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Investigation of relationships between physical characteristics of recreational runners and lower extremity injuries

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An Investigation of Relationships Between Physical Characteristics of Recreational Runners and Lower Extremity Injuries

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We hereby certify that this dissertation, submitted by *Steven Jackson*, conforms to acceptable standards and is fully adequate in scope and quality to fulfill the dissertation requirement for the degree of Doctor of Philosophy in Physical Therapy.

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ABSTRACT

Purpose: The purpose of this study was to investigate the relationship between anthropometric measurements, proximal and distal lower extremity muscle performance, core muscle endurance, lower extremity flexibility, and neuromuscular control with the incidence of injury in recreational runners over one season. Also, when a relationship was established, we sought to evaluate the predictive validity for any of the variables being investigated for risk of injury in this population.

Study Design: Prospective cohort

Methods: Anthropometric measurements, proximal and distal isometric lower extremity muscle performance, isometric core muscle endurance, lower extremity flexibility and neuromuscular control were measured in 75 recreational runners prior to the start of a graded marathon training program. Incidence of injury was tracked over the course of 18 weeks, May 2014 – October 2014. Data was analyzed comparing the differences between injured and non-injured groups.

Results: There were 33 repetitive stress injuries yielding a gross injury rate of 46% (male n=13, female n=20). Of all the variables analyzed, 5 variables emerged as possible a predictors including age, dominant limb rear foot posture, non dominant limb ankle DF ROM (extended), limb difference of Y balance scale composite scores and limb difference in the 6 M hop test. These variables were entered into a binary logistic regression analysis. Results of the regression indicated only the composite Y balance score difference variable as yielding a significant contribution ($p = 0.01$), with and predictive validity, (OR = 1.46, 95% CI =1.127 – 1.892). The model predicted 69.2% of the injuries with a specificity of 82% and sensitivity of 54.5%. A cutoff point of 3.6% was determined using a receiver operating characteristic curve. Runners were 3 times more likely to get injured with an asymmetry ≥ 3.6%.

Conclusions: An asymmetry of lower extremity neuromuscular control ≥ 3.6% measured by the Y balance scale has been identified as a potential risk factor for injury in recreational runners.

Clinical Relevance: This test can be performed as part of a pre-training screening or physical and may be helpful in identifying recreational runners at risk for injury.

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CHAPTER 1: INTRODUCTION

Problem Statement and Goal

Distance running as a means for fitness has gained popularity in recent years. An illustration of this can be observed by the substantial increase in road race participation. In 1990, 4.8 million individuals participated in running with an increase to 19 million in 2013.[1] An increase in running participation has also resulted in an increase in incidence of lower extremity injuries.[2-4] The rate of injury is estimated to range between 19.4% and 79.3% for recreational runners over the course of 1 year.[4] As with any musculoskeletal disorders, prevention of injury is desired when possible. The foundation of effective prevention is the ability to accurately identify risk factors, or variables that increases ones chance of experiencing an injury.[5]

Determining risk factors for injury is considered epidemiologic research. Prospective cohort studies are considered one of the strongest types of evidence in epidemiologic research.[6] Previous prospective studies of recreational distance runners have reported several risk factors including training error (increasing mileage too quickly), gender (female > males), history of previous injury, and body mass index (BMI) > 26 kg/m^2.[3-5,7,8]

Recent studies have investigated a potential relationship between hip external rotator/ abductor weakness, abnormal lower extremity mechanics, and various lower extremity injuries in runners and other athletes.[9-19] Many of these studies are retrospective in nature, investigating characteristics of injured athletes compared to non injured athletes. As a result, one cannot delineate whether hip weakness and abnormal mechanics are a cause or consequence of lower extremity injuries in runners.

Others contend that the focus on hip weakness is too narrow a view suggesting that other factors such as core strength, trunk proprioception, and lower extremity neuromuscular control may play a role in abnormal lower extremity mechanics.[18,20-22] Bell et al recently reported that decreased plantar flexor strength ($p = 0.007$) was found in a group that exhibited medial knee displacement or increased knee valgus with the overhead squat test compared to controls who could perform the test with proper mechanics.[23] These results correlate with previous electromyographical (EMG) study that shows significant increase in medial gastrocnemius activation ($p = 0.01$) with valgus stress to the knee indicating that it may be a key component with valgus moment support.[24]

Neuromuscular control (NC) is defined as the active restraint of excessive motion and coordinated dampening of joint loads in response to sensory feedback.[25] NC is often measured in the research by force plates or motion sensor analysis. These tests require expensive equipment and are not readily available to all clinicians. The Star Excursion Balance Test (SEBT) is a commonly used clinical test to measure lower extremity neuromuscular control of athletic populations.[26-28] The SEBT has been demonstrated to have predictive validity for risk of lower extremity injury in high school basketball players.[28] Specifically, players with an anterior right/left reach difference greater than 4 cm were 2.5 times more likely to suffer a lower extremity injury.[28]

Despite there being a fair amount of research identifying risk factors for injury in distance running, there is a paucity of prospective studies investigating the relationship among hip weakness, ankle plantar flexion weakness and lower extremity neuromuscular control with lower extremity injuries in this population.

Research Question

What is the relationship between anthropometric measurements, proximal/ distal lower extremity muscle performance, core muscle endurance, lower extremity flexibility and neuromuscular control with incidence of injury in recreational runners? In addition, if a relationship is established, to what degree does each variable contribute to the incidence of injury in recreational runners? Finally, is there predictive validity for injury within this population for any of the variables being investigated?

Relevance and Significance

The relationship between hip external rotator/abductor weakness and various lower extremity injury diagnoses has been investigated/established/questioned. Weakness of hip abductor and external rotator strength is hypothesized to increase the dynamic valgus moment at the knee during running. While most of the motion in the knee occurs in the sagittal plane, decreased strength of the hip has been shown to result in increased transverse plane motion.[9-19] Bell et al[23] reported contradictory results with their study reporting greater strength of hip abductors and external rotators in an experimental group that presented with more medial knee displacement or dynamic knee valgus moment with the overhead squat compared to controls with normal mechanics. This study also reported a statistically significant relationship between plantar flexor weakness and medial knee displacement.[23] Regardless of origin, these aberrant mechanics can result in increased abnormal forces or strain on structures about the knee, ankle, and foot resulting in various injuries such as patellofemoral syndrome, iliotibial band syndrome, and medial tibial torsion syndrome. Other injuries such as plantar fasciitis and Achilles tendonitis are possible, but knee injuries have been found to be much more prevalent.[2-4,8] While acute injuries such as ligament sprains or muscle strains are possible, the majority of running related injuries can be contributed to overuse.[2-5,29]

An overuse injury has been defined as an “injury of the musculoskeletal system that results from the combined fatigue effect over a period of time beyond the capabilities of the specific structure being stressed.”[5] This definition is based on the theory that all biological tissues have a tensile limit or failure point.[5,30,31] Stress to tissues at or below this point may not result in injury if sufficient time allowed for the tissue to recover. An injury can occur if the stress applied exceeds the failure point or sufficient recovery time is not allowed between applications of stress.[5,30,31]

Distance running is a sport or activity predicated on repetitive stress over a long duration. Though it has not been standardized, observational research shows that elite runners average a cadence of 180 steps a minute while beginning runners average approximately 160 steps per minute at any distance over 2km.[32] Currently, the most definitive research shows that weekly distance ran and a rapid increase in mileage (or repetition) is the strongest risk factor associated with running related injuries.[2,4,5,8]

Practical Applications

In a recent editorial, Fredericson and Misra discuss the need for prospective studies to "more completely delineate the role of proximal muscle strength with lower extremity injuries."[2] Others contend that lower extremity neuromuscular control plays more of a role than muscle performance with aberrant mechanics at the knee with athletic activities such as running or jumping.[20] Results of this study may help to further clarify relationships between these impairments and incidence of injury in recreational runners. We also hoped to identify tests that may be performed as part of a pre-distance running screen and potential interventions that can be integrated into a cross training regimen for distance running in an effort to reduce the occurrence of lower extremity injury with this population.

Approach

Participants

A sample of convenience was obtained from volunteers of various running groups and clubs training in preparation for local half or full marathons in the Chicago, Illinois area. Running groups are organized with specific running programs that assist novice runners achieve their goal of running a marathon or half marathon. These running groups have structured training regimens designed to gradually increase running distance leading up to the event. Use of these groups as participants helped to control for variables such as running surface, running distance ran per week, and increasing running distance too rapidly, which had been found to be the strongest predictor of running injuries.[2-5,8]

The term novice or recreational runner is one that has been used in the literature to describe the population of non-elite or noncompetitive runners.[7,8,10] This served as the operational definition of recreational runners in this proposed study. Previous prospective running studies have been very liberal with their inclusion and exclusion criteria because recreational runners span a wide range of demographics, backgrounds, experience, and characteristics. History of previous injury has been established as the second strongest risk factor for potential running injuries.[2,5,7,8] Despite this finding, many previous prospective studies have not excluded subjects due to previous running related injuries.[4,7,8] Bredwig et al addressed this concern by excluding subjects if they suffered a lower extremity running related injury within the past three months.[33] The inclusion/exclusion criteria used was healthy 18-65 year old males/females, non elite or noncompetitive runners who had not suffered a previous running related lower extremity injury within the past three months.

Procedures

Participants were required to fill out a base line questionnaire addressing age, gender, height, weight, running experience, shoe wear, cross training participation and history of previous injury. If an injury was revealed, detailed description of previous injuries including location, duration since onset or cessation of symptoms, and time off from running was provided. Additional information including cross training and/or participation in other sports or recreational activities was also recorded.

Anthropometric Measurements

In addition to height and weight, other anthropometric measurements were also recorded including leg length discrepancy, medial longitudinal arch angle, static rear foot position, and Q angle. Leg length discrepancies have been reported as a potential risk factor for recurrent stress fractures in athletes including runners.[34] Leg length was measured from anterior superior iliac spine to medial malleolus.

Medial longitudinal arch measurements have also been validated as a predictor of dynamic foot posture with midstance of gait by use of instrumented gait analysis.[35] This method has also reported good intra-tester (r = 0.90) and inter tester reliability (r = 0.81).[36] Medial longitudinal arch angle was be measured as originally introduced by Dahle et al with describing an intersecting a line from the medial malleolus to the navicular tuberocity with another line from the navicular tuberosity to the first metatarsal head. Angles ≤ 90 degrees were defined as low and associated with a pronated foot. Angles ≥ 180 degrees were defined as high and associated with a supinated foot.[37] This study also used rear foot position to further describe the static posture of the foot. Calcaneal inversion greater than 3 degrees was associated with a supinated foot while calcaneal eversion greater than 3 degrees was considered associated with a pronated foot. Static rearfoot position was measured in weight bearing with axis of goniometer over line bisecting the posterior calf and movable arm bisecting the posterior calcaneus.[37]

Quadriceps angle (Q angle) was measured proximally by a line from the anterior inferior iliac spine to the mid patella and distally by a line from mid patella to the tibial tubercle. Powers describes the Q angle as reflecting the frontal plane forces on the patella.[18] Huberti and Hayes report that a 10 degree increase in the Q angle results in a 45% increase in patellofemoral contact pressure.[38] Good reliability for measuring Q angles with a goniometer has reported for both intratester (ICC = 0.92) and intertester (ICC = 0.88).[39] Interestingly, this same study reports a significant difference between Q angles measured with an magnetic resonance imaging versus a goniometer ($p < 0.05$) noting that goniometric measurements underestimate the degree of Q angles when matched with MRIs.[39] For the purposes of this study, Q angles were measured with a goniometer as typically performed clinically.

Range of Motion and Flexibility

Bell et al identified decreased flexibility of ankle musculature as another contributing factor to medial knee displacement with overhead squatting.[23] Lun et al measured ankle dorsiflexion amongst other static lower limb variables in recreational runners in a prospective study but found no significant difference between the group of athletes who suffered injuries compared to the non injured group.[40] This study suffered from a high attrition rate as 153 subjects enrolled and only 87 completed the entire study. Interestingly, the authors did note if injured runners were classified into groups by diagnosis, there was a significant difference between the groups for ankle dorsiflexion with for those with patellofemoral syndrome.[40] Decreased ankle dorsiflexion has been associated with increased pronation of midfoot with ambulation. Ankle dorsiflexion range of motion was measured using a goniometer with one arm bisecting the distal fibula and the other bisecting the 5th ray. These measurements were taken with knee bent and knee extended to differentiate between soleus and gastrocnemius flexibility.

In addition to ankle dorsiflexion, mobility of the 1st ray has also been implicated in aberrant running mechanics. Dicharry reports less than 30 degrees metatarsophalangeal joint (MTP) extension of first ray significantly alters the kinematics of the foot and ankle with running.[41] This limitation has been associated with a medial heel whip with running due to inability to roll over the forefoot at toe off. First ray MTP extension was measured bilaterally with a hinged finger/toe goniometer.

Muscle Performance

Isometric muscle performance was measured using the micro*FET II*^{TM} (Hogan health industries, Draper, UT, USA) hand held dynamometer (HHD). This device is portable and practical for use in a clinical setting. Researchers employing hand held dynamometry have reported concurrent validity for measurement of muscle performance of lower extremity strength in healthy individuals (r = 0.74 to 0.78) when compared to gold standard isokinetic dynamometry.[42] These researchers also reported intra-session intra-rater reliability of lower extremity muscle performance healthy individuals ranging from ICC 0.16 – 0.98.[42] The wide range of reported reliability can be attributed to differences in testing methods and population investigated. Accuracy of HHD measurements can be affected by inadequate strength of the tester and lack of stabilization of participant and device.[43] Studies that incorporate a stabilizing apparatus produce better reliability measurements.[42,44-46] Many of the stabilizing techniques used in previous studies are often impractical for clinical use and limit the portability a HHD. Kolber et al investigated the use of a portable PVC stabilization device (StabD) and HHD, reporting excellent test retest reliability for isometric external and internal rotation of the shoulder (ICC = 0.971 – 0.972).[47] To my knowledge no studies have investigated the use of a PVC StabD for the lower extremity in healthy individuals.

Isometric hip external rotation, hip abduction, knee extension and ankle plantar flexion was measured using a hand held dynamometer (HHD), stabilizing techniques and a portable stabilization device. These four movements were chosen because previous research reports weakness of these muscle groups can associate with increased transverse plane motion about the knee.[9-18,23,24]

Isometric hip abduction was measured in the supine on a treatment table with a stabilizing strap across the pelvis. The force pad of HHD was place 5cm above the knee joint line and with other end of StabD stabilized against a wall. Previous studies report fair to good intrarater reliability (ICC = 0.88 to 0.94) of this test position with participant and micro*FET II*^{TM} stabilized.[45,48] Hip external rotation was measured with participants in the sitting position on the edge of a plinth with hips and knees flexed to 90 degrees. The test leg was anchored with a strap at the thigh and a towel roll was placed between the legs to limit involvement of hip adductors.[9-11,13] The force pad of HHD was placed 5 cm proximal to the medial malleolus of test leg with other end of StadD against a wall.

A recent EMG study reports the primary muscle activated during absorption phase of running is the quadriceps.[49] The aberrant knee valgus moment occurs during this phase of gait. Quadriceps muscle performance was measured with participants sitting on the edge of the plinth with hips and knees flexed to 70 degrees. A stabilizing strap was placed over bilateral thighs just distal to the hip joint line bilaterally and arms were folded across chest. The force pad was placed 5 cm above imaginary bimalleolar line. Ankle plantar flexion was measured on a plinth in long sitting position and arms across chest without back support. The force pad of HHD was placed on the plantar surface of the metatarsal heads with the other end of StabD against a wall. This test position without the StabD has been reported to have good to excellent intrarater reliability (ICC of 0.73 - 0.93, standard error of measurement range 8-22 N) in healthy subjects.[23]

Once positioned, the testing procedure using the StabD was the same for each measurement as described by Kolber et al.[47] Participants were asked to perform isometric contraction against manual resistance to ensure their understanding of the desired action to be measured. The stabilization device was then positioned as described previously for each test position. Participants were asked to maintain a six seconds isometric contraction. Peak values were recorded for three repetitions. There was a ten second rest period between contractions. Rest period between muscle groups tested were set at three minutes to allow for change in test position. Testing sequence was alternated between positions to avoid systemic error.[47] Fifteen participants were randomly chosen and measured again after a 10 min rest period to measure intra-rater reliability. Intra-class correlation coefficients were used to analyze pilot intra-rater reliability of HHD with StabD for the lower extremity.

Hewett et al suggests that a key component of improving neuromuscular control is the ability to control the body's core dynamic stability of the knee in subjects following anterior cruciate ligament (ACL) reconstruction.[22] McGill et al describe core trunk stability measurement in terms of endurance by holding static positions challenging anterior, posterior, and lateral muscle groups.[50] The flexor endurance was performed with the participant in a supine hook lying position and arms folded across chest with a 60-degree wedge supporting the spine posteriorly. The wedge was removed 10 cm away from subject and the duration at which the participant was able to maintain the 60 degree angle was measured.[50]

Extensor endurance was measured with the participant positioned prone with a small pillow under the lower abdomen to decrease the lumbar lordosis. Then participants were instructed to maintain maximum cervical flexion with pelvic stabilization through gluteal muscle contraction with goal of holding the sternum off of the table as long as possible, as previously described by Ito et al.[51] The duration the participant was able to maintain appropriate test position was measured and recorded.

Lateral trunk endurance was measured with the participant in sidelying of side being measured. The top leg was place in front of the bottom leg. Participants were instructed to lift their hips off of the plinth supporting their upper trunk with forearm. The top, uninvolved arm was folded across opposite shoulder. The duration participants are able to hold hips off plinth was measured.[50]

Lower Extremity Neuromuscular Control

Two primary tests were used to measure lower extremity neuromuscular control (LENC). The Star excursion balance test (SEBT) incorporates both strength and LENC to perform. It has been shown to be predictive for risk of injury in high school basketball players finding that players with an anterior right/left reach difference greater than 4 cm are 2.5 times more likely to suffer a lower extremity injury.[28] The SEBT consists of 8 reaching components with one leg while maintaining single leg stance on the opposite lower extremity in the center of a grid taped to the floor. Maximal reach distance is measured for each direction and normalized accounting for leg length. Good intratester reliability on different days (ICC of 0.78 – 0.96 on days 1 and 0.82-0.96 on day 2) for the SEBT has been reported.[26] Redundancy was also found in several of the directions of the test and has been simplified from 8 reaches to 3 directions which is now known as the Y balance test (YBT).[52] Participants were allowed 6 trials for each direction on each leg as motor learning for the task has been shown to plateau after this point. Subjects were allowed 3 trials in each direction; the greatest distance attained was used for statistical analysis.

The neuromuscular test used is the timed 6-meter hop test. This test is another inexpensive practical test that can be easily performed in a clinical setting. This test is one component of a series of 4 hop tests that have been found to be valid and reliable tools to measure progression of subjects following an ACL reconstruction.[53] The timed 6-meter hop test requires the elements of forward propulsion, speed, and force attenuation in conjunction with neuromuscular control, all of which are similar constructs found with running. Participants were asked to hop on one lower extremity for over a distance of 6 meters and measured for time. The test was performed bilaterally for 2 repetitions. Mean times of both trials were recorded for each leg.[53]

Injury Recording

Participants and running group leaders were educated on the process of how injuries were recorded. Runners were asked to keep a weekly running log. If an injury occurs, the location or body part involved was recorded. The injury was classified using the method utilized by Taunton et al[7] which includes:

- *Grade I: pain after running*
- *Grade 2: pain during running but not restricting distance or speed*
- *Grade 3: pain during running restricting distance or speed*
- *Grade 4: pain preventing all running*

In addition, subjects recorded how many days of running sessions they are unable to participate in due to injury. This information was cross-checked by group leaders who kept track of attendance and injured runners as part of their normal duties. Participants were asked to fill out a post training regimen questionnaire to identify any other injuries or discrepancies found with other records. Length of injury recording was 18 weeks.

Data Analysis

Descriptive statistics were employed to show distribution of all variables collected or measured prior to the start of the training regimen and during including injuries, body part involved, and severity grade of injuries. A gross overall measurement of incidence rate of injury was derived by dividing the number of injuries (regardless of location and severity) by the number of total participants.[7] Differences between injured participants' measurements and characteristics were compared to non-injured participants' using an independent *t* test. The level of significance was set at $\alpha = 0.05$. Variables that exhibit statistically significant difference between the groups were considered potential predictors. Once these are identified, a binary logistic regression was also used to develop a model to potentially predict the risk injury based on participant demographics, training characteristics, muscle performance and results of functional tests. A receiver operating characteristic (ROC) curve was generated to identify potential cutoff values for the clinical tests to predict injury occurrence. Intraclass correlation coefficients (3,1) were used to measure pilot test-retest reliability of HHD with StabD for lower extremity muscle performance. Strength measurements were normalized for body mass using the formula: strength (N) /body mass in kilograms (kgs). Lastly, The minimal detectable change (MDC) for each variable was also calculated at 95% level of confidence, employing the formula $MDC_{95} = 1.96 \times \sqrt{2} \times SEM$.[54]

Resources

A proposed study of this nature is feasible, as it does not require significant funding or resources. Hand held dynamometry has been shown to be a valid and reliable measurement tool for hip abduction/external rotation and ankle plantar flexion strength. This can be used clinically and is relatively inexpensive compared to large isokinetic devices such as Biodex^{TM} and Cybex^{TM} machines. Subjects can be obtained via volunteers from various running groups and clubs training in preparation for local half or full marathons as mentioned previously. Participants were provided with running logs, which can that were electronically recorded on a computer. The YBT and 6-meter hop test require only measuring tape, markers, and a stopwatch to administer.

Barriers and Issues

There were two primary issues of concern regarding this proposed research. This study can be considered as an epidemiologic investigation of running related musculoskeletal injuries. Prospective cohort studies are considered one of the strongest types of evidence in epidemiologic research.[6] The drawback of these type of studies is they require large subject size to be able to show true variance based on the presence of the test variables opposed to chance.[6] Large subject group not only require more resources for recruitment but also generate a lot of data needs to be collected and analyzed. Additional research assistants were needed to aid in data collection for anthropometric measurements, muscle performance, and ROM/flexibility. These additional personnel were recruited and underwent specific training from the primary investigator on how the measurements were taken for the purposed of this study to ensure continuity of data collection. Interrater reliability between testers was assessed prior to study if more than one tester collected data for the same variable.

The second area of concern is that the incidence of injury statistic was largely dependent on the compliance of the participants. Even if subjects did actively write in the logs as instructed, the accuracy of their recordings was essential to the internal validity of this study. This information can be cross-checked by group leaders who keep track of attendance and injured runners as part of their normal duties.

CHAPTER 2: REVIEW OF LITERATURE

Introduction

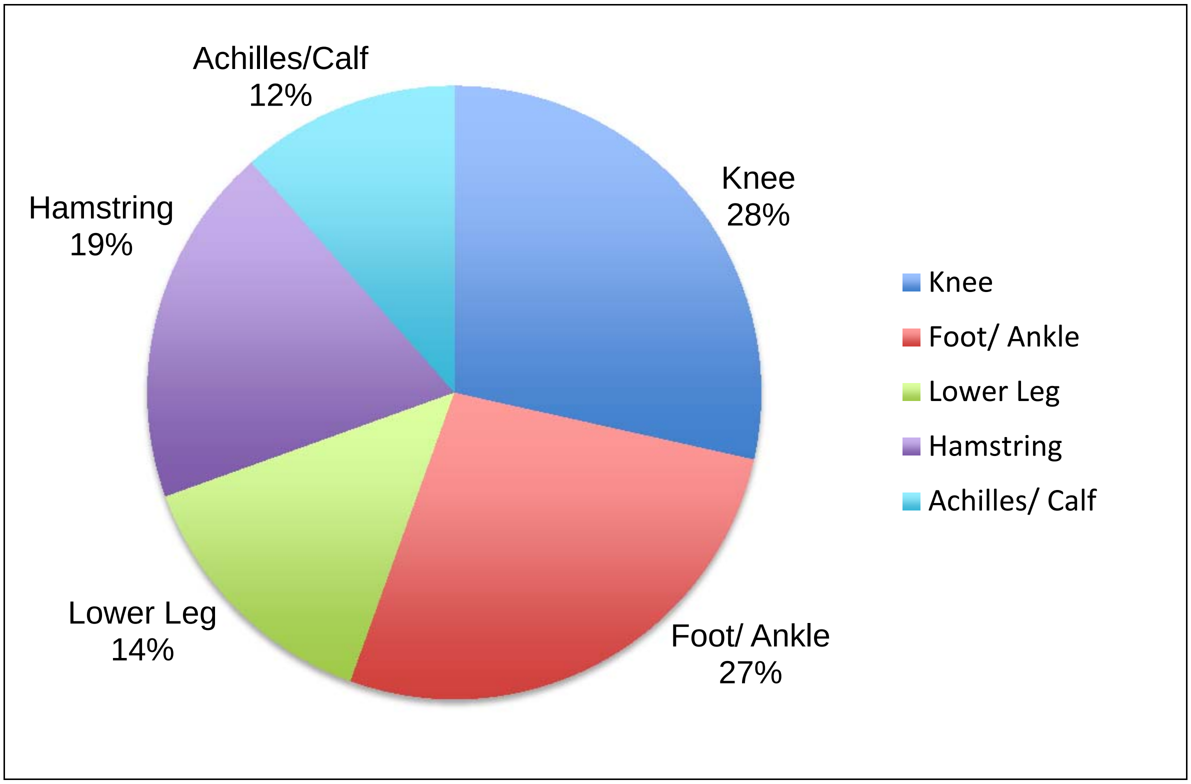
An estimated 30 million people in the United States choose running as a mode of exercise with 10 million who classify themselves as those who run regularly.[55] Injury rates have been reported as high as 90% by marathon participants with post race follow up questionnaires.[56] Sixty five percent of runners experience musculoskeletal-related injuries annually.[57] Fifty to seventy-five percent of these runners will lose at least 1 week of training due to injury.[55]

Despite the growing popularity of road running and the concurrent increased incidence of running related injuries, little is known about the intrinsic or extrinsic factors attributed to these injuries, especially in the novice runner population. This literature review will explore the etiology of common running related injuries, contributing factors, and biomechanical principles associated with running and gait. A thorough understanding of normal running and walking mechanics is needed to aid with identification of deviations and aberrant movement patterns that may potentially be associated with running related injuries.

Most Common Running Related Injuries

The next section of the review will focus on the most common lower extremity injuries found in recreational runners. Increasing mileage too quickly has been consistently reported to be the strongest predictor of running injuries.[2-5,8] History of previous injury has been established as the second strongest risk factor for potential running injuries.[2,5,7,8] While some injuries can be attributed to acute sprains or strains, most running injuries are classified as repetitive stress or overuse injuries.[3] The next section of the review will summarize the most common lower extremity overuse injuries found in recreational runners.

Figure 2.2
Distribution of Injuries[29]



Patellofemoral Pain Syndrome

The most commonly reported site of injury in the running population is the knee, accounting for nearly 28% of running injuries.[29] Another study reported an incidence of 42%.[58] The two most prevalent types of running related knee injuries are patellofemoral pain (PFPS) and iliotibial band syndrome (ITBS).[2,3,7,56,57] PFPS is the most common cause of knee pain of the general population in the US.[59] Historically, the primary cause of PFPS was considered to be aberrant lateral tracking of the patella, resulting in excessive compressive forces on the patellar facets.[60,61] Quadriceps weakness, imbalance of vastus medialis oblique (VMO)/vastus lateralis (VL) timing, and excessive static Q-angles (> 20 degrees) were previously thought of as chief contributors to abnormal patellar tracking.[62,63] Recent studies have reported no relationship between Q-angles and incidence of PFPS.[18,64,65] Currently, the more widely accepted view is based on the work of Powers et al[18] who introduced the concept of a dynamic Q angle. Rather than the patella tracking laterally on the femur, Powers and colleagues describe how the femur internally rotates at the hip altering its relation with the patella in subjects with PFPS.[17,18] Decreased muscle performance of hip abduction and external rotation has been shown to result in increased transverse plane motion with negative impact on patellofemoral mechanics.[9,11-19,66] The potential relationship between hip external rotator/abductor weakness, abnormal lower extremity mechanics, and various lower extremity injuries in runners and other athletes has been investigated in recent studies.[9,11-19] Many of these studies are retrospective in nature, investigating characteristics of injured athletes compared to non injured athletes. As a result, one cannot delineate whether hip weakness is a cause or consequence of lower extremity injuries.

Females with PFPS have been observed to exhibit 26% less hip abduction strength and 36% less hip external rotation strength compared to age matched controls without.[11] Runners with PFPS have been observed to demonstrate increased hip adduction during stance phase, even becoming more pronounced with fatigue.[66]

Interestingly, no significant difference was observed in hip strength when measured prospectively in runners who did and did not develop PFPS with a 10 week training program.[67] Focusing only on hip strength, other predisposing factors for PFPS were not investigated.[67] Further prospective research is needed to better understand the relationship between hip strength, aberrant knee valgus, and development of PFPS in recreational runners of both genders.

Iliotibial Band Syndrome

Another common knee injury associated with running is iliotibial band syndrome (ITBS) with an incidence reported near 12%.[58] The ITB is a thick strip of fascia from the tubercle of the iliac crest, extending down the lateral side of the thigh, and attaching to the lateral tibial condyle and into the proximal fibular head.[68] Previously, clinicians theorized that repeated knee flexion and extension caused friction of the band over the lateral femoral condyle.[19,58,68,69] A more recent investigation observed that the ITB moves very little and that the pain of ITBS results from compression of a layer of innervated fat and connective tissue between the ITB and lateral femoral epicondyle.[70]

Multiple factors that contribute to ITBS have been reported in the literature. A recent biomechanical analysis by Grau et al classified runners into two major categories.[71] One category consisted of less experienced runners, more likely to be female, demonstrating weak hip abduction, increased hip adduction, and internal rotation of the knee. The other category consisted of advanced runners, exhibiting decreased hip adduction and knee external rotation.[71] A two year prospective study of 400 female runners reported increased hip adduction and knee internal rotation contributing to runners with ITBS.[72] A retrospective analysis of 2002 runners identified 168 runners as being diagnosed with ITBS.[58] Hip abductor weakness, leg-length discrepancies, and a history of downhill running were the most significant factors contributing to onset of ITBS in this sample of runners.[58] Interestingly, Grau further investigated the role of hip abductor weakness in runners with ITBS reporting no significant difference of strength between healthy runners and injured runners.[73] A major limitation of this study was a very small sample size, n = 20, 10 runners per group.[73] Of the 10 runners per group, 7 were male despite females being identified as more likely to be injured.[71] More research is needed to better explain the role of intrinsic and extrinsic factors associated with ITBS in runners of both genders.

Plantar Fasciitis

While the knee is most commonly involved, foot/ankle injuries are the second most common region for running related injuries accounting for up to 27% of all running injuries.[29] Plantar fasciitis (PF) is the most common cause of foot pain in runners.[29,58] PF is characterized as inflammatory or degenerative changes of the plantar fascia typically at its insertion on the medial calcaneal tubercle or along the longitudinal arch.[74,75] The exact etiology of PF remains unclear but the condition has been linked to training errors and excessive rearfoot pronation in runners.[7,76,77] Prevalence also tends to be higher in those with decreased dorsiflexion range motion (< 0 degrees) and a BMI > 30 kg/m^2.[74,78] In a retrospective analysis of 267 runners with PF, elevated longitudinal arches and excessive rear foot valgus were observed as the most common static intrinsic factors.[58] Greater tension forces of the plantar fascia have been observed in cadavers with greater arch height and length.[79] However, no significant difference was observed in studies that evaluated plantar longitudinal arch height and rearfoot alignment when comparing distance runners with PF to non injured controls.[80,81] Further research is needed to better delineate the role of both static and dynamic foot posture characteristics in running related injuries.

Achilles Tendinopathy

The prevalence of injuries to the Achilles tendon has been reported at 6.5- 9.5% in recreational runners.[29,58] The etiology of Achilles tendinopathy is attributed to excessive loading during vigorous physical activity.[82] Repetitive stress beyond a tendon's physiological threshold results in inflammation of the sheath and/or degeneration of the body of the tendon.[82] Loading of the Achilles tendon has been estimated to reach up to 9 kilonewtons during running (corresponding to 12.5 times the body weight). Tendon damage can also result from stresses within physiological limits, if sufficient time is not allowed for recovery of repetitive micro trauma.[82,83] Risks for development of Achilles tendinopathy include external and internal factors. Reported external risk factors include altered weight bearing surfaces (excessively hard, slippery or uneven), inappropriate footwear, and training errors.[82,83] Reported internal risk factors include old age, obesity, decreased gastrocnemius/soleus flexibility, and excessive subtalar eversion.[82,83] The elastic properties of the Achilles tendon plays a key role in attenuation of ground reaction forces and transference to kinetic energy to aid with propulsion with running. Variations in the lower extremity biomechanics, due to either internal or external factors, appear to be related the etiology of Achilles injuries in runners.

Stress Fractures

Besides soft tissues injuries, recreational runners are also susceptible to stress fractures defined as a partial or complete fracture of the bone due to repetitive submaximal loading.[84] The most common sites for fracture are the tibia and second through fourth metatarsals.[85] Stress fractures are one of the most severe running related injuries as they typically require 4-8 weeks of rest or non-physically demanding activity to heal.[84] Women have been reported more at risk than men purportedly due to a combination of less bone mineral density, menstrual irregularities, and nutritional issues commonly termed the female triad.[85,86] Other reported risk factors for both men and women include excessive hip abduction and rearfoot eversion during stance phase of running.[87] Aberrant mechanics have been associated with a decrease in the amount of time it takes for ground reaction force to reach its peak with initial contact of gait know as vertical loading rates.[88] Runners who develop stress fractures have been observed to have faster vertical loading rates than non injured runners.[88]

Training Errors

While the role of various internal factors such as aberrant mechanics and physical characteristics are still being investigated, training error is the most commonly reported risk factor for running related injuries.[2] However, the term training error is very broad and does not adequately describe the multiple variables associated with this concept.[2,5,89] Training characteristics can be categorized into four main categories: volume, duration, frequency, and intensity.[89] Training volume, the number of miles a runner runs over a period of time typically reported on a per week basis, has been established as one of the most consistent risks factors associated with running injuries reported in the literature.[2]

Running greater than 40 miles per week has been observed to be associated with an increased injury risk.[3,90] A 10 year retrospective study yielded similar results with an increased risk for women who run 40-49 miles per week and men who run 30-39 miles per week.[91] Runners are often cautioned about increasing training volume > 10% per week in a graded training program also known as the 10% rule. Despite its popularity, this has not been supported by the literature.[92] A randomized control trial of novice runners participating in a recreational 4 mile running event investigated this concept. The control group trained for 8 weeks, utilizing a "standard" training regimen increasing their volume at a rate of 23.7% a week. The test group trained for 13 weeks, increasing volume at a rate of 10.5% per week. At 20.8% for the control group and 20.3% for test group, the authors reported no statistically significant difference of injury rates between the 2 groups ($p = 0.90$) when measured after each respective program was completed.[92]

Volume has also been described in terms of duration, which is defined as how long a runner is engaged or exposed to the act of running (typically standardized to 1000 hours of exposure). The amount of duration tolerated differs between novice and experienced marathon runners. Novice runners report an incidence of 33 injuries per 1000 hours[8] as contrasted with , experienced marathon runners with an incidence of 7.4 injuries per 1000 hours.[93] Additionally, runners with experience less than 3 years have been reported to be 2.2 times more likely to experience a running related injury compared to more experienced runners.[94]

There is sparse literature concerning the other factors of training characteristics including frequency and intensity. Frequency has been defined as the number of sessions a runner participates in per week. Increased risk of injury has been reported for those who ran only once a week compared to those who ran 3 times a week.[7] Other studies report increased risk in those who ran 6-7 times per week compared to those who ran 2-5 times.[3,90] When further analyzing the data, controlling for volume in the aforementioned studies, they reported no significant difference of injury rates based on frequency.[89] More research is needed to better investigate the effect of frequency on risk of injury in recreational runners.

Training intensity is commonly described in terms of average pace in minutes per mile (or kilometer) or kilometers per hour.[89] The literature on the relationship between pace and incidence of running related injuries is conflicting.[3,93,95] Jacobs and colleagues report runners with a pace faster than 8 minutes/mile had increased incidence of injury compared to those slower than 8 minutes/mile.[95] This descriptive study detailed the training experience of entrants leading up to a 10-kilometer race but was not designed to control for other confounding variables. Interestingly, they report their group of injured runners also ran greater volumes and with greater frequency than the non injured group.[95] Both Walter et al and Jakobsen et al reported no significant relationship between average pace and increased risk for injury between groups of injured and non injured runners when controlling for volume and frequency.[3,93] More research is needed to better investigate the effect of training pace on risk of injury in recreational runners.

Biomechanics of Ambulation and Running

One of the many challenges with identifying risk factors for running is the innate variability and anatomical variations within individual runners.[5] In addition, runners tend to naturally self-select a gait pattern that minimizes metabolic costs.[96] As a result, there has been no consensus or accepted ideal running form, making it difficult for clinicians and/or researchers to consistently determine which deviations or impairments may be related to increased risk for injury in this population. Advancements in gait analysis technology have yielded a better understanding of running/ walking biomechanics. In this section, a review of current concepts in the literature regarding normative biomechanics of ambulation and running will be presented.

The gait/ running cycle refers to the time period from when one foot contacts the ground until that same foot makes contact with the ground again.[41] The gait cycle is divided into two primary phases. The stance phase refers to the period when the foot is touching the ground. The period when the foot is not in contact with the ground is known as swing phase of gait.[41] Double limb support is defined as the time period when both feet are in contact with the ground.[41] Conversely, single limb support refers to the period when only one foot is in contact with the surface. Spatial parameters that further describe gait include step length, stride length, and cadence.[41,97,98] Stride length is defined as the distance from initial contact of one foot to initial contact of the same foot. Step length is defined as the distance from initial contact of one foot to the initial contact of the opposite foot. Cadence or step rate describes the number of steps during a known time period. These factors can be used to describe both running and walking gait cycles.[97]

Running is distinguished from walking by the period in which neither foot is in contact with the ground known as the float phase.[41,97] With running, the stance phase is divided into two phases: absorption and propulsion. The absorption phase refers to the period from initial contact to mid stance, while propulsion occurs from mid stance to pre-swing phase of gait.[41,98] The swing phase is divided into initial and terminal swing phases. Double float occurs at beginning and end of each swing phase. The time in stance phase decreases and swing phase increases during running as compared to walking. As a result, the stance phase during running accounts for less than 50% of the gait cycle as contrasted to 60% during walking. Consequently, double-float phase duration increases to 20% during running. A greater velocity can be achieved by increasing step length, increasing cadence, or both.[41] See Table 2.1 below for a summary of running kinematics of the trunk, pelvis, and lower extremities.

Table 2.1
Running Biomechanical Analysis[41,98-103]

	Initial Contact	Loading Response	Mid- Stance	Terminal Stance	Pre- Swing	Initial Swing	Mid-Swing
Trunk	**Sagittal**: point of minimal flexion (2°)		**Sagittal**: point of maximal flexion (23°)				
Pelvis	**Sagittal**: point of minimal anterior tilting **Transverse**: External rotation weight bearing side	**Coronal**: tilts laterally towards weight bearing side	**Coronal**: pelvis level **Transverse**: maximal external rotation on weight bearing side	**Coronal**: maximal downward tilting away from weight bearing side	**Sagittal**: point of maximal anterior tiling	**Coronal**: pelvis rises away from weight bearing side	
Hip	**Coronal**: adducted 5 ° on weight bearing side **Transverse:** neutral position	**Coronal**: maximal adduction of weight bearing side **Transverse**: internally rotates	**Transverse**: peak internal rotation (6° - 14°)	**Coronal**: begins to abduct on weight bearing side **Transverse**: hip begins externally rotating to neutral	**Sagittal**: peak extension		**Sagittal**: peak flexion (60 ° **Coronal**: begins to abduct on weight bearing side
Knee	**Sagittal**: flexed at 25° on weight bearing side	**Sagittal**: flexes to 45° on weight bearing side **Transverse:** peak internal rotation 3.3° – 4.4 °	**Sagittal**: knee begins to extend	**Sagittal**: point of minimal flex 6.2° - 10.3 °		**Sagittal:** knee begins to flex	**Sagittal**: peak flexion (can reach 110 °)
Ankle/ Foot	Positioned 6° - 8 ° of supination of weight bearing side	Pronation begins of weight bearing side **Sagittal**: Talocrual joint in 3 ° plantar flexion at initial contact and gradually dorsiflexes with stance phase	In position of peak pronation 6° - 8 °. **Sagittal**: DF of the 1st MTP begins. Peak talocrual DF 24° Rapid progression from peak DF to plantar flexion	Gradual return to supinated position over swing phase to next initial contact **Sagittal:** Maximal DF of 1st MTP occurs here.	**Sagittal:** Peak talocrural plantar flexion		

1st MTP = first metatarsophalangeal joint; DF= Dorsiflexion

Lumbopelvic Kinematics

The spine or trunk is often described as one unit in the literature when discussing gait mechanics.[99] In the sagittal plane, the trunk typically is described as not extending past 0 degrees on a vertical line perpendicular to surface throughout the running cycle.[41] Runners shift their center of mass forward by way of a slight forward trunk lean increasing efficiency for forward propulsion.[41] The movements of flexion and extension occur between the point of minimal flexion (2 degrees) and the point of maximal flexion (23 degrees) in biphasic oscillations per running cycle.[99] Minimal trunk flexion occurs just prior to foot strike with the trunk flexing during the stance phase with maximal flexion occurring at the end of mid stance phase. The moment of minimal flexion changes as speed increases, occurring earlier in the double float phase before foot strike.[99] This sagittal plane motion of the trunk repeats itself as the contralateral foot strikes the ground.

Movement of the pelvis in the sagittal plane is described as anterior and posterior tilting. Total motion occurs only within a 5 – 7 degree range.[99] The minimizing of pelvic tilting has been theorized to be an energy conservation mechanism. In normal standing, the pelvis is tilted anteriorly 11 degrees. With running, pelvic tilting occurs in biphasic oscillations within one complete running cycle between 15 – 20 degrees.[99] The description of tilting is similar to that of the trunk where end ranges are demarked as moments of maximal or minimal anterior tilting. During the absorption phase of stance, the pelvis tilts posteriorly reaching the point of minimal anterior tilt. The pelvis then tilts anteriorly from mid stance reaching the point of maximal anterior tilt at toe off. This process is repeated for each lower extremity resulting in the biphasic oscillation pattern.[99]

In the coronal plane, the trunk laterally flexes to the weight bearing side with early to mid stance phase. As speed increases, this moment occurs earlier at initial contact of the weight bearing side. The net medial-lateral amplitude of displacement from a vertical axis has been reported to range from 4 to 18 degrees.[99] The range in which pelvic obliquity or lateral tilting has been reported varies due to the different subject populations and speed of runners observed in those studies. An amplitude of 10.6 degrees was observed in a cohort of male runners mean age 32 years while a range of 2 degrees was observed in a group of very young runners (5 -11 years old).[100,104] Pelvic obliquity is present at initial contact with ipsilateral side higher, leveling at midstance, and downward tilting reaching maximum downward obliquity at terminal stance of that side. During float phase, the pelvis rises with initial swing of the ipsilateral side. Maximal lateral bending of the trunk and maximum upward obliquity of the pelvis occur at the same time.

Investigations of axial trunk rotation in the transverse plane are sparse due to difficulty accurately measuring this motion. Three dimensional motion analysis demonstrated total trunk rotation in one direction of 23 degrees.[100] Pelvic rotation in the transverse plane ranges between 13.9 to 18 degrees. Axial rotation of the pelvis has been described as internal and external rotation. Internal rotation occurs when the ipsilateral side of the pelvis is anterior to the opposite side. Pelvic rotation with running in the transverse plane is nearly an exact opposite of that with walking. With walking, maximal internal rotation occurs at initial contact of the ipsilateral side.[99] It is theorized that this helps to promote increased stride length with walking.[98] In contrast, the pelvis is externally rotated at initial contact of the ipsilateral side with maximal external rotation occurring at midstance. This pattern decreases the horizontal distance of one's center of mass to the point of initial contact by the corresponding foot. There is a weak positive correlation of trunk axial rotation with that of the pelvis ($r = 0.37$; $DF = 100$; $p < 0.0001$).[100] Trunk rotation precedes that of the pelvis with both considered out of phase 21% of the time during a gait cycle.[100]

Hip and Knee Kinematics

Total hip flexion and extension is greater with running (60 degrees) compared to walking (40 degrees).[41] Peak hip flexion occurs during mid to terminal swing phase for both. Peak hip extension occurs just prior to toe off with walking. With running, peak extension occurs at toe off due to initial contact occurring with the limb more underneath the center of mass as opposed to anterior as seen with walking.

The timing of knee kinematics in the sagittal plane is similar for walking and running however the degree at which these movements occur is substantially greater with running. With running, the knee flexes from approximately 25 degrees at initial contact to 45 degrees at mid stance.[41] This portion of the gait cycle is described as the absorption phase. Peak angles for knee flexion can reach up to 110 degrees with swing phase of gait and is dependent on running speed.[41] The point of minimal knee flexion ranges from 6.2 to 10.3 degrees occurring at terminal stance.

In the coronal plane, hip adduction has been measure relative to the pelvis during stance phase. At initial contact, the hip is adducted approximately 5 degrees. This angle increases slightly during absorption phase presumably to aid with force attenuation until midstance and then begins to abduct through terminal stance. By toe off, the hip is abducted to approximately 3-4 degrees in relation to the pelvis. Hip abduction continues through swing phase with maximal hip abduction (approximately 7-8 degrees) occurring during mid swing. The hip begins to adduct again during terminal swing presumably to position the limb to prepare for initial contact. In the coronal plane, the knee deviates into slight valgus upon initial contact and early stance phase. The knee continues to adduct through mid stance and ends in a slightly abducted position in terminal stance. This total motion is very minimal with peak angles of 1.3-1.6 degrees.[102] The collateral ligaments of the knee check these coronal plane motions with the medial collateral ligament limiting varus motion and the lateral collateral ligament limiting valgus motion.

In the transverse plane, the hip is positioned relatively neutral during terminal swing and at initial contact. The hip internally rotates during absorption phase of gait, with peak angle approximately ranging from 6-14 degrees and then again returns to neutral during terminal swing.[99,102] Peak angles of 3.3 – 4.4 degrees for knee internal rotation have recently been reported with during the absorption phase of gait.[102]

Foot and Ankle Kinematics

Kinematics of the foot and ankle are more difficult to describe in terms of cardinal planes because of the numerous articulation that are not oriented in one plane. Typically, these motions are described as pronation or supination representing a combination of multiplanar movements. Pronation consists of dorsiflexion (DF) at the talocrual joint, forefoot valgus and, subtalar joint eversion. Supination consists of plantar flexion (PF) at the talocrual joint, forefoot varus and subtalar joint inversion.[98] The foot moves from a 6-8 degree supinated position upon initial contact to 6-8 degree pronated position during the absorption phase and then supinates during the propulsion phase until the next moment of initial contact with running.[101] Motion in the sagittal plane occurs primarily in the talocrual joint. Talocrual DF occurs during the absorption phase of the running cycle with the stance leg moving from 0 – 24 degrees of DF. Talocrual PF occurs during the propulsion phase of the running cycle with moving from 24 degrees of DF to 3 degrees of PF.[98,103]

Another important motion with running is dorsiflexion of the metatarsophalangeal (MTP) joint of the first ray. The normal range for this joint is approximately 85 degrees, all of which is not needed for walking or running.[41] A compensatory "heel whip" has been reported in runners that exhibit < 30 degrees of dorsiflexion of the 1st MTP joint due to early lateral shifting of foot pressure away from the first ray.[41] This action has been found to cause increased transverse plane motion or rotational forces throughout the kinetic chain.[41]

Running Muscle Activity Patterns

In addition to joint kinematics, knowledge of muscle activity is also key to understanding how force is generated to support and propel the center of mass with running. Muscle activation patterns have been reported to be similar with walking and running.[49,96,105] Changes in speed have been reported to increase intensity and alter timing of muscle activation of gait primarily during stance phase. These differences have been related to the difference in double and single leg support. As stated previously, stance phase accounts for 60% of gait cycle with walking, 20% of which is comprised of double limb support. Conversely, stance phase accounts for 40% of with running and there is no period of double limb support.[41,98] EMG activity changes are greater proximally as speeds increase but remain relatively consistent in distal musculature across speeds.[105] The main contributor to the absorption phase of running is the quadriceps, accounting for twice the braking acceleration with contributions from gluteus maximus and gluteus medius accounting for half of the vertical support for the body's center of mass.[49] The gastrocnemius and soleus muscles function as one unit serving as the chief contributor during the propulsion phase accounting for twice the peak forward acceleration and half of the vertical support for the body's center of mass. [49]

SUMMARY

The etiology of common running related injuries, training errors, and normative biomechanical principles associated with running were presented in this review of the literature. A common theme of the injuries discussed is that gender appears to be a key factor as females are more at risk for PFPS, ITBS, and stress fractures when compared to their male counterparts. In terms of biomechanics, some variation of an increased hip adduction moment and/or knee internal rotation/valgus moment also appears to be related to an increased risk for injury. There is debate in the literature whether or not these aberrant mechanics are due to hip abduction weakness or some other factor. Distally, excessive rear foot pronation and decreased talocrual DF have been also associated with an increased risk for injury. Recent advancements in gait analysis technology have yielded a better understanding of the biomechanics associated with running. Having a better comprehension of these biomechanics gives a framework for understanding normal movement patterns. Conversely, a better understanding of deviations or aberrant movement patterns may also give insight into abnormal stresses on tissues or joints potentially leading to tissue breakdown and subsequent injury.

This study was designed to prospectively investigate physical characteristics of recreational runners that have been previously associated with overuse injuries in this population. Hopefully the results of this study have yielded more insight into the impairments associated with increased incidence of injury in recreational runners. Future epidemiological research is needed to validate the tests and measures identified that may be performed as part of a pre-distance running screen. In addition, potential interventions targeting identified impairments can now be integrated in to a cross training regimen for distance running in an effort to reduce the occurrence of lower extremity injuries in the growing population of recreational runners.

CHAPTER 3: METHODOLOGY

Introduction

This chapter outlines the methodology used to investigate the specific aim of this dissertation project which is to prospectively explore the relationships between anthropometric measurements, lower extremity/trunk muscle performance, ankle/foot dorsiflexion range of motion, and lower extremity neuromuscular control with incidence of injury in recreational runners over the course of an 18 week marathon training program. Eligibility criteria for both targeted participants and clinicians assisting with data collecting in this study are clearly outlined, as well as the methods used for participant recruitment, training of investigators and collection of data for the study. The chapter concludes with methods of data analysis to be employed in this project.

Recruitment Procedures

This project employed a prospective, cohort design. A sample of convenience was obtained from volunteers of two local running groups training in preparation for the fall marathon season with most participants running the 2014 Chicago Marathon. Running groups members were targeted as participants for this project by design. Running groups are organized with structured training regimens with gradual progression of running distance that assists novice runners achieve their goal of completing a marathon or half marathon. Use of these groups for potential research subjects helps to control for variables such as running surface, distance ran per week, and a rapid increase in running distance, found to be the strongest predictor of running injuries.[2-5,8] Another benefit of using running groups is that a group leader supervises them. This person can serve as a contact to cross check group member injuries opposed to relying on runners alone.

The main source for participants was sought from the Chicago Area Runners Association (CARA). This organization has 8,600 registered members and is the third largest running association in the nation.[106] The primary investigator (PI) contacted the head of the organization regarding collaborating on this study. The proposal was reviewed and approved by the association's medical review committee. Once approval was obtain and access to members was granted, volunteers were solicited via email and through association's website. Two group primary leaders emerged as interested parties. The PI attended pre training group meetings to inform the runners about the study and provide education on the specifics of the study.

Description of Participants

A total of 75 runners agreed to participate in the study. This study was approved by the Nova Southeastern University Institutional Review Board. Informed written consent was obtained from all participants and their rights were protected throughout the investigation.

Inclusion/ Exclusion Criteria

The following inclusion criteria was used to determine eligibility for this study:

1.) Age between 18-65 years old

2.) Registered members of the running group Chicago Area Running Association (CARA) participating in the Chicago Marathon training program. Runners who have received recent medical care not related to a running injury had to show proof of medical clearance from their respective medical provider.

3.) Recreational runners: Male time – half marathon > 1:11:00; marathon > 2:31:00, Female time –half marathon > 1:21:00, marathon >3:01:00

The term novice or recreational runner is one that has been used in the literature to describe the population of non-elite or noncompetitive runners.[7,8,10] This study used the same qualifications as the Chicago Marathon to define elite since this was the event participants were primarily training for. Any male with a half marathon time of < 1:11:00 or marathon time of < 2:31:00 was considered elite and not eligible for the study.[107] Any female with a half marathon time of < 1:21:00 or marathon time < 3:01:00 was considered elite an not eligible for study.[107]

The following exclusion criteria was used to determine eligibility for this study:

1.) Any injury suffered within the past 3 months that required runner to seek care from a medical professional.
2.) Any running related injury suffered within the past 3 months that required the runner to stop training for 2 more sessions
3.) Unwillingness to comply with completion of weekly running logs and injury reporting as outlined explicitly in the informed consent.

History of previous injury has been established as the second strongest risk factor for potential running injuries.[2,5,7,8] Despite this finding, many previous prospective studies have not excluded subjects due to previous running related injuries.[4,7,8] Bredwig et al addressed this concern by excluding subjects if they suffered a lower extremity running related injury within the past three months.[33] This project employed similar criteria.

Overall, this criterion is intentionally lenient to aid with this project's generalizability as recreational runners encompass a wide range of demographics, backgrounds, experience, and physical characteristics. History of previous injury was self-reported by runners via a running background form described later. This form was attached to recruitment email. Volunteers who do not meet the inclusion exclusion criteria were screened out ahead of data collection session by the primary investigator (PI). Running background forms were also reviewed after data collection to exclude data from participants who do not meet the criteria.

Additional Investigators

Additional investigators were needed to collect data on this number of participants. The PI is a faculty member for the physical therapy orthopedic residency program at the University of Chicago. The PI solicited the help of four additional investigators consisting of residents and/or colleagues to assist with data collection. Each licensed physical therapist assisting was assigned a particular variable they were responsible for measuring including anthropometrics, range of motion (ROM), strength using hand held dynamometry (HHD), trunk muscle performance, and functional testing. To avoid issues with interrater reliability, each assistant only measured their assigned variable.

Participating assistants were asked to review a detailed Manual of Standard Operations and Procedures (MSOP), which describes in detail all the study procedures and operational definitions for the tests and measures to be performed. A copy of the MSOP used in this study can be found in Appendix B. Assistants were required to study the MSOP prior to a 1 hour training session from the PI pertaining to the specifics of measuring their assigned variables. During these sessions, assistants performed assigned measurements following the procedures outlined in the MSOP on a volunteer supplied by the PI. The PI deemed the assistant competent based observation of the procedures being performed correctly.

Data collection took place at the site where the runners met weekly to aid with the convenience and maximize participation. On the day of data collection, the research team was organized into five stations corresponding with the various measurements mentioned previously. Data collection took place outdoors after consented participants returned from a 7 mile run. They were allowed a 15 minute break for water and stretching prior to the start of data collection. Participants were divided equally into five numbered test groups. Each test group began testing at the testing station with their corresponding number. The groups rotated from station to station until all data were collected. Each individual assistant was blinded to participants' results from other stations in an effort to reduce bias. The PI compiled all data after the collection process was completed. Multiple data collection sessions were necessary to attain the total number of 75 participants investigated.

Procedures

Demographic Information

Consented participants were required to fill out a baseline running background intake form requesting information on their age, gender, height, body mass, running experience, choice of wear, and history of previous injury. If an injury is revealed, a section on the questionnaire had a space allowing for detailed descriptions of previous injuries including location, duration since onset and cessation of symptoms, and time off from running due to injury. Additional information including cross training as well as participation in other sports or recreational activities was also requested. A copy of the running background form used in this study is included in Appendix B.

Anthropometric Measurements

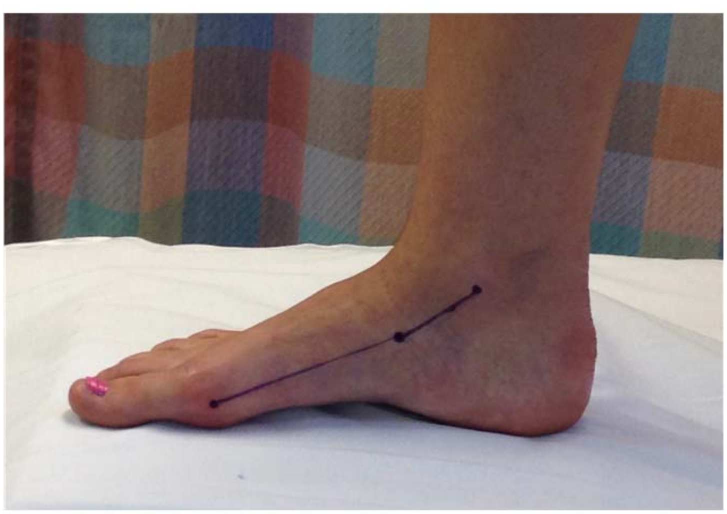
The anthropometric measurements that were recorded include: leg length, medial longitudinal arch angle, static rear foot posture, and quadriceps angle (Q angle).

1. Leg Length: Leg length was measured using a tape measure proximally from anterior superior iliac spine (ASIS) to distally at the center of the medial malleolus. The center of the medial malleolus was determined as the intersection between the greatest length and width of the malleolus as measured by a tape measure (Figure 3.1). This method has been validated with a correlation to the gold standard of radiographs (r=0.98).[108] This method has also demonstrated excellent interrater reliability (ICC = 0.99) between testers.[108] Leg length discrepancies have been reported as a potential risk factor for recurrent stress fractures in athletes including runners.[34]

Figure 3.1
Leg Length

2. Medial Longitudinal Arch Angle: Medial longitudinal arch angle was measured bilaterally with a line drawn from the center of the medial malleolus to the navicular tuberosity, and with another line from the navicular tuberosity to the first metatarsal head (Figure 3.2).[37] These points and lines were drawn on the patient with a skin marker. The angle was measured using a small (arms 6in long, 1in wide) plastic 360 degree goniometer with the axis over the navicular tuberosity. Angles ≤ 90 degrees have been defined as low and associated with a pronated foot.[37] Angles ≥ 180 degrees have been defined as high and associated with a supinated foot.[37] Medial longitudinal arch measurements have been validated as a predictor of dynamic foot posture with mid-stance of gait by use of instrumented gait analysis.[35] This method has a reported intratester reliability as r = 0.90 and intertester reliability of r = 0.81.[36]

Figure 3.2
Medial Longitudinal Arch Angle



3. Static Rear Foot Posture: Static rear foot posture was measured with a small 360 degree plastic goniometer (arms 6 inches long, 1 inch wide) in weight bearing with the participant standing on the edge of a table. The stationary arm of the goniometer was over a point bisecting the posterior calf and the mobile arm bisecting the posterior calcaneus (Figure 3.3).[37] The landmarks for the center of the posterior calcaneus and posterior calf were first established with participant prone on the table. The center of the calcaneus was determined as the intersection between the greatest length and width of the calcaneus as measured by a tape measure. For the posterior calf, a mark was made 20 cm up from the bottom of the calcaneus. The width of the posterior calf was measured with a tape measure and the center point was marked at the half way point of this measurement. Intrarater reliability of ICC = 0.84-0.93, SEM 1.5-2.06 degrees has been reported for use of a goniometer to measure rearfoot alignment in standing.[109] Calcaneal inversion greater than 3 degrees has been associated with a supinated foot while calcaneal eversion greater than 3 degrees has been associated with a pronated foot.[37]

Figure 3.3
Static Rear Foot Posture

4. Q Angle: Q angles were measured with a standard goniometer modified with the stationary arm extended to allow for it to reach the ASIS. This method limits potential variability and error from tester with projecting an imaginary line from the ASIS to the tip of the arm of a standard length goniometer.[39] The participant was lying supine with knees flexed to 10 degrees over a rolled towel. The 10 degrees of flexion was measured with a goniometer.[39] The axis of the goniometer was placed over the center of the patella determined as the intersection between the greatest length and width of the patella measured by a tape measure. The extended arm of the goniometer was aligned with the ASIS to the mid patella. The other arm of the goniometer was aligned with the center axis at the mid patella to the tibial tuberosity (Figure 3.4).

Q angles have been described as reflecting the frontal plane forces on the patella.[18] A10 degree increase in the Q angle has been reported to result in a 45% increase in patellofemoral pressure.[38] The reliability for measuring Q angles with the method described above has reported as intratester (ICC = 0.92) and intertester (ICC = 0.88).[39] Interestingly, this same study reports a significant difference between Q angles measured with magnetic resonance imaging (MRI) versus a goniometer ($p < 0.05$) noting that goniometric measurements underestimate the degree of Q angles when matched with MRI.[39]

Figure 3.4
Q Angle

Ankle/ Foot Range of Motion

Ankle/ Foot range of motion (ROM) included ankle dorsiflexion (knee extended and knee flexed) and first ray metatarsophalangeal (MTP) dorsiflexion. Decreased ankle dorsiflexion ROM has been associated with increased pronation of midfoot with ambulation.[110] In addition to ankle dorsiflexion, mobility of the 1st ray has also been implicated in aberrant running mechanics.[41] Dicharry reported that less than 30 degrees of 1st ray MTP dorsiflexion significantly alters the kinematics of the foot and ankle with running.[41] This limitation of 1st ray MTP dorsiflexion has been associated with a medial heel whip with running due to inability to properly roll over the forefoot at toe off.

1. Ankle Dorsiflexion ROM: Ankle dorsiflexion ROM was measured passively at the talocrural joint using standard 360 degree goniometer (arms 12 inches long, 3 inches wide) with stationary arm bisecting the distal fibula and the mobile arm bisecting the 5th ray (Figure 3.5). Intratester reliability of ankle dorsiflexion has been reported as ICC = 0.64 to 0.92 for dorsiflexion using a standard goniometer.[110] A more recent study investigating ankle ROM and jump landing mechanics reported an ICC= 0.90, standard error of measurement = 1.8°; flexed-knee assessment and ICC = 0.84, standard error of measurement = 2.6° with knees extended.[111] For purposes of this study, these measurements were taken in a similar test position of patient in long sitting on a table for knee extended with feet hanging over edge and sitting over edge for knee flexed positions respectively.[111]

Figure 3.5
Ankle Dorsiflexion ROM

2. <u>1st MTP Dorsiflexion ROM</u>: 1st MTP dorsiflexion was measured passively using a small plastic 360-degree goniometer (arms 6 inches long, 1 inch wide). The participant was seated on the examination table with feet hanging over the edge. The axis of the goniometer was placed medially at the first MTP joint with stationary arm aligned with the first metatarsal bone and the mobile arm aligned with the first proximal phalanx (Figure 3.6). A recent study investigated the reliability of goniometric and visual estimate measurements of 1st ray extension.[112] Intra-rater reliability was reported ICC = 0.95 with a SEM 1.8° for experienced examiners but considerably lower for inexperienced examiners with the ICC = 0.322 and the SEM 3.0°. These measurements were also taken using pictures opposed to live subjects.[39,112]

Figure 3.6
1st MTP Dorsiflexion ROM

Lower Extremity Isometric Muscle Performance

Lower extremity isometric muscle performance (MP) was measured using the micro*FET* II™ (Hogan health industries, Draper, UT, USA) hand held dynamometer (HHD). This device is portable and practical for use in a clinical setting. Hand held dynamometry has demonstrated concurrent validity for measurement of MP of lower extremity strength in healthy individuals (r =0.74 to 0.78) when compared to the gold standard of isokinetic dynamometry.[42] The intra-session intra-rater reliability of lower extremity MP using HHD in healthy individuals has been reported ranging from ICC 0.16 – 0.98 with a SEM ranging from 0.1 to 0.44 kg.[42,46] The wide range of reported reliability can be attributed to differences in testing methods and population investigated. Accuracy of HHD measurements can be affected by inadequate strength of the tester and lack of stabilization of participant and device.[43] Studies that incorporate a stabilizing apparatus produce better reliability measurements.[42,44-46] Many of the stabilizing techniques used in previous studies are often impractical for clinical use and limit the portability a HHD. Kolber et al[47] investigated the use of a portable PVC stabilization device (StabD) and HHD, reporting excellent test retest reliability for isometric external and internal rotation of the shoulder (ICC = 0.971 – 0.972; SEM 0.62 – 1.15 kg). No studies to date have investigated the use of a PVC StabD for the lower extremity in healthy individuals.

Maximum isometric MP in hip external rotation, hip abduction, hip adduction, knee extension, and ankle plantar flexion were measured using a hand held dynamometer (HHD) with stabilizing techniques and a portable stabilization device. These four movements were chosen because previous research reports weakness of these muscle groups can be associated with increased knee transverse plane motion.[9-18,23,24]

1. Hip Abductor MP: Hip abductor MP was measured in supine on a table with a stabilizing strap across the pelvis. The force pad of HHD was placed 5cm above the lateral malleolus with other end of StabD stabilized against a wall (Figure 3.7). Stabilization of the participant and the dynamometer with this test position has yielded an intrarater reliability of ICC 0.88 to 0.94.[45,48]

Figure 3.7
Hip Abductor MP

2. <u>Hip Adductor MP</u>: Hip adductor MP was measured in supine on a table with a stabilizing strap across the pelvis. The force pad of HHD was placed 5cm above the medial malleolus with other end of StabD stabilized against a wall (Figure 3.8). Intratester reliability for hip adductor strength using a HHD has been reported at 0.79 without stabilization and 0.89 with stabilization in a healthy population of young adults age 21-33.[113]

Figure 3.8
Hip Adductor MP

3. Hip External Rotator MP: Hip external rotator MP was measured with participants in the sitting position on the edge of a table with hips and knees flexed to 90 degrees. The test leg was anchored with a strap at the thigh and a towel roll was placed between the legs to limit involvement of hip adductors.[9-11,13] The force pad of HHD was placed 5 cm proximal to the medial malleolus of test leg with other end of StabD against a wall (Figure 3.9).

Figure 3.9
Hip External Rotator MP

4. Knee Extensor MP: Knee Extensor MP was measured with participants sitting on the edge of the table with hips and knees flexed to 90 degrees. A stabilizing strap was placed over bilateral thighs just distal to the hip joint line bilaterally and arms were folded across chest. The HHD force pad was placed 5 cm above imaginary bimalleolar line and the other end or the StabD against a wall (Figure 3.10).

Figure 3.10
Knee Extensor MP

5. Ankle Plantar Flexor MP: Ankle plantar flexor MP was measured on a table in a long sitting position, with arms folded across chest without back support. A rolled towel was placed underneath the knee of the test leg with a stabilizing strap over the proximal tibia. The force pad of the HHD was placed on the plantar surface of the metatarsal heads with the other end of StabD against a wall (Figure 3.11). This test position without the StabD has been reported to have intrarater reliability ICC of 0.73; SEM = 8 N in healthy subjects.[23]

Figure 3.11
Ankle Plantar Flexor MP

Once positioned, the testing procedure using the StabD was the same for each measurement as described by Kolber et al.[47] Participants were asked to perform isometric contraction against manual resistance to ensure their understanding of the desired action to be measured. The stabilization device was then positioned as described previously for each test position. Participants were asked to maintain a six second isometric contraction. Peak values were recorded for three repetitions. There was a ten second rest period between contractions. Rest period between muscle groups tested was set at three minutes to allow for change in test position. Testing sequence was alternated between positions to avoid systemic error.[47] Fifteen participants were randomly chosen and measured again after a 10 min rest period to measure intra-rater reliability.

Trunk Isometric Muscle Performance

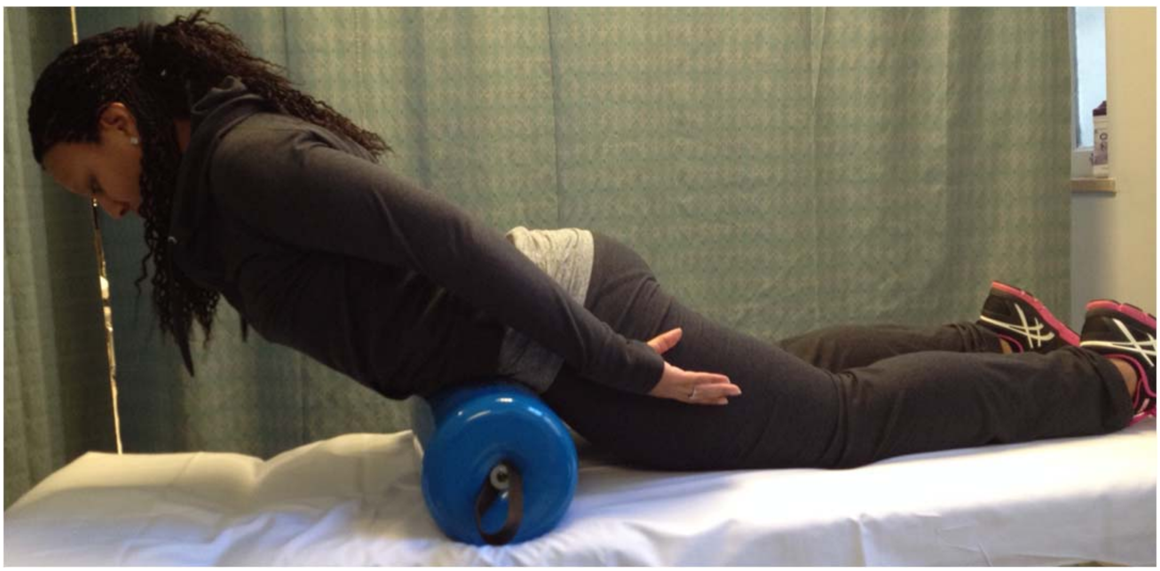
Trunk muscle performance has been identified as a key component of lower extremity neuromuscular control and dynamic stability of the knee in subjects following anterior cruciate ligament (ACL) reconstruction.[22] Core trunk stability has been described in terms of endurance by holding static positions challenging anterior, posterior and lateral muscle groups.[50] These endurance tests also have reported high levels intrarater reliability (ICC ≥ 0.97).[50]

1. <u>Trunk Flexor Endurance</u>: Flexor endurance was performed with participant in sitting on a mat next to a 180-degree wall mounted protractor. Participants crossed arms across chest and reclined back to 30 degrees from a vertical line perpendicular with the floor (Figure 3.12). The duration at which participant can maintain this angle was measured with a stop watch to the nearest second.[50]

Figure 3.12
Trunk Flexor Endurance

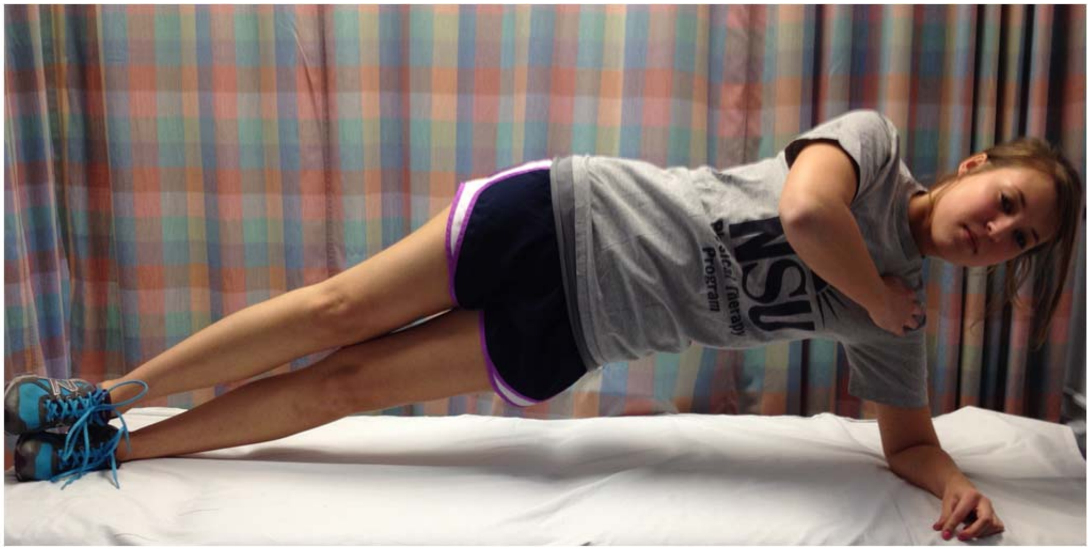
2.Trunk Extensor Endurance: Extensor endurance was measured with the participant positioned prone with a small pillow under the lower abdomen to decrease the lumbar lordosis, They were then instructed to maintain maximum cervical flexion with pelvic stabilization through gluteal muscle contraction with goal of holding the sternum off of the table as long as possible (Figure 3.13) as previously described by Ito et al.[51] The duration the participant was able to maintain appropriate test position was recorded.

Figure 3.13
Trunk Extensor Endurance



3. Trunk Lateral Endurance: Lateral endurance was measured with the participant in side lying of side being measured. The top leg was placed on top of the bottom leg. Participants were instructed to lift their hips off of the table supporting their upper trunk with forearm. The top arm was folded across opposite shoulder (Figure 3.14). The duration participants were able to hold hips off table was measured.[50]

Figure 3.14
Trunk Lateral Endurance



For all trunk muscle performance measurements, participants were allowed to perform 3 submaximal trials of 5 – 10 seconds to ensure they can correctly attain and maintain desired posture. Once the investigator establishes that participant can perform task with proper technique, the one-time maximal hold duration was recorded. Participants were cued to hold each posture as long as possible. There were five-minute rest periods between each measurement.

Lower Extremity Neuromuscular Control

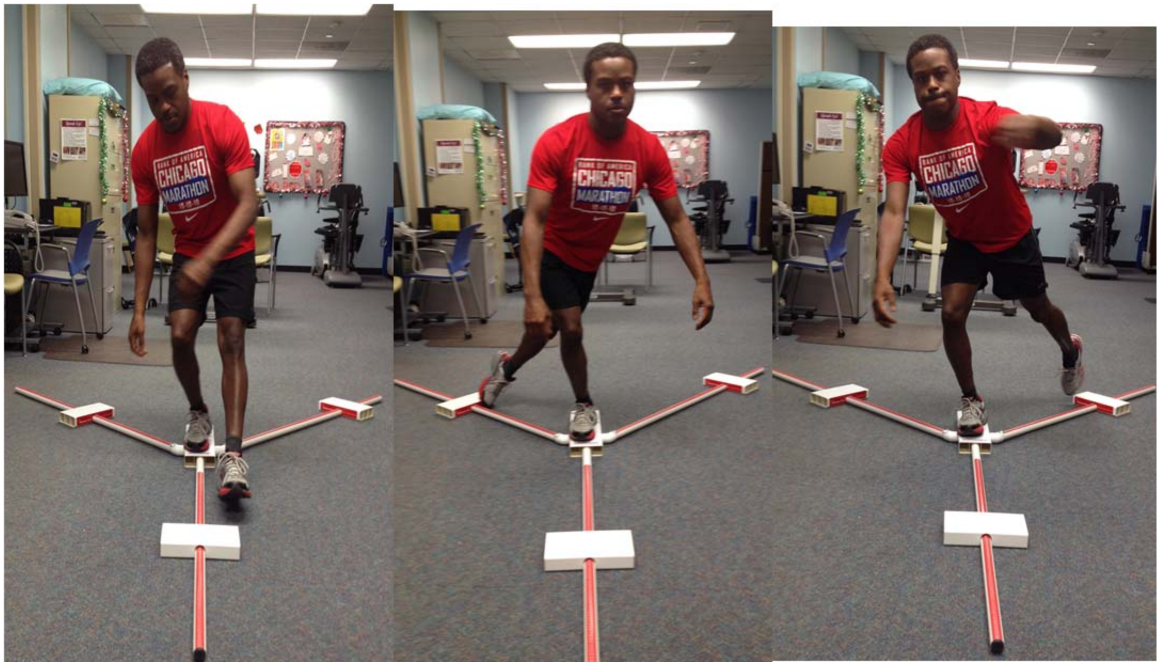
Two primary tests were used to measure lower extremity neuromuscular control, the Y balance test (YBT) and 6-meter hop test. The YBT is a condensed version of the star excursion balance test (SEBT). The SEBT requires both strength and adequate lower extremity neuromuscular control to perform task correctly. It has been reported to be predictive for risk of injury in high school basketball players finding that players with an anterior right/left reach difference greater than 4 cm were 2.5 times more likely to experience a lower extremity injury.[28] The SEBT consists of 8 reaching components with one leg while maintaining single leg stance on the opposite lower extremity in the center of a grid taped to the floor. Maximal reach distance is measured for each direction and normalized accounting for leg length. Good intratester reliability on different days (ICC of 0.78 – 0.96 on days 1 and 0.82-0.96 on day 2) for the SEBT has been reported with a SEM of 1.77 – 3.38 cm.[26] Redundancy was found in several of the directions of the test and has been simplified from 8 reaches to 3 directions which is now known as the Y balance test (YBT).[52] A YBT kit (functionalmovement.com, Danville, VA) constructed of PVC pipe has since been developed for this specific purpose. The YBT was employed in this study with reported intertester reliability ranging from 0.97 to 1.00.[114]

1.) Y Balance Test: Lower extremity neuromuscular control was measured using the Y balance test kit. Participants were asked to stand on the middle platform on one leg where the pipes intersect and reach as far as possible moving the marker along the PVC marked to the nearest 0.5 cm. These directions are termed anterior, posterior medial, and posterior lateral (Figure 3.15). Participants were allowed six trials for each direction on each leg as motor learning for the task has been shown to plateau after six trials. The participants were then allowed three trials in each direction; the greatest distance attained was used for statistical analysis. Composite scores of all three measurements were calculated for each leg using the formula:

$$Composite\ Score = \frac{\text{Anterior} + \text{Posteriomedial} + \text{Posterolateral}}{\text{3 x Leg Length}} \times 100$$

This formula helps to normalize the results by accounting for leg length differences with and between subjects.

Figure 3.15
Y Balance Test



2.) <u>6-meter Hop Test</u>: The distance of 6 meters was measured with a large rolling tape measure. The investigator gave the command “ready, set, go”. Upon go, the participants were asked to hop on one lower extremity for a distance of 6 meters marked by cones. The duration from start to finish was measured seconds using a stopwatch (Figure 3.16) with values rounded to the nearest hundredth of a second. The test was performed on each leg for 2 repetitions. Mean times of both trials were recorded for each leg. This test is one component of a series of 4 hop tests that have been found to be valid and reliable (ICC = 0.82 - .93; SEM 3.04 – 5.59) tools to measure progression of subjects following an anterior cruciate ligament (ACL) reconstruction.[53] The timed 6-meter hop test requires the elements of forward propulsion, speed, and force attenuation in conjunction with neuromuscular control, all of which are similar constructs found with running.

Figure 3.16
6 meter Hop Test

Injury Recording

Participants and running group leaders were educated on the process of how injuries were recorded over the 18 week period. Runners were asked to keep a weekly running log. The PI collected information from the participants' logs on a bi-weekly basis. No specific education was provided on whether or not participant should train with pain. This decision was left up to participant and their healthcare provider. If an injury occurs, the location or body part involved was recorded. The injury was classified using the method utilized by Taunton et al[7] which includes:

- *Grade 1: pain after running*

- *Grade 2: pain during running but not restricting distance or speed*
- *Grade 3: pain during running restricting distance or speed*
- *Grade 4: pain preventing all running*

In addition, participants recorded how many days of running sessions they are unable to participate in because of injury. This information was cross-checked by group leaders who kept track of attendance and injured runners as part of their normal duties. Participants were asked to fill out a post training regimen questionnaire to identify any other injuries or discrepancies found with other records. Length of injury recording was recorded over an 18 week period.

Data Analysis

Descriptive statistics were employed to show distribution of all variables collected or measured prior to the start of the training regimen and during training including injuries, body part involved, and severity grade of injuries. A gross overall measurement of incidence rate of injury was derived by dividing the number of injuries (regardless of location and severity) by the number of total participants.[7] Differences between injured participants' dominant and nondominant limb measurements and characteristics were compared to non injured participants' using an independent *t* test in order to screen data for potential predictors. The level of significance was set at $\alpha = .05$ for comparisons between the two groups. A more liberal level of significance, $\alpha = .15$, was used for data screening to allow for inclusion of more variables in the regression analysis. Variables that exhibited statistically significant difference between the groups were considered potential predictors. Once these were identified, a binary logistic regression was used to develop a model to potentially predict the risk injury based on participant demographics, training characteristics, muscle performance, and results of functional tests. A receiver operating characteristic (ROC) curve analysis was employed to identify potential cutoff values for the clinical tests where injuries were more likely to occur. Intraclass correlation coefficients (3,1) were used to measure pilot test-retest reliability of HHD with StabD for lower extremity MP. Strength measurements were normalized for body mass using the formula: strength (N)/body mass in kilograms (kg). The minimal detectable change (MDC) for each variable was also calculated at 95% level of confidence, employing the formula $MDC_{95} = 1.96 \times \sqrt{2} \times SEM$.[54] All data were analyzed using SPSS for Windows, Version 19 (SPSS Inc., Chicago, IL).

Summary

This chapter outlined the methodology used to investigate risk factors for injury in recreational runners. Extensive planning and preparation transpired prior to the data collection in order to ensure the methodology was appropriate to address the specific goals of this study. The measurements employed were comprehensively researched as delineated in this chapter. Steps taken to maximize the internal validity included thorough training of additional investigators who participated in data collection for this study with strict adherence to the manual of operating procedures developed by the PI.

CHAPTER 4: RESULTS

Introduction

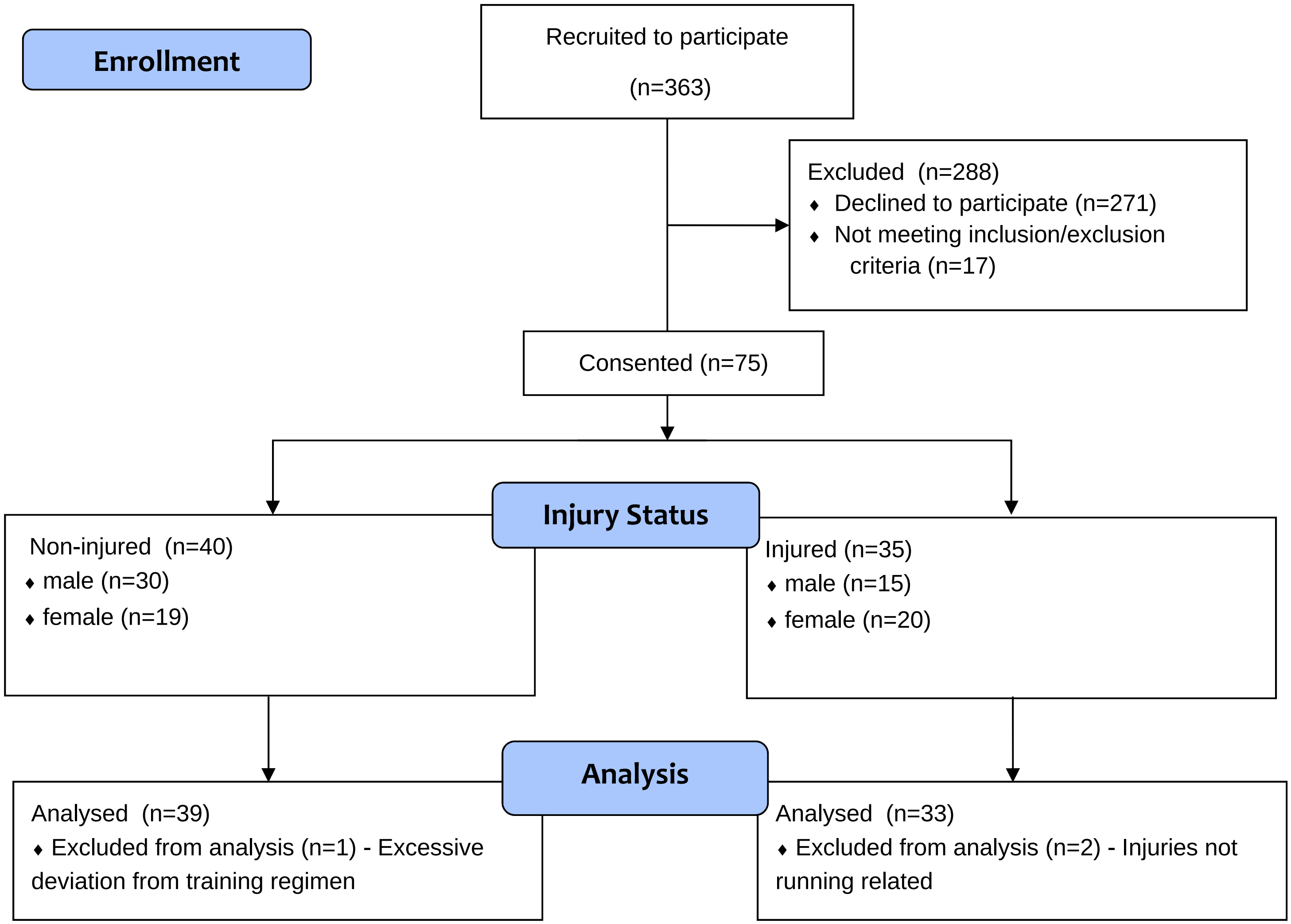
There is a paucity of prospective research studies investigating the relationship between anthropometric measurements, static foot posture, lower extremity and trunk muscle performance, and neuromuscular control with lower extremity injuries amongst recreational runners. This chapter will discuss the results of an investigation of the aforementioned physical characteristics in an effort to identify those that may lend to increased risk for injuries in this population.

Participants

Between May 2014 and June 2014, participants were recruited from two local running clubs, which are subgroups of the larger Chicago Area Running Association (CARA). Between the two groups, 363 runners were solicited with 75 consenting for participation. A flow diagram outlining participant recruitment, reasons for exclusion or removal from study, and grouping by injury status can be seen in Figure 4.1. These participants were followed over the course of 18 weeks and injury data was recorded as described previously in Chapter 3. Participants were classified into one of two injury status groups over the course of the 18 weeks observation period: injured and non injured.

Figure 4.1

Flow Diagram of Participant Recruitment and Participation



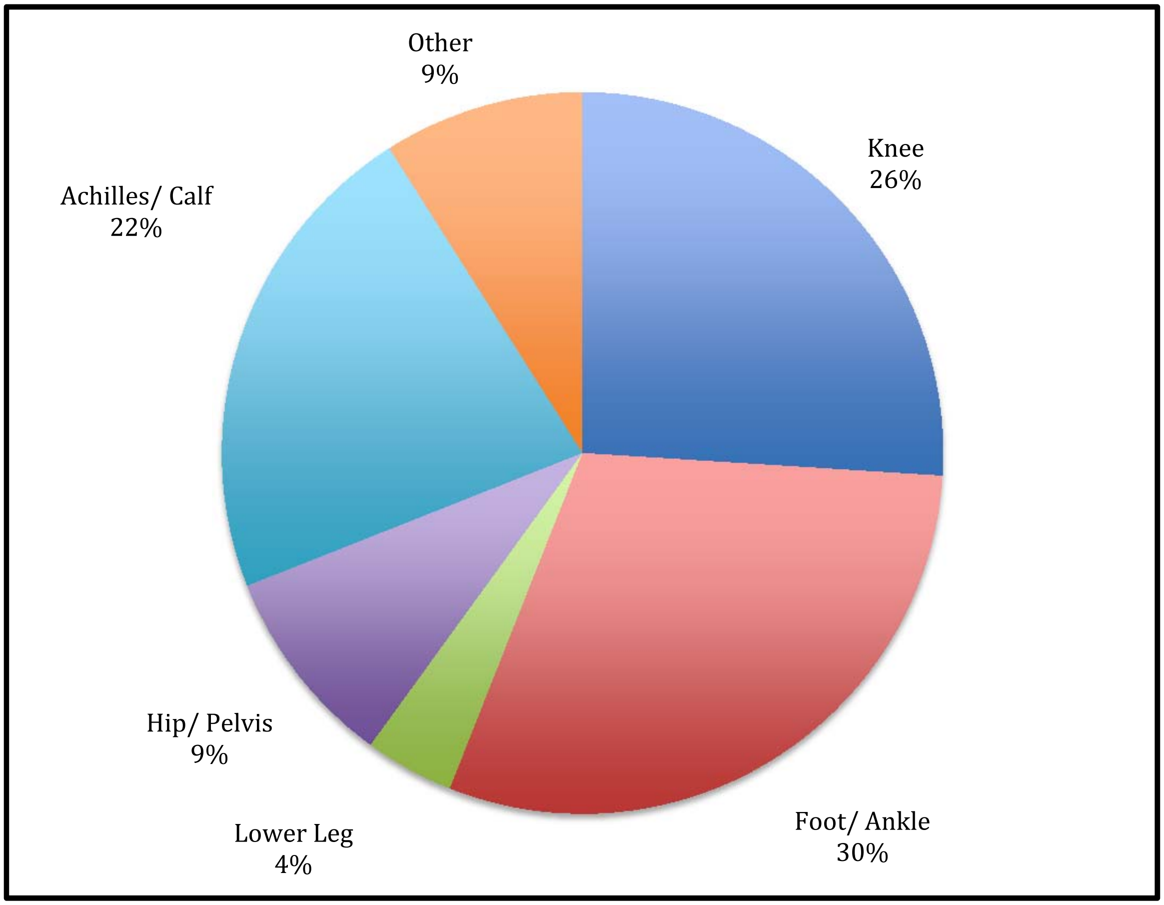
There were 72 participants eligible for data analysis of which 33 suffered from injuries over the course of the training program. This yielded a gross injury rate of 46%. There were 13 male injuries for a rate of 39% and 20 female injuries for a rate of 51%. Table 4.1 lists demographic characteristics for both the injured and non injured groups. All participants reported use of footwear from popular running shoe brands. Sixty-Seven out of 72 participants (93%) reported participation on some type of cross training. Figure 4.2 presents the distribution of the location of the reported injuries from the participants.

Table 4.1
Participants' Demographics and Physical Characteristics

Variable	Total Sample N=72	Non Injured N=39	Injured N=33
Age (y), $\bar{X}$, ± SD, (Range)	40.61 ± 10.23 (24-66)	43.15± 9.37 (25-61)	37.79 ± 10.61 (24-66)
Gender			
Women (%)	39 (54 %)	19 (49%)	20 (61%)
Men (%)	33 (46%)	20 (51%)	13(39%)
Height (cm)$\bar{X}$, ± SD (Range)	171.32 ± 8.94 (154.91-193.43)	170.76± 8.88 (154- 190)	172.02 ± 9.24 (154.95- 180.79)
Mass (kg) $\bar{X}$, ± SD, (Range)	69.52 ± 12 (49.53-103.57)	70.56 ±13.0 (50.42-103.59)	68.34 ± 10.92 (49.52-99.58)
BMI (kg/m^2) Mdn (IQR Q1-Q3) (Range)	23.42 (22.13-24.67) (18.46 – 43.48)	23.65 (22.23-24.67) (19.66-43.48)	22.93 (21.54-24.17) (18.46-29.16)
History of Previous Injury	N= 49 (68%)	N=26 (67%)	N=23 (70%)
Running Experience (y), $\bar{X}$, ± SD (Range)	9.52 ±6.83 (1-40)	9.97 ± 6.46 (1-30)	9.09± 7.33 (1-40)

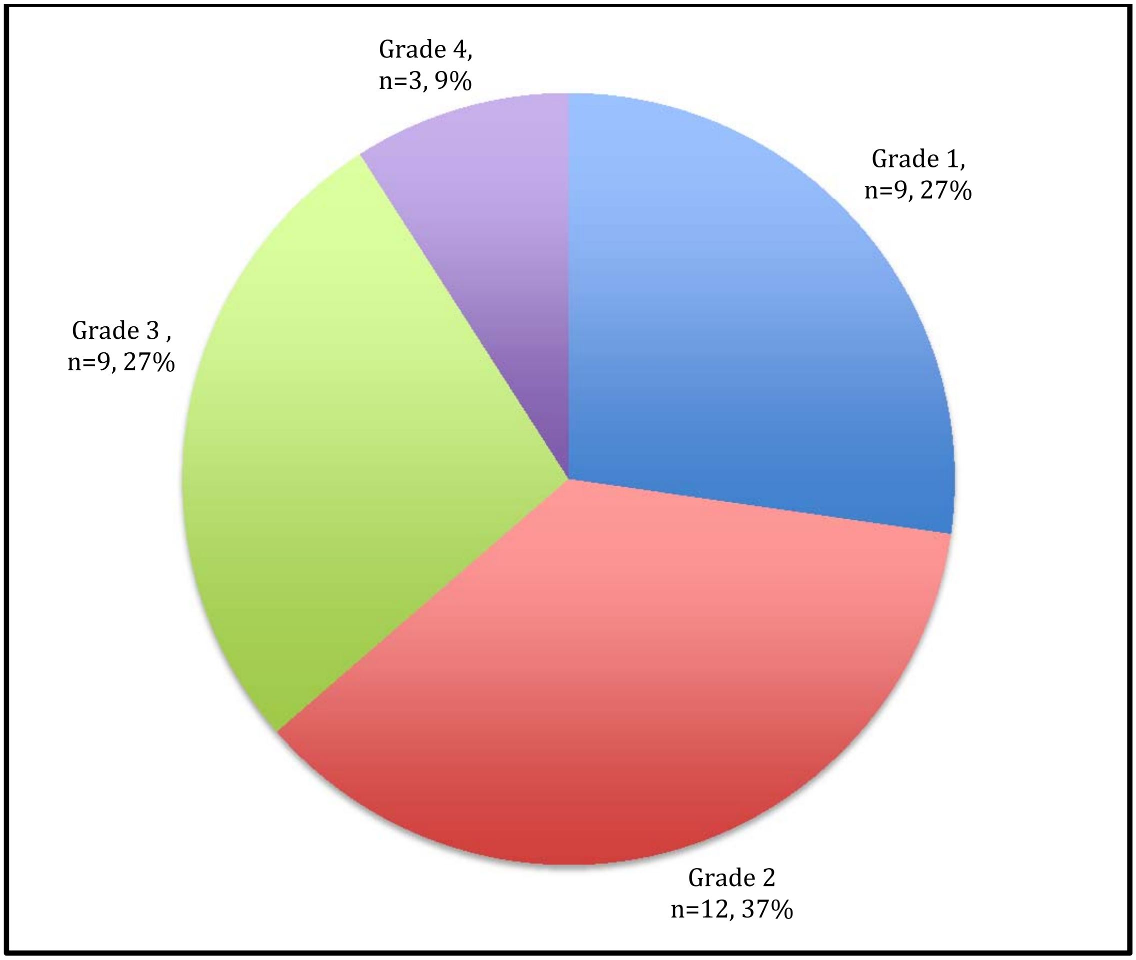
$\bar{X}$ = Mean; SD= Standard Deviation; y= years; kg= Kilograms; cm = Centimeters;
BMI = Body mass index; Mdn = Median, IQR = Interquartile Range; Q1 = 1st Quartile; Q3 = 3rd Quartile

Figure 4.2
Location of Injuries (Males and Females)



The three most common sites of injury were the foot/ankle (30%), the knee (26%), and Achilles/calf (22%). Figure 4.3 illustrates the distribution of injury grades amongst the participants who reported injuries over the course of the training program. Forty three percent (21/49) of the injuries occurred on the dominant side. Thirty three percent (16/49) of the injuries occurred on the non dominant side. Eighteen percent of the injuries occurred bilaterally (9/49). Eight percent (4/49) of the injuries that occurred were not to the either lower extremity.

Figure 4.3
Injury Grade Distribution



Grade I: pain after running
Grade 2: pain during running but not restricting distance or speed
Grade 3: pain during running restricting distance or speed
Grade 4: pain preventing all running

Of the 33 participants suffering injuries, 8 (24%) returned to running without pain. The average number of weeks it took to return to running without pain was 4.4 weeks. Of the reported injuries, 3 reported pain preventing all running related activities (Grade 4 injuries). The time missed from running for these 3 participants were 2 weeks, 2 weeks, and 10 weeks. A total of 49 injuries were reported as some participants reported multiple injuries.

Reliability of Hand Held Dynamometer with Stabilization Device

Intersession intrarater reliability for the hand held dynamometer (HHD) with the stabilization device (StabD) was assessed for the lower extremity muscle groups in this study. The intersession intrarater results were highly reliable for all muscle groups measured. Table 4.2 presents mean strength values with standard deviations, intraclass correlation coefficients (ICC) statistics with 95% confidence intervals.

Table 4.2
Intersession Intrarater Reliability of Hand Held Dynamometer with Stabilization Device

Lower Extremity Action (N)	$\overline{X}$ (SD) Measurement 1	$\overline{X}$ (SD) Measurement 2	ICC [a]	95% CI
Hip Abductors	132.91 (33.85)	143.52 (34.46)	.96	(.89, .99)
Hip Adductors	121.73 (27.74)	114.71 (28.28)	.97	(.90, .99)
Hip External Rotators	107.19 (29.57)	102.01 (30.12)	.98	(.94, .99)
Knee Extensors	267.86 (79.18)	271.33 (70.22)	.93	(.82, .98)
Ankle Plantar Flexors	266.27 (79.91)	252.50 (80.69)	.98	(.93, .99)

n = 15 participants (30 limbs): Male n=7 ($\overline{X}$ age = 35.86); Female n=8 ($\overline{X}$ age = 32.63)
[a] Intraclass correlation coefficients (3,1) = ICC
N=Newton, $\overline{X} = Mean$, SD = Standard deviation; CI = Confidence Interval

Minimal Detectable Change for Muscle Performance Measurements

For clinical purposes, reporting values for the standard error of measurement (SEM) and minimal detectable change (MDC) can be beneficial as it gives the reader information to how much a subject's score needs to change for the investigator to be confident this change is greater than the inherent error of the measurement itself. To determine the MDC at 95% level of confidence, we employed the formula $MDC_{95} = 1.96 \times \sqrt{2} \times SEM$.[54] Table 4.3 lists the MDC_{95} for raw lower extremity isometric muscle performance measurements.

Table 4.3
MDC_{95} for Raw Lower Extremity Isometric Muscle Performance

Variable (Newtons)	Standard Error of Measurement	Minimal Detectable Change $_{95}$
Hip Abductors	5.82	16.13
Hip Adductors	5.47	15.16
Hip External Rotators	3.14	8.70
Knee Extensors	17.20	47.48
Ankle Plantarflexors	9.55	26.47

Risk Factors for Injury

Independent-sample *t* tests were conducted to compare demographics, anthropometric measurements, trunk muscle performance, lower extremity muscle performance, and lower extremity neuromuscular control of the dominant and nondominant limbs between the injured and non injured cohorts. A Mann-Whitney *U* test (see Table 4.4) was conducted to compare the difference of BMI between both groups. The results of the test were not significant, $z = -1.28$, $p = .20$. The non injured group had a median of 23.65, while the injured group had median of 22.93. Tables 4.5 – 4.14 lists the results of the *t* test for all other variables analyzed.

Table 4.4
Mann -Whitney *U* test -Body Mass Index

Variable	Median (IQR Q1-Q3) All Participants N=72	Median (IQR Q1-Q3) Non Injured N=39	Median (IQR Q1-Q3) Injured N=33	Z	*P*
BMI (kg/m^2) [b]	23.42 (22.13-24.67)	23.65 (22.23-24.67)	22.93 (21.54-24.17)	-1.84	.20

BMI = Body mass index, kg= Kilograms m= Meters, Avg= Average
IQR = Interquartile range; Q1 = 1st quartile; Q3 = 3rd Quartile

Table 4.5
Independent *t* test for Anthropometric Measurements & Demographic Data

Variable	All Participants N=72 X (SD)	Non Injured N=39 X (SD)	Injured N=33 X (SD)	Mean Difference (95% CI)	*P*
Age (y)	40.83 (10.33)	43.64 (8.96)	38.66 (10.71)	5.34 (-.65, 8.60)	.09
Height (cm)	171.29 (8.29)	170.72 (8.78)	171.96 (9.20)	-1.24 (-5.47, 2.99)	.56
Mass (kg)	68.98 (11.61)	70.49 (13.01)	68.33(10.91)	2.24 (-5.49, 3.01)	.44
Years of Experience	9.34 (6.54)	9.87 (6.39)	9.00 (7.30)	.87 (-2.35, 4.09)	.59

X =Mean; SD= Standard Deviation; y= years; CI= Confidence Interval

Table 4.6
Independent *t* test for Dominant Side Ankle/Foot Range of Motion and Lower Extremity Measurements

Variable	All Participants N=72 X (SD)	Non Injured N=39 X (SD)	Injured N=33 X (SD)	Mean Difference (95% CI)	*P*
Leg Length Discrepancy (cm)	.34 (.52)	.30 (.51)	.45 (.64)	-.15 (-. 44, .13)	.29
Medial Longitudinal Arch Angle (°)	109.50 (13.01)	110.28 (9.37)	108.52 (16.60)	1.77 (-4.42, 7.95)	.57
Rearfoot Posture (°)	3.53 (1.94)	3.85 (2.04)	3.13 (1.75)	.72 (- .19, 1.62)	.12
Q Angle (°)	5.73 (2.46)	5.87 (1.96)	5.57 (2.99)	.30 (-.87, 1.46)	.61
Ankle Dorsiflexion Knee Extended (°)	10.63 (5.50)	9.85 (5.60)	11.61 (5.30)	-.18 (-4.35, .82)	.18
Ankle Dorsiflexion Knee Flexed (°)	16.12 (5.37)	15.61 (4.74)	16.76 (6.07)	-1.16 (-3.70, 1.39)	.37
1^{st} MTP Extension (°)	78.84 (12.82)	77.71 (13.44)	80.26 (12.06)	-2.56 (-8.63, 3.52)	.40

° = Degrees, cm = centimeters, Q = Quadriceps, MTP=Metatarsal phalangeal; CI = Confidence Interval; X =Mean; SD= Standard Deviation

Table 4.7
Independent *t* test for Nondominant Side Ankle/Foot Range of Motion and Lower Extremity Measurements

Variable	All Participants N=72 X (SD)	Non Injured N=39 X (SD)	Injured N=33 X (SD)	Mean Difference (95% CI)	*P*
Medial Longitudinal Arch Angle (°)	108.97 (15.15)	109.04 (13.44)	108.89 (17.26)	.16 (-7.06, 7.37)	.97
Rearfoot Posture (°)	3.76 (2.13)	3.99 (2.04)	3.47 (2.24)	.52 (-.49, 1.53)	.31
Q Angle (°)	5.52 (2.73)	5.53 (1.73)	5.54 (3.64)	-.17 (-1.31, 1.28)	.98
Ankle Dorsiflexion Knee Extended (°)	11.68 (5.16)	10.79 (4.90)	12.81 (5.34)	-2.01 (-4.43, .39)	.10
Ankle Dorsiflexion Knee Flexed (°)	17.21 (5.39)	16.84 (4.61)	17.68 (6.27)	-.85 (-3.40, -1.71)	.51
1st MTP Extension (°)	79.57 (13.09)	80.48 (12.18)	78.45 (14.33)	2.02(-4.21, 8.26)	.53

° = Degrees, cm = Centimeters, Q = Quadriceps, MTP=Metatarsal Phalangeal; CI = Confidence Interval; X =Mean; SD= Standard Deviation

Table 4.8
Independent *t* test for Dominant Side Lower Extremity Isometric Muscle Performance

Variable (N)	All Participants N=72 X (SD)	Non Injured N=39 X (SD)	Injured N=33 X (SD)	Mean Difference (95% CI)	*P*
Hip Abductors	126.74 (29.11)	126.65 (27.47)	126.84 (31.47)	-5.57 (-14.06, 13.67)	.98
Hip Abductors Normalized	1.86 (.40)	1.87 (.40)	1.84 (.41)	-.04 (- .17, .22)	.78
Hip Adductors	120.07 (31.59)	120.22 (33.41)	119.88 (29.70)	-7.58 (-14.70, 15.40)	.96
Hip Adductors Normalized	1.76 (.42)	1.77 (.07)	1.74 (.07)	-.04 (.17, .23)	.73
Hip External Rotators	100.71 (22.23)	101.17 (21.67)	101.01 (23.03)	2.47(-9.56, 11.62)	.85
Hip External Rotators Normalized	1.48 (.32)	1.50 (.33)	1.46 (.32)	.06 (- .11, - .19)	.62
Knee Extensors	292.50 (86.01)	290.30 (83.98)	295.24 (89.77)	-8.73 (-45.90, 36.02)	.81
Knee Extensors Normalized	4.25 (1.02)	4.24 (1.04)	4.25. (1.00)	-.08 (- .49, .48)	.99
Ankle Plantar flexors	233.97 (67.55)	228.74 (62.70)	240.52 (73.66)	-11.79 (-43.84, 20.27)	.47
Ankle Plantar flexors Normalized	3.43 (.98)	3.37 (.93)	3.50 (1.06)	-.12 (- .59, .34)	.60

N= Newton; CI = Confidence Interval; X =Mean; SD= Standard Deviation

Table 4.9
Independent *t* test for Nondominant Side Lower Extremity Isometric Muscle Performance

Variable (N)	All Participants N=72 X (SD)	Non Injured N=39 X (SD)	Injured N=33 X (SD)	Mean Difference (95% CI)	*P*
Hip Abductors	120.96 (24.16)	118.49 (20.22)	124.05 (28.48)	5.75(- 17.03, 5.90)	.34
Hip Abductors Normalized	1.78 (.39)	1.77 (.40)	1.80 (.39)	.09 (-.22, .15)	.68
Hip Adductors	113.65 (23.23)	110.28 (18.11)	117.86 (28.16)	5.48 (-18.51,3.35)	.17
Hip Adductors Normalized	1.68 (.38)	1.64 (.38)	1.72 (.40)	.09 (-.25, .11)	.43
Hip External Rotators	98.45 (22.34)	99.54 (23.35)	97.08 (21.41)	5.33(-8.18, 13.12)	.65
Hip External Rotators Normalized	1.45 (.33)	1.47 (.36)	1.41 (.30)	.08 (-.10, .22)	.44
Knee Extensors	248.45 (71.52)	244.57 (64.67)	253.30 (80.22)	17.07(-42.78, 25.31)	.61
Knee Extensors Normalized	3.63 (.98)	3.59 (.91)	3.68 (1.08)	.23(-.55, .39)	.73
Ankle Plantar flexors	230.65 (73.82)	227.26 (65.00)	234.88 (84.51)	17.62(-42.76,27.51)	.67
Ankle Plantar flexors Normalized	3.43 (.98)	3.37 (1.08)	3.42 (1.22)	.27(-.59, .49)	.85

N= Newton; CI = Confidence Interval; X =Mean; SD= Standard Deviation

Table 4.10
Independent *t* test for Trunk Muscle Performance

Variable (sec)	All Participants N=72 X (SD)	Non Injured N=39 X (SD)	Injured N=33 X (SD)	Mean Difference (95% CI)	*P*
Trunk Flexor Endurance	139.74 (90.45)	127.03 (60.30)	154.76 (115.78)	-27.74 (-70.20, 14.72)	.20
Trunk Extensor Endurance	99.71 (44.03)	93.56 (39.06)	106.89 (48.89)	-13.32 (-34.01, 7.35)	.20
Right Trunk Lateral Endurance	67.21 (27.61)	67.72(25.42)	66.61 (30.41)	1.11 (-12.00, 14.23)	.87
Left Trunk Lateral Endurance	64.38 (26.82)	65.79 (23.61)	62.70 (30.42)	2.04 (-10.02, 14.10)	.74
Trunk Lateral Endurance Difference	9.51 (9.05)	8.92 (9.15)	10.21 (9.03)	-1.29 (-5.58, 3.00)	.55

Sec = Seconds; CI= Confidence Interval; X =Mean; SD= Standard Deviation

Table 4.11
Independent *t* test for Dominant Side Y Balance Directional Reach Scores

Variable	All Participants N=72 X (SD)	Non Injured N=39 X (SD)	Injured N=33 X (SD)	Mean Difference (95% CI)	*P*
Y Balance Forward Reach (cm)	56.76(5.50)	57.20 (3.76)	57.90 (6.97)	-.75(-3.33, 1.83)	.56
Y Balance Posterior Medial Reach (cm)	90.80 (10.76)	90.90 (8.45)	90.20 (13.29)	.69 (-4.47, 5.84)	.79
Y Balance Posterior Lateral Reach (cm)	90.06 (9.44)	91.50(8.45)	89.80 (11.07)	1.77 (-2.83, 6.36)	.45

cm = Centimeter, CI= Confidence Interval, SD= Standard Deviation

Table 4.12
Independent *t* test for Nondominant Side Y Balance Scale Directional Reach Scores

Variable	All Participants N=72 X (SD)	Non Injured N=39 X (SD)	Injured N=33 X (SD)	Mean Difference (95% CI)	*P*
Y Balance Forward Reach (cm)	57.74 (5.91)	56.99 (3.75)	58.69 (7.79)	-1.70(-4.48, 1.08)	.23
Y Balance Posterior Medial Reach (cm)	90.32 (10.61)	90.58 (7.74)	89.99 (13.51)	.59(-4.47, 5.64)	.82
Y Balance Posterior Lateral Reach (cm)	91.52 (10.22)	91.98 (8.48)	90.95 (12.17)	1.03(-3.83, 5.90)	.67

cm = Centimeter; CI= Confidence Interval, SD= Standard Deviation

Table 4.13
Independent *t* test for Composite Y Balance Scale Score and the Difference between Dominant and Nondominant Sides

Variable	All Participants N=72 X (SD)	Non Injured N=39 X (SD)	Injured N=33 X (SD)	Mean Difference (95% CI)	*P*
Dominant Y Balance Composite Score (%)	91.67 (9.22)	92.39 (7.70)	90.76 (10.89)	2.46 (-1.89, 6.81)	.27
Nondominant Y Balance Composite Score (%)	92.55 (9.70)	92.40 (8.09)	92.73 (11.54)	-.33 (-4.96, 4.29)	.89
Y Balance Composite Score Absolute Mean Difference	3.03 (2.75)	2.14 (1.40)	4.11 (3.48)	-2.02 (-3.24, -.82)	.001[a]

[a] Significant difference $p < .05$
CI= Confidence Interval, % = Percentage, SD= Standard Deviation

Table 4.14
Independent *t* test 6 Meter Hop Tests and the Difference between Dominant and Nondominant Sides

Variable	All Participants N=72 X (SD)	Non Injured N=39 X (SD)	Injured N=33 X (SD)	Mean Difference (95% CI)	*P*
Dominant 6 Meter Hop (sec)	2.95 (.55)	3.00 (.39)	2.88 (.70)	.11(-.15, .37)	.40
Non Dominant 6 Meter Hop (sec)	2.92 (.59)	2.95 (.40)	2.87 (.76)	.08 (-.20, .36)	.55
6 Meter Hop Absolute Mean Difference (sec)	.25 (.27)	.21 (.22)	.31(.32)	-.101 (-.23, .03)	.12

[a] Significant difference $p < .05$
sec= Seconds; CI= Confidence Interval, SD= Standard Deviation

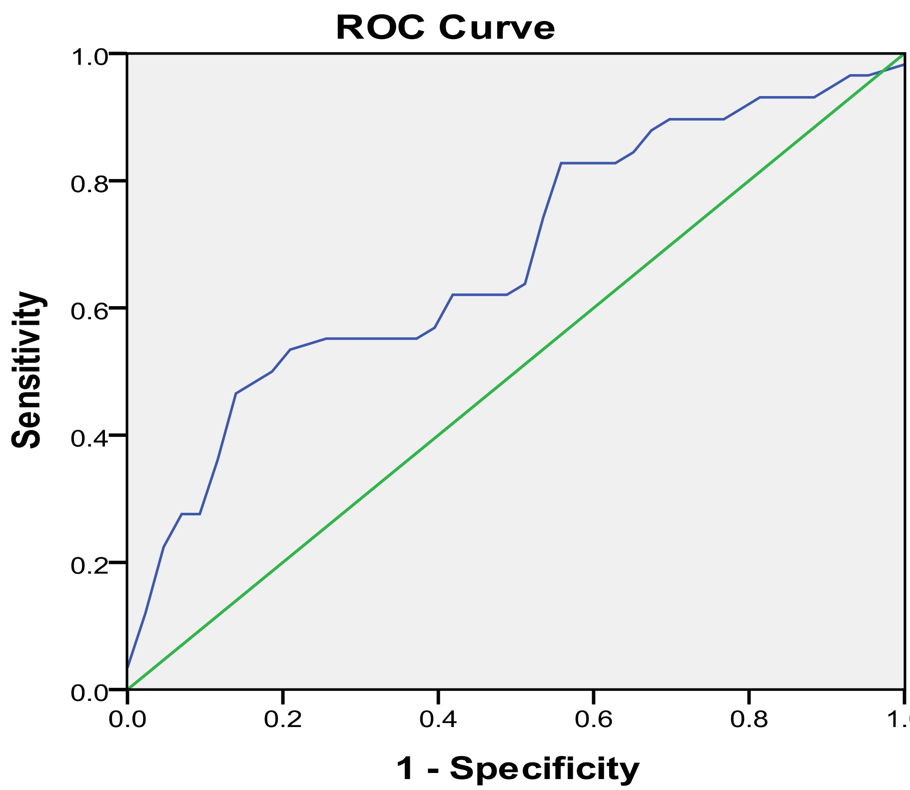
Of the 21 variables analyzed, 5 potential variables emerged from the data screening (α = .15) as possible predictors. Results showed a significant difference in participants' ages (mean difference of 5.34, 95% CI -.65, 8.60, *p*=. 09) between the injured group ($\bar{X}$=38.66, SD =10.71) and the non injured group ($\bar{X}$=43.64, SD =8.96). There was a significant difference in non dominant ankle DF with knee extended (mean difference of -2.01, 95% CI -4.43, .39, *p*= .10) between the injured group ($\bar{X}$=12.81, SD =5.34) and the non injured group ($\bar{X}$= 10.79, SD =4.90). There was also a significant difference in dominant rearfoot posture (mean difference of .72, 95% CI - .19, 1.62, *p*=. 12) between the injured group ($\bar{X}$= 3.13, SD=1.75) and the non injured group ($\bar{X}$= 3.85, SD =2.04). A significant difference was also observed in composite Y balance scale scores differences (mean difference of -2.02, 95% CI -3.24, -.82, *p* = .01) between the injured group ($\bar{X}$= 4.1%, SD =3.48) and the non injured group ($\bar{X}$=2.1%, SD =1.40). Lastly, there was a significant difference in 6 meter hop differences between limbs (mean difference of -.10, 95% CI -.23, .03, *p* = .12) between the injured group ($\bar{X}$=. 31, SD =. 32) and the non injured group ($\bar{X}$=. 21, SD =2.20).

Predictive Validity of Identified Risk Factor

These variables were entered using a forward stepwise method into a binary logistic regression analysis. Results of the regression indicated only the composite Y balance score difference variable as yielding a significant contribution (*p* = .01). The composite Y balance score difference represented the only predictive risk factor (OR = 1.46, 95% CI =1.13, 1.90). A receiver operating characteristic (ROC) curve was drawn in Figure 4.4 using SPSS software to determine a cut off point of 3.6 %. The model predicted 69.2% of the injuries correctly with a specificity of 82% and sensitivity of 54.5%.

This curve and the corresponding area under the curve (AUC) shows that difference in composite scores on the Y balance has predictive ability to discriminate injured versus non injured recreational runners (AUC=0.68, 95% confidence interval: .56, .81, p= .008). Runners with an asymmetry ≥ 3.6% had a positive likelihood ratio of 3.0.

Figure 4.4
ROC Curve For Composite Y Balance Difference



A total of 48 injuries were reported with 9 participants reporting multiple injuries. Of the 33 injured runners, 19 had a Y balance composite score difference ≥ 3.6 %. The top three location of injuries were the knee at 36.8% (7/19) the foot/ankle at 26.3% (5/19), the Achilles/calf at 26.3% (5/19) and the hip and lower back at 5% (1/19) each.

Summary

The results of this study present the relationships between anthropometric measurements, lower extremity muscle performance, trunk muscle performance, and lower extremity neuromuscular control with risk of injury for recreational runners. Of the

21 different variables investigated, only asymmetry of the composite Y balance score ≥ 3.6 % was determined to be predictive for injury. Though lower extremity isometric muscle performance was not identified as a risk factor for injury, a pilot investigation of test re-test reliability using a HHD and StabD yielded excellent reliability for all muscle groups tested. Minimal detectable change values were calculated and reported for lower extremity isometric muscle performance.

Chapter 5: DISCUSSION

This chapter will focus on interpreting the outcomes of this study and how they relate to the existing literature. Each research objective will be reviewed with descriptions of what inferences may be drawn; their potential impact and the clinical relevance will be presented. Limitations and delimitations of the present study will also be identified and explained, as well as recommendations for future research. This chapter will conclude with a summary of the entire project.

Injury Summary

The overall injury rate of 46% this study is within the range of previously reported for recreational runners (19.4% - 79.3%).[4] Our rate of 46% is less than studies which specifically focused on those training for a marathon that reported injury rates of 48.4% and 65.1%.[3,115] In terms of gender, women had a higher injury rate at 51% compared to 39% for men. This finding is consistent with another investigation of running related injuries conducted by Taunton et al that yielded rates of 54% for females and 46% for males.[58] Conversely, other studies have reported higher injury rates in males.[3,8] Gender was not identified as a risk factor for injury in our study based on a logistic regression analysis (p = .31). Previous epidemiology studies also did not identify gender as a predictive risk factor for running related injuries.[90,116]

The foot and ankle (excluding Achilles tendon) were the most common sites of injury in our study at 30% (15 out of 49). The knee was the second most common site at 26% (13 out of 49). The Achilles, which was analyzed as an independent region, ranked third at 22%. This distribution is similar to the one reported by Lopes et al in a recent literature review.[29] This is in contrast to previous reports where the knee was by far the most common site of injury.[7,58] A potential explanation may be that increased focus has been placed on addressing different aspects associated with knee pain over the past several years due to its long-standing position as the most prevalent area for injury in runners. Over the past decade, an emphasis has been put on hip muscle performance in an effort to treat knee pain. Powers and colleagues describe how the femur internally rotates at the hip altering its relation with the patella in subjects with PFPS.[15,17,18] A recent literature review concluded satisfactory evidence exists that proximal exercises are effective in treating PFPS.[117] Over the past several years, this theory has been disseminated to clinicians in peer reviewed medical journals and to the public at large through various different media outlets. One example of this can be found in Runner's World, the most popular running magazine in the United States.[118] In a recent article titled, "*To Relieve Your Runner's, Strengthen Your Hips,*" readers are educated on gluteal strengthening exercises in an effort to address running related knee pain.[119] Another article from five years earlier highlights a literature review also suggesting hip weakness as a potential etiology for lower extremity injuries in runners.[120,121]

Identification of Risk Factors

The primary variable identified as a potential risk factor for injury in this cohort of recreational runners was difference in composite Y balance scale scores. We found that a difference greater than 3.6 % when normalized for leg length had significantly greater odds for injury (OR = 1.46, 95% CI =1.13 – 1.89). Our results are similar to other prospective studies that employed the modified SEBT or Y balance test as a screening tool for injury.[28,122,123] Plisky et al reported an asymmetry of the anterior reach component of the test greater or equal to 4 cm had significantly greater odds of injury

(OR= 2.7, 95% CI 1.4 – 5.3) in a population of high school basketball players.[28] They also reported a normalized composite right reach distance lower than 94% with the modified SEBT was associated with greater risk of non contact injuries in this population. We were not able to determine a composite percentage cut point, as total composite Y balance scale scores were not significantly different between injured ($\bar{X}$= 92.1%, SD =11.03) and non injured groups ($\bar{X}$= 92.5%, SD=8.63).

Another study conducted by Butler et al investigating a cohort of Division III college football players reported a Y balance test composite score below 89.6%, increased odds for non-contact injuries by 250%.[122] They also reported an OR =3.5, 95% CI, 2.4-5.3 for this cut off point. This study did not report an increased risk for injury based on any reach distance asymmetry. One must be cautious drawing conclusions from this study due to inadequate power as the injury group consisted of only 6 out of 59 subjects enrolled. [122]

A more recent study by Smith et al investigated a cohort of 184 Division I athletes participating in multiple sports reported an anterior reach asymmetry > 4 cm was significantly associated with non-contact injury (OR=2.33, 95% CI 1.15-4.76). [123] Thirty cross country athletes (13 male, 17 females) and 10 track and field athletes (7 males, 3 females) were included in the study population. The authors did not report sport specific injury rates or Y balance test results.

Theoretically, the concept of asymmetry in neuromuscular control between lower extremities as a risk factor for injury in distance running seems plausible. Distance running is a highly symmetrical sport where decreased neuromuscular control and or aberrant mechanics can result in increased abnormal forces or strain on structures about the lower extremity kinetic chain resulting in various injuries. These asymmetries are magnified by the repetitive stress over long durations associated with distance running which eventually can lead to tissue breakdown and injury. Neuromuscular control, as measured by the Y balance test, has exhibited predictive validity for risk of injury in the populations of high school and college athletes. To date, our study is the only one to identify an asymmetry of neuromuscular control as a risk factor for injury in a cohort of recreational runners. Our study reports an asymmetry of composite scores on the Y balance test ≥ 3.6 % as a risk factor.

Role of Lower Extremity Muscle Performance

The potential relationship between hip external rotator and or hip abductor weakness, abnormal lower extremity mechanics, and various lower extremity injuries in runners and other athletes has been a popular topic of interest in recent literature.[9-19] Most of these studies are retrospective in nature, investigating characteristics of injured athletes compared to non injured athletes. As a result, one cannot delineate whether hip weakness is a cause or consequence of lower extremity injuries in runners.

Our current prospective study did not find a relationship between isometric hip muscle performance and increased risk for injury. Recently, Thijs et al prospectively investigated this relationship in 77 female recreational runners training for a 5 kilometer race. This study yielded at 21% injury rate (16 out of 77 runners). No significant difference was reported for hip muscle performance between the injured and non injured runners including abduction (p = .55) and external rotation (p = .61).[67] Our results were in contrast to the findings of Leetun et al which reported hip external rotation strength as a predictive risk factor for injury in a cohort of 140 collegiate athletes (OR = .86, 95% CI = .77, .97).[9]

This difference in results is likely multifactorial. For one, the definitions of injury differ considerably. Leetun et al defined injury as the student athlete requiring attention from medical staff and also having to miss at least one day of practice or competition.[9] An injury rate of 29% (41 out of 138) was reported. [9] Seventeen percent of these injuries were the result of contact with another athlete[9] where all of the injuries reported in our study were not the result of contact injuries. Only 34 of the 140 athletes enrolled in the Leetun study were cross country runners. The other 104 participants were basketball players, thus being exposed to repetitive jumping rather than distance running. These different tasks place different stresses on the lower extremities, possibly accounting for the differences in the results. This current study focused solely on runners thus being more externally valid to that specific sport.

Leetun et al also reported hip strength in terms of percent of body weight, with males (mean mass =78.8 kg) reported at 32.6% for hip abductors and 21.6% for external rotators. For females (mean mass =65.1 kg), percent of body weight for hip abductors was reported at 29.2% and 18.4% for hip external rotators.[9] In comparison, the results of our study when converted to percent body weight, reported dominant limb hip strength in terms of percent of body weight, with males (mean mass =76.7 kg) reported at 19.11 for hip abductors and 15.55% for external rotators. For females (mean mass =62.6 kg), percent of body weight for hip abductor was reported at 22.20% and 17.33% for hip external rotation. Based on these results, the Leetun study sample was stronger for both muscle groups and both genders. This difference may be attributed to the fact that their sample was collegiate athletes that all have to participate in an organized strength and conditioning program constructed and supervised by a strength and conditioning coach. Despite exhibiting weaker measurements, hip strength was not found to be a risk factor in our investigation of recreational runners.

It is important to distinguish isometric hip strength from motor control of the hip. Isometric strength is defined as a muscle's ability to maintain a static posture against a load without changes in muscle length, joint angles or movement of the limb being tested.[124] Motor control is defined as the active restraint of excessive motion and coordinated dampening of joint loads in response to sensory feedback.[25] Simply put, one measures the ability to limit movement completely while the other measures how one modulates a desired movement while adapting to external factors. Isometric hip strength has been reported not to have predictive validity. Aberrant dynamic knee valgus mechanics can be present both with and without hip strength deficits.[125] A recent prospective study of 400 female runners by Noehren et al reported that runners who developed PFPS exhibited significantly greater hip adduction angles ($p = .007$) with instrumented running analysis.[126] Hip internal rotation angle ($p = .47$) or rear foot eversion ($p = .10$) where not identified as risk factors.[126] Isometric hip strength should be considered a key component of lower extremity neuromuscular control and running mechanics but should not be perceived as the sole risk for injury. To be clear, we are not stating that practitioners should disregard hip strength in this population. The evidence suggests there can definitely be hip weakness in the presence of repetitive stress injuries in runners.[9-19] This decrease in muscle performance is likely a symptom of the injury and can potentially contribute to a greater decrease in one's ability to properly control lower extremity running mechanics and thus may be considered a precipitating factor.

A previous investigation has reported isometric hip adductor to hip abductor ratio as being statistically significant, *p* = .01 in subjects with PFPS $(\bar{X} = 1.3, \text{SD } .66)$ compared to non injured controls $(\bar{X} = 1.03, \text{SD} = .18)$ with the PFPS.[127] The purported theory is that an imbalance between these muscle groups may play a role in increased incidence of injury. We calculated isometric hip adduction/abduction ratios by dividing dominant limb hip adductor by dominant limb hip abductor measurements. Our results showed there was not a significant difference in hip adduction/ abduction ratio (mean difference of .01, 95% CI -.07, .07, *p* = .98) between the injured group ($\bar{X}$=. 95, SD =. 13) and the non injured group ($\bar{X}$= .95, SD =. 17). This calculation was also conducted for the non dominant limb (mean difference of .02, 95% CI -.03, .08, *p*=. 52) between the injured group ($\bar{X}$=. 96, SD = .15 and the non injured group ($\bar{X}$= .94, SD = .12). The chief difference between our study and the other investigations cited is the prospective methodology we employed opposed to assessing strength retrospectively to injury. This muscle imbalance appears to be a symptom of injury rather than a cause.

Role of Core Muscle Performance

Though core strengthening is often considered an essential component of rehabilitation after injury, there is no established evidence associating a decrease in core muscle performance with an increased risk for injury. The results of our prospective investigation did not find core muscle performance to be a predictive risk factor for injury in recreational runners. These findings are consistent with Leetun et al who also prospectively assessed core strength in a group of collegiate athletes.[9] Both Leetun et al and our study measured core strength similarly using the McGill protocol for flexion and lateral endurance.[50] The method for measuring lumbar extension endurance differed as we employed the method described by Ito et al instead of the Biering-Sorensen method due to its tendency to cause lumbar stiffness in pre trial testing.[51] In the Leeten study, subjects who were injured generally had lower core muscle performance measurements than the non injured group however this difference was not statistically significant. To my knowledge, there are no other studies that prospectively assess core muscle performance as a risk for injury in a population of recreational runners. The current evidence does not support decreased core muscle performance as potential risk factor for injury in recreational runners.

Other core related measures have been investigated prospectively as risk factors for injury.[21,128] Zazulak et al investigated core proprioception as measured by active and passive repositioning of the trunk in a sample of 277 collegiate athletes over the course of 3 years. No significant difference was reported between injured and non injured male athletes however core proprioception deficits as measured by active repositioning error were significantly greater ($P < .05$) in women with any knee injuries ($\bar{X}$=2.2°), and ligamentous or meniscal injuries ($\bar{X}$=2.4°) compared to non injured women ($\bar{X}$=1.5°).[21] Active proprioceptive repositioning predicted knee injury status with 90% sensitivity and 56% specificity in female athletes.[21] With the same population, Zazulak et al also measured magnitude of trunk displacement with perturbations.[128] Trunk displacement was greater in athletes with knee, ligament, and ACL injuries than in non injured athletes ($P < .05$). Lateral displacement was the strongest predictor of ligament injury ($P = .009$).[128] Components of core neuromuscular control have been reported as potential risk factors for injury in collegiate athletes. The distribution and location of the injuries in the two Zazulak et al studies reported only on the knee, differing from our study that reported injuries to all areas of the lower extremity.

A direct comparison of trunk or core neuromuscular control to lower extremity neuromuscular control has yet to be investigated. A study by Sato et al investigated the effect of a 6 week core strength training program on ground reactions forces, lower extremity neuromuscular control (as measured by the SEBT), and 5000m performance for a group of recreational runners.[129] Results of the study reported no significant difference in ground reaction forces or SEBT scores following the strengthening program, but runners did exhibit improved performance with a 5000m run.[129] The results of this study should be interpreted with caution as there were a small number of subjects (N=20) and the researchers did not measure core muscle performance before or after the training program.[129] The relationship between core muscle performance and its relationship with lower extremity neuromuscular control needs to be investigated further.

Role of Distal Kinetic Chain Factors

No significant difference was observed between the injured and non injured groups in our study for medial longitudinal arch angle, 1st metatarsophalangeal (1st MTP) extension range of motion (ROM), ankle plantar flexion strength, and ankle dorsiflexion ROM (knee flexed). Dominant limb rearfoot posture and non dominant limb ankle dorsiflexion ROM (knee extended) did meet the data screening threshold but were not significantly different between the two groups, and were found not to be significant predictors in the logistic regression model. Our findings are consistent with Lun et al who also measured ankle dorsiflexion, plantar flexion ROM and static rear foot and forefoot valgus amongst other variables in a cohort 87 recreational runners.[40] They reported no significant difference when comparing measurements between injured and non injured runners except for left subtalar varus in women (0.2 to 4.2).[40] These findings are also consistent with the results of a larger prospective study (N=355) conducted by Wen et al assessing lower extremity alignment consisting of similar variables to our study including arch index and heel valgus.[130] The authors also reported no significant differences with any of their other lower extremity alignment variables measured.[130] Static lower extremity distal kinetic chain factors do not appear to be associated with increased risk for injury in recreational runners.

Hand Held Dynamometry with Stabilization Device Reliability

Hand Held Dynamometry **(**HHD) has demonstrated a wide range of (ICC .16 – .98) intra-session intra-rater reliability in measuring lower extremity muscle performance often due to varying testing methods and differences among populations tested.[42] Accuracy of HHD measurements can be affected by inadequate strength of the tester and lack of stabilization of participant and device.[43] Investigations that incorporate a stabilizing apparatus produce better reliability measurements, however many of the techniques reported are impractical in a clinical setting and often compromise the portability of the HHD.[42,44-46] The results of this study indicate that use of a HHD with a PVC stabilization device produces excellent intrarater reliability for lower extremity isometric muscle performance of hip abductors, external rotators, adductors, knee extensors, and ankle plantar flexors (ICC = .93, – .98). The use of the stabilization device limits the concerns regarding strength of the tester and stabilization of the HHD while maintaining portability for more practical use in a clinical setting. This current study is the first to investigate the reliability of HHD utilizing a PVC stabilization device for lower extremity isometric muscle performance in healthy individuals.

Limitations and Delimitations

Limitations

An epidemiologic investigation of this nature presented a lot of challenges. The chief obstacle was the extensive time needed for data collection of 21 different variables for each of the 75 participants enrolled. Data collection was conducted over two sessions and would have not been possible without the assistance of additional investigators. A manual of standard operating procedures was employed in an effort to ensure standardization of measurement techniques and to control for variability. Though reliability measures were cited for each measure used, we did not formally conduct pilot intrarater reliability tests for each variable other than HHD pilot study.

The obstacle of time also dictated the location and timing when data collection could take place. Our target population was a community recreational running group. The groups' long runs occurred early on weekend mornings. As a result, data collection sessions had to occur outdoors after a 7 mile run to maximize participation. Each home site was located in community parks with field houses. The external walls of these facilities were used to stabilize the HHD. Portable plinths and other equipment were also brought on site for data collection.

Adequate rest time was allotted to limit the effect of fatigue on the measurements taken. This variation in our methods could have an effect on extrapolating our results to other populations if measurements are not performed under the same conditions. We also did not have the opportunity to investigate the effects of fatigue on the participants' measurements, as this would have required testing both prior to and after the 7 mile run.

As stated previously, this study required assistance from additional investigators. Though these investigators underwent training for their assigned measures, separate intra tester reliability investigations for each variable were not conducted due to time constraints as these investigators all participated in this study voluntarily outside of their normal full time work schedules. The PI made a concerted effort to choose clinical tests and measures that were reported as most reliable in the literature whenever possible. An intrarater reliability study was conducted for the novel use of the stabilization device in conjunction with a HHD for measuring lower extremity isometric muscle performance. We were able to determine MDC_{95} based on the reliability and SEM calculated for lower extremity isometric muscle performance however was unable to do so for the other measurements due to not conducting reliability studies for variables included.

Another limitation of this study is the primary dependent variable of injury status being reliant on self-reporting by the participants. We attempted to ensure the accuracy of this data through triangulation of bi weekly contact by the PI, the runner's training logs, and group leaders attendance logs. We also employed a clear operational definition of injury by incorporating varying degrees of severity similar to Taunton et al. including:[58]

- *Grade I: pain after running*
- *Grade 2: pain during running but not restricting distance or speed*
- *Grade 3: pain during running restricting distance or speed*
- *Grade 4: pain preventing all running*

In particular, the bi weekly contacts by the PI were very helpful with injury reporting.

This was done via email where the participants were asked to choose one of the above classifications that best described their status. These checks were performed in a standard fashion the day following the last long run at the end of each 2 week interval.

Delimitations

This concept could also be a considered a delimitation to this study as we intentionally did not try to diagnose participants' injuries. This would have required more of the participants' time to be evaluated by a healthcare professional. As stated previously, time was a limited resource in this study as the participants were training on their free time opposed to professional runners that typical train daily, as road racing is their primary source of income. Novice or recreational runners are the prime population at risk for injury with the increasing popularity of running in the general public. Site of injury was recorded allowing for comparison of our distribution of injuries to be compared with previous prospective studies.[3,58]

A second delimitation of this study was the omission of assessing foot strike pattern as a potential risk factor. In addition to the growing popularity of running for fitness, there has also been an increased interest in barefoot or minimalist running. There is controversy over whether barefoot running is helpful or harmful in terms of risk for injury.[131] Advocators contend that this method promotes more of a forefoot strike pattern, which has been reported to improve force attenuation with initial contact of stance phase.[132] Detractors report concerns of increased risk of injury associated with running with less supportive footwear.[133] It has yet to be determined if foot strike pattern is associated with risk for injury in recreational runners.[134] We intentionally chose not to delve into this debate primarily due to practicality. Most studies assessing foot strike patterns measure this objectively using sophisticated motion analysis or force plate equipment.[135-137] One of our main objectives was to identify risk factors based on test and measures that easily can be performed in a clinical setting. Motion analysis labs are not frequently available in clinical settings due to their costs and space requirements.

Recommendations for Future Research

Our findings suggest that asymmetry in lower extremity neuromuscular control should be considered as a risk factor for injury in recreational runners. A logical next step would be to see if this holds true in other populations of more advanced or elite runners. In our study, though we identified the foot, ankle (30%) and knee injuries (26%) as the most common sites, we did not specify which specific diagnoses were most prevalent. A similar investigation could be performed to further delineate which specific diagnoses those with lower extremity neuromuscular control asymmetries are at risk for developing over the course of a training regimen.

It also seems plausible to investigate the effect of neuromuscular training as a preventative intervention for those who exhibit asymmetries. A prospective randomized control trial comparing a test group exhibiting asymmetries receiving neuromuscular training opposed to a control group with similar asymmetries not receiving training, being followed over the course of a graded marathon-training program would be ideal.

Based on the Y balance test being able to predict 69.2% of injuries correctly, it seems reasonable to investigate the ability of other dynamic tests designed to measure lower extremity neuromuscular control to see if they exhibit predictive validity, as there are still 30.8% of injuries unaccounted for. It is possible that other dynamic tests may also serve as pre training screening tools in conjunction with the Y balance test in this population.

Based on our positive results for intrarater reliability using the PVC stabilization device with the HHD, future research investigating the inter rater reliability is an appropriate next step. The muscle groups chosen for this study was based on previous evidence that decreased muscle performance could contribute to aberrant running mechanics.[12,13,15,17,18] As a result, not all lower extremity movements were included. Further investigation of other movements including hip extension, internal rotation, knee flexion, ankle dorsiflexion, inversion, and eversion is also necessary. Lastly, our target population was healthy asymptomatic runners at the time of testing. Future research should focus on the validity and reliability with the use of the PVC stabilization device for measuring muscle performance in symptomatic populations.

Dissertation Summary

The popularity of distance running has considerably increased in recent years. This surge in running participation has also resulted in an increase in incidence of lower extremity injuries. The purpose of this study was to investigate the relationship between anthropometric measurements, proximal and distal lower extremity muscle performance, core muscle endurance, lower extremity flexibility, and neuromuscular control with the incidence of injury in recreational runners over one marathon training season. Also, when a relationship was established, we sought to evaluate the predictive validity for any of the variables being investigated for risk of injury in this population.

We conducted a prospective cohort study of 75 recreational runners who were registered members of the Chicago Area Running Association (CARA) following a set 18 week training regimen in preparation for the fall marathon season with the majority participating in the Chicago Marathon. Anthropometric measurements, proximal and distal isometric lower extremity muscle performance, isometric core muscle endurance, lower extremity flexibility and neuromuscular control were measured. Incidence of injury was tracked over the course of 18 weeks, May 2014 – October 2014. Data was analyzed comparing the differences between injured and non-injured groups.

There were 33 repetitive stress injuries yielding a gross injury rate of 46% (male n=13, female n=20). Of all the variables analyzed, 5 variables emerged as possible a predictors including age, dominant limb rear foot posture, non dominant limb ankle DF ROM (extended), limb difference of Y balance scale composite scores and limb difference in the 6 M hop test. These variables were entered into a binary logistic regression analysis. Results of the regression indicated only the composite Y balance score difference variable as yielding a significant contribution (OR = 1.46, 95% CI =1.127 – 1.892, p = 0.01). The model predicted 69.2% of the injuries with a specificity of 82% and sensitivity of 54.5%. A cutoff point of 3.6% was determined using a receiver operating characteristic curve. Runners were 3 times more likely to get injured with an asymmetry ≥ 3.6%.

An asymmetry of lower extremity neuromuscular control ≥ 3.6% measured by the Y balance scale has been identified as a potential risk factor for injury in recreational runners. This test can be performed as part of a pre-training screening or physical and may be helpful in identifying recreational runners at risk for injury. Future research is needed to determine if interventions focused on improving lower extremity neuromuscular control symmetry reduces risk for injury in recreational runners.

APPENDIX A

LETTER OF SUPPORT FOR THE PROJECT

THE UNIVERSITY OF CHICAGO MEDICAL CENTER

THERAPY SERVICES
PHYSICAL THERAPY
OCCUPATIONAL THERAPY
CARDIOPULMONARY REHAB

MC 1081 Room W 107
5841 South Maryland Avenue
phone 773.702.6891
fax 773.702.5340

February 12, 2014

Memo:

To: Steven Jackson, PT, MPT, OCS

From: Jennifer Gilbertson, Assistant Director, Outpatient Therapy Services

I am writing to confirm that the University of Chicago Therapy Services Department fully supports you in conducting your clinical research study, "**An Investigation of Relationships between Physical Characteristics of Recreational Runners and Lower Extremity Injuries**". In doing so we recognize the responsibility for safeguarding the rights and welfare of the human subjects being investigated and for complying with all regulations as outlined by the US Department of Health and Human Services.

In support, we will provide facilities and equipment needed for the department to serve as your primary data collection and storage site. The department has adequate space to conduct your baseline measurements that you propose in this study. We will also supply you with a secure file cabinet where you can keep hardcopies of informed consents and paper questionnaires.

Please let us know if you need anything else to help you complete this research project.

Sincerely,

Jennifer Gilbertson PT, MHS, OCS

Jennifer Gilbertson PT, MHS, OCS
Assistant Director, Outpatient Therapy Services
The University of Chicago Medicine

APPENDIX B

MANUAL OF STANDARD OPERATING PROCEDURES

Manual of Standard Operations and Procedures

INFORMED CONSENT/INSTITUTIONAL REVIEW BOARD (IRB) APPROVAL

Data collection for this study will not commence before satisfaction of all requirements and official approval from the Nova Southeastern University institutional review board (IRB). All participants must provide signed informed consent prior to being enrolled in the study. The primary investigator (PI) and any assisting investigator will be allowed to obtain informed consent from participants. Photo copies will be provided to participants and originals will be kept by the PI.

ELIGIBILITY CRITERIA

Inclusion/ Exclusion Criteria

The following inclusion criteria will be used to determine eligibility for this study:

1. Age between 18-65 years old
2. Registered members of the running group Chicago Area Running Association (CARA)
3. Recreational runners: Male time – half marathon > 1:11:00; marathon > 2:31:00, Female time –half marathon > 1:21:00, marathon >3:01:00

The following exclusion criteria will be used to determine eligibility for this study:

4. Lower extremity injury suffered within the past 3 months
5. Inability to comply with completion of weekly running logs and injury reporting

This study will include both genders and members of minority groups. No individuals will be excluded from participation in this study on the basis of race, creed, color, gender, national or ethnic origin, or sexual orientation.

DESCRIPTION OF HUMAN PARTICIPANTS

75 recreational runners who are registered members of CARA following a set 18 week training regimen in preparation for the fall marathon season with the majority

participating in the Chicago Marathon.

DEMOGRAPHIC INFORMATION

Participants will be required to fill out a base line questionnaire addressing age, gender, height, weight, running experience, training characteristics and history of previous injury. If an injury is a revealed, detailed description of previous injuries including location, duration since onset or cessation of symptoms, and time off from running will be provided. Additional information including cross training and/or participation in other sports or recreational activities will also be recorded.

PROCEDURES

ANTHROPOMETRIC MEASUREMENTS

Participants will also instructed to perform a 5 minute light jog around the test facility for a dynamic warm up in an effort to reduce injury during the data collection process. Anthropometric measurements will be recorded including leg length discrepancy, medial longitudinal arch angle, static rear foot posture, and quadriceps angle (Q angle).

1. Leg Length: Leg length will be measured using a tape measure proximally from anterior superior iliac spine (ASIS) to distally at the center of the medial malleolus. The center of the medial malleolus will be determined as the intersection between the greatest length and width of the malleolus as measured by a tape measure.

2. Medial Longitudinal Arch Angle: Medial longitudinal arch angle will be measured bilaterally as with an intersecting line from the center of the medial malleolus to the navicular tuberosity with another line from the navicular tuberosity to the first metatarsal head. These 3 points will be drawn on the patient with a marker. The angle will be measured using a small (arms 6in long, 1in wide) plastic 360 degree goniometer with the axis over the navicular tuberosity. Angles $\leq$ 90 degrees were defined as low and associated with a pronated foot. Angles $\geq$ 180 degrees were defined as high and associated with a supinated foot.

3. Static Rear Foot Posture: Static rear foot posture will be measured with a small 360 degree plastic goniometer (arms 6in long, 1in wide) in weight bearing with the participant standing on the edge of an plinth. The stationary arm of the goniometer will be over a point bisecting the posterior calf and the mobile arm bisecting the posterior calcaneus. The landmarks for the center of the posterior calcaneus and posterior calf will first be established with participant prone on the plinth. The center of the calcaneus will be determined as the intersection between the greatest length and width of the calcaneus as

measured by a tape measure. For the posterior calf, a mark will be made 20 cm up from the bottom of the calcaneus. The width of the posterior calf will be measured with a tape measure and the center point will be marked at the half way point of this measurement.

4. Q Angle: Q angles will be measured with a standard goniometer modified with the stationary arm extended to allow for it to reach the ASIS. This method limits potential variability and error from tester with projecting an imaginary line from the ASIS to the tip of the arm of a standard length goniometer. The participant will be lying supine with knees flexed to 10 degrees over a rolled towel. The 10 degrees of flexion will be measured with a goniometer. The axis of the goniometer will be placed over the center of the patella determined as the intersection between the greatest length and width of the patella measured by a tape measure. The extended arm of the goniometer will be aligned with the ASIS to the mid patella. The other arm of the goniometer will be aligned with the center axis at the mid patella to the tibial tuberosity.

ANKLE/ FOOT RANGE OF MOTION

1. Ankle Dorsiflexion ROM: Ankle dorsiflexion ROM will be measured passively using standard 360 degree goniometer (arm 12inch long, 2 inches wide) with stationary arm bisecting the distal fibula and the mobile arm bisecting the 5th ray. For purposes of this study, these measurements will be taken in a similar test position of patient in long sitting on a plinth for knee extended and sitting over edge for knee flexed positions respectively.

2. 1st MTP Dorsiflexion ROM: 1st MTP dorsiflexion will be measured passively using a small plastic 360 degree goniometer (arms 6 inches long, 1inch wide). The participant will be seated on the examination table with feet hanging over the edge. The axis of the goniometer will be placed medially at the first MTP joint with stationary arm aligned with the first metatarsal bone and the mobile arm aligned with the first proximal phalanx.

LOWER EXTREMITY MUSCLE PERFORMANCE

Lower extremity isometric muscle performance (MP) will be measured using the micro*FET II*™ (Hogan health industries, Draper, UT, USA) hand held dynamometer (HHD). All testing procedures will use a PVC stabilizing device (StabD). Participants will be asked to perform isometric contraction against manual resistance to ensure their understanding of the desired action to be measured. The stabilization device will then be positioned as described previously for each test position. Participants will be asked to maintain a six second isometric contraction. Peak values will be recorded for three repetitions. There will be a ten second rest period between contractions. Rest period between muscle groups tested will be set at three minutes to allow for change in test position. The testing sequence will be alternated between positions to avoid systemic error.

Isometric hip external rotation, hip abduction, knee extension and ankle plantar flexion MP will be measured. These four movements were chosen because previous research reports weakness of these muscle groups can be associated with increased transverse plane motion about the knee.

1. Hip Abductor MP: Hip abductor MP will be measured in supine on a plinth with a stabilizing strap across the pelvis. The force pad of HHD will be place 5cm above the lateral malleolus with other end of StabD stabilized against a wall.

2.Hip Adductor MP: Hip adductor MP will be measured in supine on a table with a stabilizing strap across the pelvis. The force pad of HHD will be placed 5cm above the medial malleolus with other end of StabD stabilized against a wall

3. Hip External Rotator MP: Hip external rotator MP will be measured with participants in the sitting position on the edge of a plinth with hips and knees flexed to 90 degrees. The test leg will be anchored with a strap at the thigh and a towel roll will be placed between the legs to limit involvement of hip adductors. The force pad of HHD will be placed 5 cm proximal to the medial malleolus of test leg with other end of StabD against a wall.

4. Knee Extensor MP: Knee Extensor MP will be measured with participants sitting on the edge of the plinth with hips and knees flexed to 90 degrees as measured by a standard goniometer. A stabilizing strap will be placed over bilateral thighs just distal to the hip joint line bilaterally and arms will be folded across chest. The HHD force pad was placed 5 cm above imaginary bimalleolar line and the other end or the StabD against a wall.

5. Ankle Plantar Flexor MP: Ankle plantar flexion MP will be measured on a plinth in a long sitting position, with arms folded across chest without back support. A rolled towel will be placed underneath the knee of the test leg with a stabilizing strap over the proximal tibia. The force pad of HHD will be placed on the plantar surface of the metatarsal heads with the other end of StabD against the wall.

TRUNK MUSCLE PERFORMANCE

Trunk muscle performance will be determined by the participants' ability to hold static positions challenging anterior, posterior and lateral muscle groups. Participants will be allowed to perform 3 submaximal trials of 5 – 10 seconds to ensure they can correctly attain and maintain desired posture. Once the investigator establishes that participant can perform task with proper technique, a one time maximal hold duration will be recorded. Participants will be cued to hold each posture as long as possible. There will be five minute rest periods between each measurement

1. Trunk Flexor Endurance: Flexor endurance will be performed with participant in sitting on a mat next to a 180 degree wall mounted protractor. Participants will cross arms across chest and reclined back to 30 degrees from a vertical line perpendicular with the floor. The duration at which participant can maintain 60 degree angle will be measured with a stop watch to the nearest second.

2. Trunk Extensor Endurance: Extensor endurance will be measured with the participant positioned prone with a small pillow under the lower abdomen to decrease the lumbar lordosis, They will then be instructed maintain maximum cervical flexion with pelvic stabilization through gluteal muscle contraction with goal of holding the sternum off of the table as long as possible. The duration the participant is able to maintain appropriate test position will be measured recorded.

3. Trunk Lateral Endurance: Lateral endurance will be measured with the participant in side lying of side being measured. The top leg will be place in front of bottom leg. Participants will be instructed to lift their hips off of the plinth supporting their upper trunk with forearm. The top, uninvolved arm will be folded across opposite shoulder. The duration participants are able to hold hips off plinth will be measured.

LOWER EXTERMITY NEUROMUSCULAR CONTROL

Two primary tests will be used to measure lower extremity neuromuscular control, the Y balance test (YBT) and 6 meter hop test.

1. Y Balance Test: Lower extremity neuromuscular control will be measured using the Y balance test kit, which is constructed of PVC pipe. Participants will be asked to stand on the middle platform on one leg where the pipes intersect and reach as far as possible moving the marker along the PVC marked to the nearest 0.5 cm. These directions are termed anterior, posterior medial, and posterior lateral (Figure 3.15). Participants will be allowed six trials for each direction on each leg as motor learning for the task has been shown to plateau after six trials. The participant will then be allowed three trials in each direction; the greatest distance attained will be used for statistical analysis.

2. <u>6-meter Hop Test</u>: The distance of 6 meters will be measured with a large rolling tape measure. The investigator will give the command “ready, set, go”. Upon the go command, participants will be asked to hop on one lower extremity for a distance of 6 meters marked by cones. The duration it takes from start to finish will be measured seconds using a stopwatch. Values will be rounded to the nearest hundredth of a second. The test will be performed bilaterally for 2 repetitions. Mean times of both trials will be recorded for each leg.

INJURY RECORDING

Participants and running group leaders will be educated on the process of how injuries will be recorded over the 18 week period. Runners will be asked to keep a weekly running log. The PI will collect information from the participants’ logs on bi weekly basis. No specific education will be provided on whether or not participant should train with pain. This decision will be left up to participant and their healthcare provider. If an injury occurs, the location or body part involved will be recorded. The injury will be classified as follows:

- *Grade I: pain after running*
- *Grade 2: pain during running but not restricting distance or speed*
- *Grade 3: pain during running restricting distance or speed*
- *Grade 4: pain preventing all running*

In addition, subjects will record how many days of running sessions they are unable to participate in due to injury. This information can be crossed checked by group leaders who keep track of attendance and injured runners as part of their normal duties. Participants will be asked to fill out a post training regimen questionnaire to identify any other injuries or discrepancies found with other records. Length of injury recording will be recorded over an 18 week period.

RISKS/BENEFITS

The risks associated with participation in this study are minimal as most of the measurements taken are those commonly performed in a typical physical therapy setting. Participants will be required to warm up prior to data collection. The data collection pro

DATA ANALYSIS

Descriptive statistics will be employed to show distribution of all variables collected or measured prior to the start of the training regimen and during including injuries, body part involved, and severity grade of injuries. A gross overall measurement of incidence rate of injury will be derived by dividing the number of injuries (regardless of location and severity) by the number of total participants.[7] Differences between injured participants' measurements and characteristics will be compared to non injured participants' using an independent *t* test. The level of significance will be set at $\alpha = 0.05$. Variables that exhibit a statistically significant difference between the groups will be considered potential predictors. Once these are identified, a binary logistic regression will also be used to develop a model to potentially predict the risk injury based on participant demographics, training characteristics, muscle performance and results of functional tests. A receiver operating curve (ROC) analysis will be employed to identify potential cutoff values for the clinical tests where injuries are more likely to occur. Intraclass correlation coefficients (3,1) will be used to measure pilot test-retest reliability of HHD with StabD for lower extremity MP. Strength measurements will be normalized for body mass using the formula: strength (N) /body mass in pounds (lbs).). The minimal detectable change (MDC) for each variable will also be calculated at 95% level of confidence, employing the formula $MDC_{95} = 1.96 \times \sqrt{2} \times SEM$.

ASSURANCE OF DATA INTEGRITY/CONFIDENTIALLITY

All information gathered in this study will be kept completely confidential. The data collected will be transferred to a computer spreadsheet. This spreadsheet will be kept on a password protected computer. Any paper records pertaining to a participant's involvement in this study including demographic intake forms, contact information, and informed consents will be stored in a locked file cabinet in the physical therapy department at the University of Chicago. A case number will indicate the participant's identity on these records. This information will only be accessible to the PI and additional investigators. No confidential information such as the participants' name, address, phone number, or and other information that might possibly be used to link the data back to the subject will be transmitted.

APPENDIX C

NOVA SOUTHEASTERN UNIVERSITY
IRB APPROVAL NOTICE

NOVA SOUTHEASTERN UNIVERSITY

MEMORANDUM

To: Steven Jackson, Ph.D.
HPD – College of Health Care Sciences

From: David Thomas, M.D., J.D.
Chair, Institutional Review Board

Date: May 22, 2014

Re: *An Investigation of Relationships between Physical Characteristics of Recreational Runners and Lower Extremity Injuries* – NSU IRB No. 03211439Exp.

I have reviewed the revisions to the above-referenced research protocol by an expedited procedure. On behalf of the Institutional Review Board of Nova Southeastern University, *An Investigation of Relationships between Physical Characteristics of Recreational Runners and Lower Extremity Injuries* is approved in keeping with expedited review category # 4 and #7. Your study is approved on **May 22, 2014** and is approved until **May 21, 2015.** You are required to submit for continuing review by **April 21, 2015.** As principal investigator, you must adhere to the following requirements:

1) CONSENT: You must use the stamped (dated consent forms) attached when consenting subjects. The consent forms must indicate the approval and its date. The forms must be administered in such a manner that they are clearly understood by the subjects. The subjects must be given a copy of the signed consent document, and a copy must be placed with the subjects' confidential chart/file.

2) ADVERSE EVENTS/UNANTICIPATED PROBLEMS: The principal investigator is required to notify the IRB chair of any adverse reactions that may develop as a result of this study. Approval may be withdrawn if the problem is serious.

3) AMENDMENTS: Any changes in the study (e.g., procedures, consent forms, investigators, etc.) must be approved by the IRB prior to implementation.

4) CONTINUING REVIEWS: A continuing review (progress report) must be submitted by the continuing review date noted above. Please see the IRB web site for continuing review information.

5) FINAL REPORT: You are required to notify the IRB Office within 30 days of the conclusion of the research that the study has ended via the IRB Closing Report form.

The NSU IRB is in compliance with the requirements for the protection of human subjects prescribed in Part 46 of Title 45 of the Code of Federal Regulations (45 CFR 46) revised June 18, 1991.

Cc: Dr. M. Samuel Cheng
Ms. Jennifer Dillon

Institutional Review Board
3301 College Avenue • Fort Lauderdale, Florida 33314-7796
(954) 262-5369 • Fax: (954) 262-3977 • Email: *irb@nsu.nova.edu* • Web site: *www.nova.edu/irb*

NOVA SOUTHEASTERN UNIVERSITY
Health Professions Division
College of Health Care Sciences
Physical Therapy Department

Consent Form for Participation in the Research Study Entitled
An Investigation of Relationships between Physical Characteristics of Recreational Runners and Lower Extremity Injuries

Funding Source: None.

IRB protocol # 03211438Exp

Principal investigator
Steven Jackson, PT, MPT, OCS
NSU PhD Student
Email: **runningresearch@yahoo.com**
Phone: (312)566-0266

Co-investigators
M. Samuel Cheng, PT, MS, Sc.D
Morey Kolber, PT, PhD, OCS,Cert.MDT, CSCS
Department of Physical Therapy
3200 S. University Dr.
Fort Lauderdale, FL 33328
(954) 262-1273

For questions/concerns about your research rights, contact:
Human Research Oversight Board (Institutional Review Board or IRB)
Nova Southeastern University
(954) 262-5369/ Toll Free: 866-499-0790
IRB@nsu.nova.edu

Testing Site Information
University of Chicago Physical Therapy Department
5841 South Maryland
Chicago, IL 60637
773-702-6891

What is the study about?
You are invited to participate in a research study. The goal of this study is to better understand the relationships between anthropometric measurements, proximal/ distal lower extremity strength, core muscle endurance, lower extremity flexibility and neuromuscular control with incidence of injury in recreational runners. We plan to follow a local running group as they train for a marathon. We will take measurements initially before the start of the running program and track the incidence of injury over the duration of their training period. We hope to identify potential risk factors for running related injuries.

Initials: ________ Date: ________

3200 South University Drive • Fort Lauderdale, Florida 33328-2018
(954) 262-1662 • 800-356-0026, ext. 21662 • Fax: (954) 262-1783 • *www.nova.edu/pt*

Why are you asking me?
We are inviting you to participate because you are a member of a running group training for a marathon. There will be 125 participants in this research study.

What will I be doing if I agree to be in the study?
You will fill out a questionnaire detailing your previous running experience, running related injury history, and current cross training regimen. Before the start of your training program, the researcher will take measurements of your leg strength, trunk strength, balance/coordination, ankle flexibility, leg length, arch type and knee angles. After the initial baseline measurements are taken, you will participate in the marathon-training program as you normally would as a part of your running group. Over the course of the 18 week training program you will be asked to keep a running log and record any injuries that occur along the way. The primary investigator will be contacting you via phone ore email bi weekly to check on your status. The data collection will commence when your running 18 week program is over.

Is there any audio or video recording?
This research project will not include any audio or video recording

What are the dangers to me?
Muscle Soreness with muscle testing

Subjects will be asked to warm up prior to testing. Muscle soreness in not a common side effect of using a dynamometer however it is remotely possible. If it occurs, it should subside in 1-2 days.

Loss of balance with Y balance test

Subjects have the potential to loose balance and fall while performing a balance test. Our target population will be active middle aged adults who have no more risk for falling as anyone else in the normal population. Subjects will be guarded by research personnel when performing the tests.

Breach of Confidentiality

All information gathered in this study will be kept completely confidential. The PI will transfer the data collected to a computer spreadsheet. The PI will keep this spreadsheet on a password protected computer. Any paper records pertaining to a participant's involvement in this study including demographic intake forms, contact information, and informed consents will be stored in a locked file cabinet in the physical therapy department at the University of Chicago that will only be accessible to the PI.

The procedures or activities in this study may also have unknown or unforeseeable risks. Risks to you are minimal, meaning they are not thought to be greater than other risks you experience normally when training for a marathon. If you have any questions about the research, your research rights, or have a research-related injury, please contact Steven Jackson, Samuel Cheng, or Morey Kolber. You may also contact the IRB at the numbers indicated above with questions as to your research rights

Are there any benefits to me for taking part in this research study?
There are no benefits to you for participating.

Will I get paid for being in the study? Will it cost me anything?
There are no costs to you or payments made for participating in this study.

How will you keep my information private?
All paper records pertaining to your involvement in this study including running history questionnaire, contact information, and informed consents will be stored in a locked file cabinet. All identifiable subject information including consent forms will be discarded using a shredder at the end of the 3 year period required by the IRB. The measurements will be transferred to a computer spreadsheet. This electronic data will be kept on a password protected computer.

What if I do not want to participate or I want to leave the study?
You have the right to leave this study at any time or refuse to participate. If you do decide to leave or you decide not to participate, you will not experience any penalty or loss of services you have a right to receive. If you choose to withdraw, any information collected about you **before** the date you leave the study will be kept in the research records for 36 months from the conclusion of the study and may be used as a part of the research.

Other Considerations:
If the researchers learn anything that might change your mind about being involved, you will be told of this information.

NOVA SOUTHEASTERN UNIVERSITY
Institutional Review Board
Approval Date: MAY 2 2 2014
Continuing Review Date: MAY 2 1 2015

Initials: _______ Date: _______

Voluntary Consent by Participant:
By signing below, you indicate that

- this study has been explained to you
- you have read this document or it has been read to you
- your questions about this research study have been answered
- you have been told that you may ask the researchers any study related questions in the future or contact them in the event of a research-related injury
- you have been told that you may ask Institutional Review Board (IRB) personnel questions about your study rights
- you are entitled to a copy of this form after you have read and signed it
- you voluntarily agree to participate in the study entitled *An Investigation of Relationships between Physical Characteristics of Recreational Runners and Lower Extremity Injuries*

Participant's Signature: ______________________ Date: ____________

Participant's Name: ______________________ Date: ____________

Signature of Person Obtaining Consent: ______________________

Date: ______________________

NOVA SOUTHEASTERN UNIVERSITY
Institutional Review Board
Approval Date: MAY 2 2 2014
Continuing Review Date: MAY 2 1 2015

APPENDIX D

PARTICPANT RECRUITEMENT FLYER

NOVA SOUTHEASTERN UNIVERSITY
Institutional Review Board
Approval Date: MAY 2 2 2014
Continuing Review Date: MAY 2 1 2015

NOVA SOUTHEASTERN UNIVERSITY

Are you Interested in Participating in a Research Study on Running Injury Prevention?

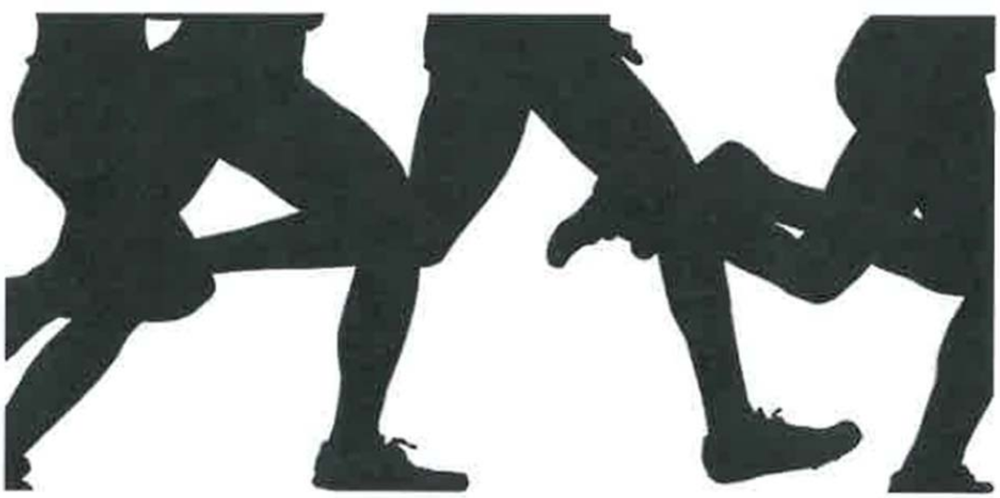
Do you meet the following criteria?

1. Age between 18-65 years old
2. Registered members of the running group Chicago Area Running Association (CARA) participating in the Chicago Marathon training program.
3. Marathon time:

- Male half > 1:11:00; Full > 2:31:00,
- Female half > 1:21:00, Full >3:01:00

For details contact :

Steven Jackson PT, MPT, OCS (PhD Student)
Email: runningresearch@yahoo.com
Phone: 312 – 566- 0266



APPENDIX E

RUNNER'S INTAKE FORMS

Running Background Information

Name:____

Email Address:______________________ **Phone**:__________________________

Preferred contact method:______________________

Age: ________ **Gender**:__________ **Height:** __________ **Weight**:_________

Past injuries/ Orthopedic Surgeries:

____

____

____

Running/Walking History Summary

of years running/walking: ________ Current weekly mileage: ________

Brand of training shoes: __________________

Orthotics? Yes/No

Cross Training

Cross training methods and frequency:

____

____

APPENDIX F

RUNNER'S TRAINING LOGS

Marathon Training Log

Week	Sunday	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Total Mileage	Injury Report
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									

REFERENCES

1. Running U. State of the Sport Report 2012-14. [Web Site]. http://www.runningusa.org/node/16977 - 16980 Accessed April 22, 2015.
2. Fredericson M, Misra AK. Epidemiology and aetiology of marathon running injuries. *Sports Med.* 2007;37:437-439.
3. Walter SD, Hart LE, McIntosh JM. The Ontario cohort study of running related injuries. *Arch Internal Med* 1989;149:2561-2564.
4. van Gent RN, Siem D, van Middelkoop M, et al. Incidence and determinants of lower extremity running injuries in long distance runners: a systematic review *Br J Sport Med.* 2007;41:469-480.
5. Hreljac A. Etiology, prevention, and early intervention of overuse injuries in runners: A biomechanical perspective. *Phys. Med. Rehabil. Clin. N. Am.* 2005;16:651-667.
6. Marczyk G, DeMatteo D, Festinger D. Essentials of Research Design and Methodology. Hoboken, N J: John Wiely & Sons, Inc; 2005.
7. Taunton JE. A prospective study of running injuries: the Vancouver Sun Run "In Training" clinics. *Br J Sport Med.* 2003;37:239-244.
8. Buist I, Bredeweg SW, Bessem B, van Mechelen W, Lemmink KA, Diercks RL. Incidence and risk factors of running-related injuries during preparation for a 4-mile recreational running event. *Br J Sport Med.* 2008;44:598-604.
9. Leetun DT, Ireland ML, Willson JD, Ballantyne BT, Davis IM. Core stability measures as risk factors for lower extremity injury in athletes. *Med Sci Sports Exercerc.* 2004;36:926-934.
10. Dierks TA. Proximal and distal influences on hip and knee kinematics in runners with patellofemoral pain syndrome during a prolonged run. *J Ortho Sports Phys Ther.* 2008.
11. Ireland ML WJ, et al. Hip strength in females with and without patellofemoral pain. *J Ortho Sports Phys Ther.* 2003;33:671-676.
12. Neimuth P. Hip weakness in lower extremity athletic injuries. *Int J Sports Med.* 2007;8(4):179-192.
13. Bolgla LA. Hip strength and hip and knee kinematics during stair descent in females with and without patellofemoral pain syndrome. *J Ortho Sports Phys Ther.* 2008;38:12-17.
14. Plisky MS. Medial tibial stress syndrome in high school cross country runners: incidence and risk factors. *J Ortho Sports Phys Ther.* 2007;37:40-47.
15. Niemuth PE, Johnson RJ, Myers MJ, Thieman TJ. Hip muscle weakness and overuse injuries in recreational runners. *Clin JSport Med.* 2005;15:14-21.
16. Robinson RL, RJ. N. Analysis of hip strength in females seeking physical therapy treatment for unilateral patellofemoral pain syndrome. *J Ortho Sports Phys Ther.* 2007;35:232-238.
17. Souza RB. Femur rotation and patellofemoral joint kinematics: A weight-bearing magnetic resonance imaging analysis. *J Ortho Sports Phys Ther.* 2010;40:277-285.
18. Powers CM. The influence of abnormal hip mechanics on knee Injury: A biomechanical perspective. *J Ortho Sports Phys Ther.* 2010;40:42-51.
19. Fredericson M, Cookingham CL, Chaudhari AM, Dowdell BC, Oestreicher N, Sahrmann SA. Hip abductor weakness in distance runners with iliotibial band syndrome. *Clin JSport Med.* 2000;10:169-175.
20. Heiderscheit BC. Lower extremity injuries: Is it just about hip strength. *J Orthop Sports Phys Ther.* 2010;40:39-41.
21. Zazulak BT, Hewitt TE, Reeves NP, Goldberg B, J. C. The effects of core propioception on knee injury. A prospective biomechanical epidemiological study. *Am. J Sports Med.* 2007;35:368-373.

22. Hewett TE, Myer GD, Ford KR, et al. Biomechanical measures of neuromuscular control and valgus loading of the knee predict anterior cruciate ligament injury risk in female athletes: a prospective study. *Am. J Sports Med.* 2005;33:492-501.
23. Bell D, Padua D, Clark M. Muscle Strength and Flexibility Characteristics of People Displaying Excessive Medial Knee Displacement. *Arch Phys Med Rehabil.* 2008;89:1323-1328.
24. Loyd DG, Buchanan TS. Strategies of muscular support of varus and valgus motions of isometric loads at the human knee. *J. Biomech.* 2001;34:1257-1267.
25. Riemann BL, Lephart SM. The sensorimotor system, part I: the physiologic basis of functional joint stability. *J Athl Train.* 2002;37:71-79.
26. Hertel J MS, Denegar CR. Intratester and intertester reliability during the Star Excursion Balance Test. *J Sport Rehabil.* 2000;9:104-116.
27. Kinzey SJ AC. The reliability of the Star Excursion Balance Test in assessing dynamic balance. *J Orthop Sports Phys Ther.* 1998;27:356-360.
28. Plisky PJ RM, Kaminski TW, Underwood FB. Star Excursion Balance Test as a predictor of lower extremity injury in high school basketball players. *J Orthop Sports Phys Ther.* 2006;36:911-919.
29. Lopes AD, Hespanhol Junior LC, Yeung SS, Costa LO. What are the main running-related musculoskeletal injuries? A Systematic Review. *Sports Med.* Oct 1 2012;42(10):891-905.
30. Maganaris CN, Narici MV, Almekinders LC, Maffulli N. Biomechanics and pathophysiology of overuse tendon injuries: ideas on insertional tendinopathy. *Sports Med.* 2004;34:1005-1017.
31. Sanders M. *Ergonomics and Management of Musculoskeletal Disorders*. 2nd ed. St. Louis: Elsevier; 2004.
32. Daniels J. Daniels Running Formula. Champagne, IL: Human Kinetics; 2005.
33. Bredeweg SW, Zijlstra S, Buist I. The GRONORUN 2 study: effectiveness of a preconditioning program on preventing running related injuries in novice runners. The design of a randomized controlled trial. *BMC Musculoskel. Disord.* 2010;11:196.
34. Korpelainen R, Orava S, Karpakka J, Siira P, Hulkko A. Risk factors for recurrent stress fractures in athletes. *Am J Sports Med.* 2001;29:304-310.
35. McPoil TG, Cornwall MW. Use of the longitudinal arch angle to predict dynamic foot posture in walking. *J Am Podiatr. Med. Assoc.* 2005;95:114-120.
36. Jonson SR, Gross MT. Intraexaminer reliability, interexaminer reliability, and mean values for nine lower extremity skeletal measures in healthy naval midshipmen. *J Orthop Sports Phys Ther.* 1997;25:253-263.
37. Dahle LK, Mueller MJ, Delitto A, Diamond JE. Visual assessment of foot type and relationship of foot type to lower extremity injury. *J Orthop Sports Phys Ther.* 1991;14:70-74.
38. Huberti HH, Hayes WC. Patellofemoral contact pressures. The influence of q-angle and tendofemoral contact. *J. Bone Joint Surg. Am.* 1984;66:715-724.
39. Draper CE, Chew KT, Wang R, Jennings F, Gold GE, Fredericson M. Comparison of quadriceps angle measurements using short-arm and long-arm goniometers: correlation with MRI. *PM R.* 2011;3:111-116.
40. Lun V, Meeuwisse WH, Stergiou P, Stefanyshyn D. Relation between running injury and static lower limb alignment in recreational runners. *Br J Sport Med.* 2004;38:576-580.
41. Dicharry J. Kinematics and kinetics of gait: from lab to clinic. *Clin Sports Med.* 2010;29:347-364.

42. Kolber MJ, Cleland JA. Strength testing using hand-held dynamometry. *Phys Ther Rev.* 2005;10:99-112.
43. Wikholm JB, Bohannon RW. Hand held dynanometer measurement: Tester strength makes a difference. *J Orthop Sports Phys Ther.* 1991;13:191-198.
44. Nadler S, Deprince M, Hauesien N, Malanga G, Stitik T, Price E. Portable dynamometer anchoring station for measuring strength of the hip extensors and abductors. *Arch Phys Med Rehabil.* 2000;81:1072-1076.
45. Click Fenter P, Bellew JW, Pitts TA, Kay RE. Reliability of stabilised commercial dynamometers for measuring hip abduction strength: a pilot study. *Br J Sport Med.* 2003;37:331-334.
46. Kelln BM, McKeon PO, Gontkof LM, Hertel J. Hand-held dynamometry: reliability of lower extremity muscle testing in healthy, physically active,young adults. *J Sport Rehabil.* 2008;17:160-170.
47. Kolber MJ, Beekhuizen K, Cheng M-SS, Fiebert IM. The reliability of hand-held dynamometry in measuring isometric strength of the shoulder internal and external rotator musculature using a stabilization device. *Physiothery Theory and Prac.* 2007;23:119-124.
48. Wang C. Test-retest strength reliability: Hand-held dynamometry in community-dwelling elderly fallers. *Arch Phys Med Rehabil.* 2002;83:811-815.
49. Hamner SR, Seth A, Delp SL. Muscle contributions to propulsion and support during running. *J Biomech.* 2010;43:2709-2716.
50. McGill SM, Childs A, Liebenson C. Endurance times for low back stabilization exercises: clinical targets for testing and training from a normal database. *Arch Phys Med Rehabil.* 1999;80:941-944.
51. Ito T, Shirado O, Suzuki H, Takahashi M, Kaneda K, Strax TE. Lumbar trunk muscle endurance testing: an inexpensive alternative to a machine for evaluation. *Arch Phys Med Rehabil.* Jan 1996;77(1):75-79.
52. Hertel J BR, Hale SA, Olmsted-Kramer LC. Simplifying the Star Excursion Balance Test: Analysis of subjects with and without chronic ankle instability. *J Orthop Sports Phys Ther.* 2006;36:131-137.
53. Reid A, Birmingham TB, Stratford PW, Alcock GK, JR G. Hop testing provides a valid and reliable outcome measure during rehabilitation after anterior cruciate ligament reconstruction. *J Orthop Sports Phys Ther.* 2007;87:337-349.
54. Portney L WM. Foundations of Clinical Research: Applications to Practice. 2nd ed. Englewood Cliffs, NJ: Prentice-Hall Inc; 2000.
55. Kaufman KR, Brodine SK, Shaffer RA, Johnson CW, Cullison TR. The effect of foot structure and range of motion on musculoskeletal overuse injuries. *Am J Sports Med.* 1999;27:585-593.
56. Satterthwaite P, Larmer P, Gardiner J, Norton R. Incidence of injuries and other health problems in the Auckland Citibank marathon 1993. *Br J Sport Med.* 1996;30:324-326.
57. Lysholm J, Wiklander J. Injuries in runners. *Am J Sports Med.* 1987;15:168-171.
58. Taunton JE, Ryan MB, Clement DB, McKenzie DC, Lloyd-Smith DR, Zumbo BD. A retrospective case-control analysis of 2002 running injuries. *Br J Sport Med.* 2002;36:95-101.
59. Laprade J, Culham E, Brouwer B. Comparison of five isometric exercises in the recruitment of the vastus medialis oblique in persons with and without patellofemoral pain syndrome. *J Orthop Sports Phys Ther.* 1998;27:197-204.

60. Bolgla LA, Boling MC. An update for the conservative management of patellofemoral pain syndrome: a systematic review of the literature from 2000 to 2010. *Int J Sports Phys Ther.* 2011;6:112-125.

61. Fulkerson JP. Diagnosis and treatment of patients with patellofemoral pain. *Am J Sports Med.* 2002;30:447-456.

62. Rauh MJ, Koepsell TD, Rivara FP, Rice SG, Margherita AJ. Quadriceps angle and risk of injury among high school cross-country runners. *J Orthop Sports PhysTher.* 2007;37:725-733.

63. Cowan SM, Bennell KL, Crossley KM, Hodges PW, McConnell J. Physical therapy alters recruitment of the vasti in patellofemoral pain syndrome. *Med Sci Sports Exerc.* 2002;34:1879-1885.

64. Boling MC, Padua DA, Alexander Creighton R. Concentric and eccentric torque of the hip musculature in individuals with and without patellofemoral pain. *J Athl Train.* 2009;44:7-13.

65. Herrington L, Nester C. Q-angle undervalued? The relationship between Q-angle and medio-lateral position of the patella. *Clin Biomech. (Bristol, Avon).* Dec 2004;19(10):1070-1073.

66. Dierks TA, Manal KT, Hamill J, Davis IS. Proximal and distal influences on hip and knee kinematics in runners with patellofemoral pain during a prolonged run. *J Orthop Sports Phys Ther.* 2008;38:448-456.

67. Thijs Y, Pattyn E, Van Tiggelen D, Rombaut L, Witvrouw E. Is hip muscle weakness a predisposing factor for patellofemoral pain in female novice runners? A prospective study. *Am J Sports Med.* 2011;39:1877-1882.

68. Barber FA, Sutker AN. Iliotibial band syndrome. *Sports Med.* 1992;14:144-148.

69. Orchard JW, Fricker PA, Abud AT, Mason BR. Biomechanics of iliotibial band friction syndrome in runners. *Am J Sports Med.* 1996;24:375-379.

70. Fairclough J, Hayashi K, Toumi H, et al. Is iliotibial band syndrome really a friction syndrome. *J. Sci. Med. Sport.* 2007;10:74-78.

71. Grau S, Krauss I, Maiwald C, Axmann D, Horstmann T, Best R. Kinematic classification of iliotibial band syndrome in runners. *Scand. J. Med. Sci. Sports.* 2011;21:184-189.

72. Noehren B, Davis I, Hamill J. ASB clinical biomechanics award winner 2006 prospective study of the biomechanical factors associated with iliotibial band syndrome. *Clin Biomech. (Bristol, Avon).* 2007;22:951-956.

73. Grau S, Krauss I, Maiwald C, Best R, Horstmann T. Hip abductor weakness is not the cause for iliotibial band syndrome. *Int J Sports Med.* Jul 2008;29(7):579-583.

74. McPoil TG, Martin RL, Cornwall MW, Wukich DK, Irrgang JJ, Godges JJ. Heel pain--plantar fasciitis: clinical practice guildelines linked to the international classification of function, disability, and health from the orthopaedic section of the American Physical Therapy Association. *J Orthop Sports Phys. Ther.* Apr 2008;38(4):A1-A18.

75. Buchbinder R. Clinical practice. Plantar fasciitis. *N. Engl. J. Med.* 2004;350:2159-2166.

76. Shama SS, Kominsky SJ, Lemont H. Prevalence of non-painful heel spur and its relation to postural foot position. *J Am Podiatry Assoc.* Mar 1983;73(3):122-123.

77. Rome K, Webb P, Unsworth A, Haslock I. Heel pad stiffness in runners with plantar heel pain. *Clin Biomech. (Bristol, Avon).* Dec 2001;16(10):901-905.

78. Riddle DL, Pulisic M, Pidcoe P, Johnson RE. Risk factors for Plantar fasciitis: a matched case-control study. *J Bone Joint Surg. Am.* 2003;85-A:872-877.

79. Hicks JH. The mechanics of the foot. II. The plantar aponeurosis and the arch. *J Anat.* 1954;88:25-30.

80. Rome K, Webb P, Unsworth A, Haslock I. Heel pad stiffness in runners with plantar heel pain. *Clin Biomech. (Bristol, Avon).* 2001;16:901-905.
81. Warren BL. Anatomical factors associated with predicting plantar fasciitis in long-distance runners. *Med Sci Sports Exercerc.* 1984;16:60-63.
82. Clement DB, Taunton JE, Smart GW. Achilles tendinitis and peritendinitis: etiology and treatment. *Am J Sports Med.* 1984;12:179-184.
83. Maffulli N, Kader D. Tendinopathy of tendo achillis. *J. Bone Joint Surg. Br.* 2002;84:1-8.
84. Brukner P, Bradshaw C, Bennell K. Managing common stress fractures: let risk level guide treatment. *Phys Sports Med.* 1998;26:39-47.
85. Harrast MA, Colonno D. Stress fractures in runners. *Clin Sports Med.* 2010;29:399-416.
86. Deimel JF, Dunlap BJ. The female athlete triad. *Clin Sports Med.* Apr 2012;31(2):247-254.
87. Pohl MB, Mullineaux DR, Milner CE, Hamill J, Davis IS. Biomechanical predictors of retrospective tibial stress fractures in runners. *J. Biomech.* 2008;41:1160-1165.
88. Zadpoor AA, Nikooyan AA. The relationship between lower-extremity stress fractures and the ground reaction force: a systematic review. *Clin Biomech. (Bristol, Avon).* 2011;26:23-28.
89. Nielsen RO, Buist I, Sorensen H, Lind M, Rasmussen S. Training errors and running related injuries: a systematic review. *Int J Sports Phys. Ther.* 2012;7:58-75.
90. Macera CA, Pate RR, Powell KE, Jackson KL, Kendrick JS, Craven TE. Predicting lower-extremity injuries among habitual runners. *Arch. Intern. Med.* 1989;149:2565-2568.
91. Koplan JP, Rothenberg RB, Jones EL. The natural history of exercise: a 10-yr follow-up of a cohort of runners. *Med Sci Sports Exercerc.* 1995;27:1180-1184.
92. Buist I, Bredeweg SW, van Mechelen W, Lemmink KA, Pepping GJ, Diercks RL. No effect of a graded training program on the number of running-related injuries in novice runners: a randomized controlled trial. *Am J Sports Med.* 2008;36:33-39.
93. Jakobsen BW, Kroner K, Schmidt SA, Kjeldsen A. Prevention of injuries in long-distance runners. *Knee Surg. Sports Traumatol. Arthrosc.* 1994;2:245-249.
94. Macera CA. Lower extremity injuries in runners. Advances in prediction. *Sports Med.* 1992;13:50-57.
95. Jacobs SJ, Berson BL. Injuries to runners: a study of entrants to a 10,000 meter race. *Am. J Sports Med.* 1986;14:151-155.
96. Cavanagh PR, Williams KR. The effect of stride length variation on oxygen uptake during distance running. *Med Sci Sports Exercerc.* 1982;14:30-35.
97. Perry J. Gait Analysis: Normal and Pathological Function. Thorofare, NJ: Slack Inc; 1992.
98. Novacheck TF. The biomechanics of running. *Gait Posture.* 1998;7:77-95.
99. Schache AG, Bennell KL, Blanch PD, Wrigley TV. The coordinated movement of the lumbo-pelvic-hip complex during running: a literature review. *Gait Posture.* 1999;10:30-47.
100. Schache AG, Blanch PD, Rath DA, Wrigley TV, Starr R, Bennell KL. Intra-subject repeatability of the three dimensional angular kinematics within the lumbo-pelvic-hip complex during running. *Gait Posture.* 2002;15:136-145.
101. McPoil T, Cornwall MW. Relationship between neutral subtalar joint position and pattern of rearfoot motion during walking. *Foot Ankle Int.* 1994;15:141-145.
102. Dierks TA, Davis IS, Hamill J. The effects of running in an exerted state on lower extremity kinematics and joint timing. *J. Biomech.* 2010;43:2993-2998.
103. Ounpuu S. The biomechanics of walking and running. *Clin Sports Med.* Oct 1994;13(4):843-863.

104. Ounpuu S. The biomechanics of running: a kinematic and kinetic analysis. *Instr. Course Lect.* 1990;39:305-318.
105. Cappellini G, Ivanenko YP, Poppele RE, Lacquaniti F. Motor patterns in human walking and running. *J. Neurophysiol.* 2006;95:3426-3437.
106. CARA. Chicago Area Running Association. [Website]. http://www.cararuns.org/About CARA.aspx. Accessed Febuary 24, 2013.
107. The Bank of America Chicago Marathon. [Website]. http://www.chicagomarathon.com/. Accessed October 13, 2013.
108. Gogia PP, Braatz JH. Validity and reliability of leg length measurements. *J Orthop Sports Phys. Ther.* 1986;8(4):185-188.
109. Haight HJ, Dahm DL, Smith J, Krause DA. Measuring standing hindfoot alignment: reliability of goniometric and visual measurements. *Arch Phys Med Rehabil.* 2005;86:571-575.
110. Youdas JW, Bogard CL, Suman VJ. Reliability of goniometric measurements and visual estimates of ankle joint active range of motion obtained in a clinical setting. *Arch Phys Med Rehabil.* 1993;74:1113-1118.
111. Fong CM, Blackburn JT, Norcross MF, McGrath M, Padua DA. Ankle-dorsiflexion range of motion and landing biomechanics. *J Athl Train.* 2011;46:5-10.
112. Jones AM, Curran SA. Intrarater and interrater reliability of first metatarsophalangeal joint dorsiflexion: goniometry versus visual estimation. *J. Am. Podiatr. Med. Assoc.* 2012;102:290-298.
113. Krause DA, Schlagel SJ, Stember BM, Zoetewey JE, Hollman JH. Influence of lever arm and stabilization on measures of hip abduction and adduction torque obtained by hand-held dynamometry. *Arch Phys Med Rehabil.* Jan 2007;88(1):37-42.
114. Plisky PJ, Gorman PP, Butler RJ, Kiesel KB, Underwood FB, Elkins B. The reliability of an instrumented device for measuring components of the star excursion balance test. *N. Am. J. Sports Phys. Ther.* May 2009;4(2):92-99.
115. Nicholl JP, Williams BT. Medical problems before and after a popular marathon. *Br. Med. J. (Clin. Res. Ed).* Nov 20 1982;285(6353):1465-1466.
116. Marti B, Vader JP, Minder CE, Abelin T. On the epidemiology of running injuries. The 1984 Bern Grand-Prix study. *Am J Sports Med.* May-Jun 1988;16(3):285-294.
117. Peters JS, Tyson NL. Proximal exercises are effective in treating patellofemoral pain syndrome: a systematic review. *Int J Sports Phys. Ther.* Oct 2013;8(5):689-700.
118. Alliance for Audited Media. Six Month Circulation Averages. [Web Site]. http://abcas3.auditedmedia.com/ecirc/magtitlesearch.asp. Accessed January 18, 2015.
119. Douglas S. To Relieve Runner's Knee, Strengthen Your Hips. *Runner's World* [Web Site]. 2014; http://www.runnersworld.com/injury-treatment/to-relieve-runners-knee-strengthen-your-hips?icid=OBtrafficRW_TBD_AR1. Accessed January 18, 2015.
120. Ferber R, Hreljac A, Kendall KD. Suspected mechanisms in the cause of overuse running injuries: a clinical review. *Sports Health.* May 2009;1(3):242-246.
121. Lobby M. Tragically Hip; New research suggests weak hip are behind injuries throughout the body. *Runner's World.*2009:21, 25-26.
122. Butler RJ, Lehr ME, Fink ML, Kiesel KB, Plisky PJ. Dynamic balance performance and noncontact lower extremity injury in college football players: an initial study. *Sports Health.* Sep 2013;5(5):417-422.
123. Smith CA, Chimera NJ, Warren M. Association of Y Balance Test Reach Asymmetry and Injury in Division I Athletes. *Med Sci Sports Exercerc.* May 27 2014.

124. D N. Kinesiology of the Musculoskeletal System : Foundations for Rehabilitation. 6th ed. St. Louis, Mo: Mosby/Elsevier; 2010.

125. Willson JD, Binder-Macleod S, Davis IS. Lower extremity jumping mechanics of female athletes with and without patellofemoral pain before and after exertion. *Am J Sports Med.* Aug 2008;36(8):1587-1596.

126. Noehren B, Hamill J, Davis I. Prospective evidence for a hip etiology in patellofemoral pain. *Med Sci Sports Exercerc.* Jun 2013;45(6):1120-1124.

127. Magalhaes E, Silva AP, Sacramento SN, Martin RL, Fukuda TY. Isometric strength ratios of the hip musculature in females with patellofemoral pain: a comparison to pain-free controls. *J Strength Cond Res.* Aug 2013;27(8):2165-2170.

128. Zazulak BT, Hewett TE, Reeves NP, Goldberg B, Cholewicki J. Deficits in neuromuscular control of the trunk predict knee injury risk: a prospective biomechanical-epidemiologic study. *Am J Sports Med.* Jul 2007;35(7):1123-1130.

129. Sato K, Mokha M. Does core strength training influence running kinetics, lower-extremity stability, and 5000-M performance in runners? *J Strength Cond Res.* Jan 2009;23(1):133-140.

130. Wen DY, Puffer JC, Schmalzried TP. Injuries in runners: a prospective study of alignment. *Clin J Sport Med.* Jul 1998;8(3):187-194.

131. Lieberman DE. What we can learn about running from barefoot running: an evolutionary medical perspective. *Exerc. Sport Sci. Rev.* Apr 2012;40(2):63-72.

132. Lieberman DE, Venkadesan M, Werbel WA, et al. Foot strike patterns and collision forces in habitually barefoot versus shod runners. *Nature.* Jan 28 2010;463(7280):531-535.

133. Salzler MJ, Bluman EM, Noonan S, Chiodo CP, de Asla RJ. Injuries observed in minimalist runners. *Foot Ankle Int.* Apr 2012;33(4):262-266.

134. Tam N, Astephen Wilson JL, Noakes TD, Tucker R. Barefoot running: an evaluation of current hypothesis, future research and clinical applications. *Br J Sport Med.* Mar 2014;48(5):349-355.

135. Divert C, Mornieux G, Baur H, Mayer F, Belli A. Mechanical comparison of barefoot and shod running. *Int J Sports Med.* Sep 2005;26(7):593-598.

136. De Wit B, De Clercq D, Aerts P. Biomechanical analysis of the stance phase during barefoot and shod running. *J Biomech.* Mar 2000;33(3):269-278.

137. Hatala KG, Dingwall HL, Wunderlich RE, Richmond BG. Variation in foot strike patterns during running among habitually barefoot populations. *PLoS One.* 2013;8(1):e52548.