97162097	6.4	5.8	5.1	5.76666667	8.321308321	26	28.6	27.5	27.3666667	39.49013949	14.026073	2.530642	4.447018	3.484063	20