GENDER DIFFERENCES IN LOWER EXTREMITY KINEMATICS THROUGHOUT VARIOUS STAGES OF A 5K RUN

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

By

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

Major Program:
Advanced Athletic Training

March 2017

Fargo, North Dakota

North Dakota State University
Graduate School

Title

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

MASTER OF SCIENCE

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ABSTRACT

Running has been a popular sport because of convenience and health benefits. Fatigue among recreational runners may alter running mechanics, thereby increasing the risk for injury. The purpose of this study was to evaluate changes in lower extremity biomechanics throughout a 3.1 mile (5K) run. Ten male and ten female participants wore reflective markers to capture contralateral pelvic drop, knee adduction, knee abduction, and hip adduction. Participants ran 3.1 miles (5K) on a treadmill at a self-determined pace. A two-way, repeated measures ANOVA was conducted to capture the within-subject data across time and between-subject comparing differences in gender. Females had significantly greater contralateral pelvic drop but it did not change over time. Knee abduction angles significantly declined over the five observations. Gender differences and effects of distance can alter the biomechanics in recreational runners. More research is needed to identify predisposing factors to the development of chronic running injuries.

ACKNOWLEDGEMENTS

I would like to first and foremost thank my family for supporting me through my undergraduate and graduate careers. I would not have been able to get this far without the love and encouragement of my parents, sisters, and extended family. They understood that this is a long process and along the way gave me the motivation to continue to do my best. Thanks Mom, Dad, Melanie, and Amanda!

I would also like to thank my boyfriend, Jay, for joining me on this crazy journey. Even while apart, he would remind me of what is important and to focus on my goals. Through long days and late nights of working on my thesis, he encouraged me to work hard and never give up. I cannot thank him enough for being by my side through it all.

I want to also thank my academic advisor, Dr. Katie Lyman, for never giving up on me. She would never hesitate to make time for me, no matter what the reason. She also helped me focus on my long term goals and setting deadlines along the way motivated me to keep writing. Her positive, constructive feedback molded me into a better writer, and I have her to thank for that. She always cared about not only my graduate career, but also my life and how I was doing as a person. I owe her a great thanks for everything these past two years.

My NDSU classmates have also helped me through graduate school and my thesis. Their encouragement meant a lot because they are going through the same process. I want to thank them for their friendship and motivation through our graduate careers. Thanks Maddie, Mo, Taylor, and Brian!

Finally, I would like to thank NDSU's Health, Nutrition, and Exercise Sciences department for supporting my financial need to complete my thesis data collection. I appreciate them greatly for all they have provided.

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CHAPTER 1. INTRODUCTION

1.1. Overview of the Problem

Running has been a popular sport for decades, both recreationally and competitively. The popularity of the sport of running began in the 1970s and continued into the 1980s when 25 million Americans began exercising. Running was the sport of choice for many due to the convenience and health benefits.[1] Because of the growing popularity of running, injury prevalence is also increasing.[2] A quarter to half of all runners will suffer an injury that alters their running performance each year.[3] Some of these injuries are acute, or sudden damage to muscle, tendon, ligament, or bone. However, the majority of running injuries are chronic, overuse injuries. Running is a highly repetitive activity and stresses put on the body accumulate with every step.[4,5] Various studies have concluded that the most common running injuries occur at the knee,[1,6,7] with women sustaining more overuse injuries to the lower extremity overall than men.[8]

Many researchers have attempted to determine the causes of running-related injuries in order to aid in prevention, although there is no one cause.[1,4-13] Injuries can result from numerous factors, such as training, shoes, running surface, flexibility, previous injury, and malalignment.[1] Moreover, an increased risk for chronic injury has been linked to running longer distances.[4] Not only do longer distances cause increased stress on the lower extremity, but fatigue during those runs also plays a role in injury risk. Furthermore, fatigue has been shown to alter running biomechanics, which then leads to increased injury risk.[9-11,14-16]

Various overuse injuries have been linked to incorrect running biomechanics. Currently, patellofemoral pain syndrome is the most common injury among runners.[1,5,6,17-20] Patellofemoral pain syndrome is knee pain caused by inefficient kinematics at the knee joint. Patellofemoral pain syndrome is commonly associated with an increase in hip adduction and contralateral pelvic drop.[16] Additionally, those beginning with greater quadriceps angles (Q-angle) are predisposed to developing patellofemoral pain syndrome.[1] Iliotibial band friction syndrome is the second most common cause of knee pain[5,6,21] and is related to improper kinematics at both the hip and knee joints, such as increased hip adduction[14,22,23] and increased knee flexion.[14]

Differences in running kinematics between males and females also exist. For example, females typically have increased hip adduction[20,24,25] and knee abduction angles[20,25] during running. It is important to understand changes in running biomechanics in order to identify specific causes of such overuse injuries, as well as to predict those who may be at risk. Although previous studies have found correlations between overuse injuries and certain running kinematics, there is a gap in the literature for when the onset of biomechanical changes occurs during running.[1,5,6,14,17-20,22,23] Additionally, gender differences have not been extensively studied, and limited research exists on the differences in running kinematics between males and females.[20,24-26]

1.2. Statement of Purpose

The purpose of this study was to evaluate the changes in lower extremity biomechanics at the hip and knee joints throughout a 3.1 mile (5K) run. Kinematic differences were also compared between males and females.

1.3. Research Questions

1. In the course of a 5K run, do observable changes in joint angles occur?
2. What differences are observed in lower extremity running kinematics between males and females?

1.4. Instrumentation

Various instruments were used to collect data for this study. A Trackmaster TMX425C treadmill (Full Vision, Inc., Newton, KS) was used to allow the participant to remain in the cameras' field of view throughout the entire run. Two cameras (Casio Exilim EX-FH20) recorded two-dimensional video of the participant's lower extremity in both the frontal and sagittal views. Following the completion of the 3.1 mile run by each participant, specific joint angles were measured by a specific biomechanical software (Dartfish Motion Analysis Version 8, Dartfish, Fribourg, Swizerland). The video was uploaded to the Dartfish software and the hip and knee joint angles were measured at 0.9-1.0, 1.4-1.5, 1.9-2.0, 2.4-2.5, and 3.0-3.1 miles. The first half-mile increment was not measured due to warm up and treadmill acclimation. A standard goniometer was also used in this study to measure participants' quadriceps angle before the run.

1.5. Limitations

Limitations occur in research due to the inclusion of multiple variables. Limitations of this study included the use of two-dimensional video analysis and software instead of the gold standard three-dimensional analysis system because of the unavailability of three-dimensional technology. A treadmill was used in this study; however, this was a limitation because running on a treadmill cannot be generalized to outdoor running.[8] A treadmill allows video to be captured of the all the participants' movements throughout the entire run in one view. Additionally, participant height was a limitation that cannot be accounted for in this study. Because of the treadmill design and where the safety rails are located, certain reflective markers were difficult to view depending on the height of the participant. This limited data collection for sagittal joint angles for some participants.

1.6. Delimitations

Several delimitations existed in this research study as a result of time restrictions, available resources, and location of the study. For this study we used a convenience sample to recruit ten males and ten females, ages 18-40, through North Dakota State University and the surrounding Fargo/Moorhead communities. This was a delimitation because only participants from this small sample population were studied, which decreased the generalizability of the study. A 3.1 mile (5K) distance was selected because of time restraints and a self-selected speed was allowed for participants' safety, which may or may not have caused fatigue of the participant. However, these were delimitations to this study because many studies have reported a change in running mechanics after a fatigue protocol.[8-11,15]

1.7. Assumptions

It was assumed that each participant was able to run 3.1 miles without stopping. It was important that they continue running in order for accurate collection of joint angles. Also, participants were expected to honestly report their health status according to the inclusion and exclusion criteria. Treadmill running was a risk to the participant if they did not report a respiratory condition, cardiovascular condition, or previous lower extremity injury that occurred in the past year. Finally, to obtain consistent joint angle measurements throughout the run, participants were expected to maintain their normal running form and not to change their mechanics as a result of knowing the purpose of this study. A silent, visual signal was placed in front of the camera at every half-mile mark to blind the participant to when lower extremity joint angles were measured.

1.8. Significance of the Current Study

With the increase in running popularity, an increase in running-related injury risk also occurs. Seventy percent of distance runners are injured each year.[5] Furthermore, in 1999, 70 percent of triathlete injuries were due to the running portion of the race.[17] Changes in contralateral pelvic drop, hip adduction, knee abduction, and knee flexion are specific kinematic angles that have been associated with overuse injuries. It is important to identify when changes in these running kinematics occur to aid in preventing overuse running-related injuries.

1.9. Definition of Terms

Recreational Runner: For this study, a recreational runner was defined as someone who runs at least 15 miles per week and has been running for at least three months.[12] Additionally, it was someone "not competing on a team at the high school, college, or professional level, or an individual competing for a team in marathon or distance running races."[22(p 15)]

Running Related Injury: The definition for running related injury was referenced as "a musculoskeletal ailment attributed to running that causes a restriction of running speed, distance, duration, or frequency for at least one week."[13(p 846)]

Quadriceps Angle: The quadriceps angle was defined as the angle formed by the line of pull of the quadriceps femoris muscle with the patellar tendon.[27]

Goniometer: A goniometer was defined as "a large protractor with measurements in degrees"[28(p 115)] and is used to measure joint angles.[28] For the purpose of this study, the goniometer was only used to measure participants' quadriceps angles.

Kinematics: Kinematics were defined as "as description of movement [that] does not consider the forces that cause that movement."[3(p 82)]

CHAPTER 2. LITERATURE REVIEW

Recreational running has become an increasingly popular sport among active individuals. An increase in the amount and variety of themed races, convenience, and individuality of running has contributed to the growth in participation. According to Jacobs et al[2], it was estimated that 30 million runners of all levels existed in the United States. He also estimated that 10 million ran regularly and up to one million ran competitively.[2] Additionally, Strohrmann et al[8] stated that in 2010, 625 marathons were held in the United States.[8] However, in 2015, the 5K race remained the most popular, with over 7.6 million participants that year.[29] The purpose of this literature review is to examine previous research in order to determine risk factors for running related injuries, as well as to locate gaps in the literature where future research is warranted. Additionally, background information on running analysis will be discussed in order to guide future studies.

2.1. Epidemiology

A growth in competitive and recreational participation leads to an increase in musculoskeletal injury rates. The most common type of injury is known as an overuse, or chronic injury. Ferber et al[5] defined overuse injuries as “cumulative micro-trauma”. It can be estimated that these types of injuries tend to occur more often in long distance runners due to a greater accumulation of micro-traumas.[5,6] Epidemiological studies support this concept in that up to 70 percent of distance runners incur an overuse running injury over a one year timespan.[5] Additionally, Clements et al[17] reported that 70 percent of injuries sustained by triathletes were caused by the running portion of the race or run training.[17] Numerous research has been conducted in an attempt to determine the causes of overuse running injuries. Also, not only do an increase in injury rates occur with increased running mileage, but an increase in injury risk occurs as well.[4]

2.2. Risk Factors of Injury

In order to better understand which potential risk factors contribute to running-related injuries, it is necessary to recognize the different types of factors that exist. Taunton et al[1] explained that intrinsic and extrinsic factors lead to overuse injuries. Extrinsic risk factors for running injuries include training errors, shoes, and training surfaces. Intrinsic factors are flexibility, malalignment, anatomical characteristics, gender, history of injury, and level of experience.[1] For this literature review, malalignment, anatomical characteristics, and gender will be the main focus. Intrinsic factors can be more difficult to account for in injury prevention and underlying causes of chronic injury often stem from these factors. Hreljac et al[6] reported 80% of all overuse injuries occur at or below the knee.[6] Studies by Taunton et al[1], Jacobs et al[2], and van Gent et al[7] all revealed the most common running injury site as the knee.[1,2,7] A common overuse injury site among runners may suggest a common injury mechanism.[6] It is important to understand the biomechanics of running and the potential malalignment which can occur among runners.

2.3. Biomechanics and Kinematics

An explanation of the biomechanics of running is crucial to recognize the connections between malalignment and injury risk. Novacheck[3] described walking and running gait in his 1998 review. Gait is the cycle in which one foot contacts the ground, lifts off, swings, and contacts the ground a second time. Components of the gait cycle are known as initial contact, stance, toe off, and swing phases. The difference between walking and running gait is that walking gait involves a period in which both feet are in contact with the ground at the same time;

whereas running gait includes a double float mechanism instead. Double float is the period of time during running when both feet are in the air at the same time.[3]

Novacheck[3] also defined kinematics, which is an important term in this literature review. Kinematics is a description of the movements during gait. Kinematics can be analyzed in three different planes of movement: sagittal, frontal, and transverse. In observing lower extremity movements, the sagittal plane includes hip flexion/extension, knee flexion/extension, and ankle dorsiflexion/plantarflexion. Within the frontal plane, pelvis elevation/drop, hip abduction/adduction, and knee varus/valgus are evaluated. The transverse plane involves joint rotations, such as knee internal/external rotation, and ankle internal/external rotation. Foot pronation/supination is also an important factor, but occurs in the oblique plane of the foot and is difficult to analyze.[3]

In order to recognize malalignment or error in running gait, a definition of normal is required. Sagittal plane kinematics are the easiest to identify and Pink et al listed common values for joint angles during running gait in this plane (Table 1).[30] In contrast to the sagittal plane, the frontal plane includes significant motion at the hip. At initial contact, the pelvis is stationary, but the hip enters adduction as part of shock absorption. The pelvis then drops during stance and is elevated at the end of swing phase to prepare for the next step.[3] There is no known numerical data for normative joint angles in the frontal plane during running gait. Heiderscheit's[31] editorial on gait retraining for runners suggests the need for identifying biomechanical aspects of running that are contributing to symptoms or injury. He also states that a basic efficient running style exists, but does not apply to all runners.[31] All runners have an individualized technique that suits their anatomical structure. To determine risk factors for injury within running mechanics, common running patterns and injury rates need to be evaluated in the literature.

Table 1. Normative Values for Sagittal Plane Lower Extremity Joint Angles During Running Gait

	Phase of Gait		
Joint	**Initial Contact**	**Mid-Stance**	**Swing**
Hip	20 degrees flexion	23 degrees flexion	31 degrees flexion
Knee	15 degrees flexion	38 degrees flexion	103 degrees flexion
Ankle	4 degrees dorsiflexion	17 degrees dorsiflexion	2 degrees plantarflexion

2.4. Common Overuse Injuries

2.4.1. Patellofemoral pain syndrome

Some of the most common chronic running injuries found in the literature include patellofemoral pain syndrome (PFPS), iliotibial band syndrome (ITBS), and medial tibial stress syndrome (MTSS). The patellofemoral joint is the connection between the femur and patella. During flexion and extension of the knee, the patella glides over the distal end of the femur. Articular cartilage of the femur and patella is what allows pain-free movement. However, with malalignment of the tibiofemoral joint, the articular cartilage of the patella is irritated and/or damaged, causing pain.[16] In a study by Willson et al[16], researchers compared lower extremity kinematics in females with and without PFPS during single leg squats, running, and single leg jumps. In running, he found that the group with PFPS had greater hip adduction and greater contralateral pelvic drop. These frontal plane motions are thought to increase strain on the patellofemoral joint. [16]

In contrast to the retrospective study done by Willson et al[16], Boling et al[18] performed a prospective study identifying biomechanical risk factors for PFPS in subjects from the United States Naval Academy. Specific biomechanical measures included quadriceps angle (Q-angle), hip and knee muscle strength, and peak hip and knee angles during a jump-landing task. After following participants for 2.5 years, 40 out of the 1,597 participants developed PFPS. They discovered that those who developed PFPS had weaker hip abductor ($P = 0.05$), knee extensor muscles ($P = 0.01$), and knee flexor muscles ($P = 0.01$). Thus, they suggested that decreased knee flexion angle, increased hip internal rotation angle, and decreased knee flexor and extensor muscle strength are factors that may contribute to the development of PFPS.[18]

2.4.2. Iliotibial band syndrome

Iliotibial band syndrome (ITBS) is also a commonly reported symptomatic injury in runners. This condition most often causes lateral hip and knee pain in runners because of anatomical structures.[22] The iliotibial band is a thick band of connective tissue spanning the lateral aspect of the hip to the knee. On its distal end it crosses over the lateral femoral epicondyle and attaches on the lateral tibia.[14] Prolonged running in combination with a tight tensor fascia latae muscle can cause increased friction that leads to inflammation of the iliotibial band at the lateral femoral epicondyle.[14] Miller et al[14] described possible causative factors of ITBS such as increase in running pace and/or mileage, hip abductor weakness, and decreased flexibility. Additionally, it was suggested that lower extremity angles in the sagittal plane play a role in the development of ITBS, specifically maximum knee flexion. In this study, eight recreational runners with a history of ITBS were matched with eight healthy controls. The lower extremity angles assessed were maximum foot inversion, maximum knee flexion, and minimum knee flexion throughout an exhaustive run. At both the beginning and end of the run, the ITBS group demonstrated greater knee flexion ($P = 0.01$). Based on the results of the study, the authors proposed that greater knee flexion is a possible mechanism for ITBS. They stated that as knee flexion increases during the stance phase of running, iliotibial band friction on the lateral femoral epicondyle increases.[14]

Ferber et al[22] also linked hip abductor weakness with increased hip adduction angle that can also cause stress on the iliotibial band. To correlate running with the incidence of ITBS, Ferber et al[22] conducted a study in which running mechanics were compared between females with a history of ITBS and healthy controls. They included 35 females with prior history of ITBS, but who had no symptoms at the time of the study. Thirty-five healthy controls were matched with the ITBS group. Hip, knee, and ankle joint kinematics were then assessed during a running task. The results of the study demonstrated an increase in hip adduction angle in those with a history of ITBS ($P = 0.05$).[22] This shows that frontal plane angles of the hip and knee during running can influence injury risk.

Similar to Miller et al[14], Grau et al[32] identified kinematic abnormalities as an intrinsic cause of ITBS. Subjects who were already diagnosed with ITBS were compared with healthy controls to establish differences in lower extremity running mechanics within the frontal and sagittal planes. Five out of seven barefoot running trials were selected for analysis and significantly different results were displayed. The analysis found a decrease in hip adduction in the ITBS group ($P < 0.05$) which was unexpected in comparison to previous studies. The authors suggested that comparing running kinematics of already injured subjects to healthy controls may have skewed the results in that the runners with ITBS may have had excessively tight hip abductor muscles and iliotibial bands causing the decrease in hip adduction.[32] It is difficult to include this study as support for biomechanical risk factors associated with ITBS because of its retrospective nature and opposing conclusions.

The previous studies on ITBS described above were conducted retrospectively. In contrast, Noehren et al[23] performed a prospective study in an attempt to explain the differences in lower extremity kinematics in females before and after the development of ITBS. He recruited females between the ages of 18 and 45 years-old who ran a minimum of 20 miles per week. The subjects were injury-free at the beginning of the study. A baseline 3D kinematic running analysis was performed on all subjects and an injury history was collected. The subjects were contacted by email monthly to report running related injuries and monthly mileage. At the end of the two years, 18 runners, out of those who sustained running injuries, had developed ITBS. This translated to a 16 percent incidence rate for the development of ITBS among all reported injuries. The subjects diagnosed with ITBS were age and mileage matched with 18 healthy controls. To identify differences in running mechanics, another 3D analysis was completed for both the ITBS group and control group. The analysis specifically focused on rearfoot eversion, knee internal rotation, hip adduction, and knee flexion angles upon impact. Results showed no significant difference in knee flexion angles between the two groups ($P = 0.178$); however, the ITBS group demonstrated increased peak knee internal rotation and increased hip adduction angles ($P = 0.01$). In addition, a significant increase in femoral external rotation ($P = 0.02$) and decrease in rearfoot eversion ($P = 0.07$) were also noted in the ITBS group.[23] Overall, based on the results of this study, it was suggested that increased hip adduction and increased peak knee internal rotation predisposes female runners to ITBS. Furthermore, the results support the use of frontal and transverse plane views in examining running mechanics.

2.4.3. Medial tibial stress syndrome

Even though the most common overuse running injuries occur at the knee, medial tibial stress syndrome (MTSS) is also present among recreational runners. Raissi et al[33] defined MTSS as “exercise-induced, localized pain along the distal two-thirds of the posterior-medial tibia.”[33 (p 1)] Researchers described no one specific cause, but described the pathology of a stress reaction between the tibia and insertion of the soleus muscle. In order to better understand risk factors for the cause of MTSS, Raissi et al[33] conducted a prospective study on 66 nonprofessional athletes enrolled in a university track-and-field course. Anatomical variables were considered in this study instead of kinematic analysis. Baseline measurements were taken at the beginning of the semester and included only static lower extremity measures such as Q-angle, hip internal/external rotation, and tibial alignment. Additional measurements included the navicular drop test, leg length discrepancies, and rearfoot alignment. Subjects trained 14 hours per week for 17 weeks. After 17 weeks, each subject was evaluated for signs and symptoms of MTSS and the results revealed that 13 runners developed MTSS bilaterally. The only anatomical variable significantly connected to MTSS was a larger right (P = 0.027) and left foot (P = 0.034) navicular drop; however, this research suggested no significant relationship between other factors of lower extremity alignment and MTSS.[33]

2.5. Quadriceps Angle

In addition to navicular drop, other anatomical characteristics exist as possible links to risk for overuse running injuries. One such characteristic is the Q angle, which is formed by the line of pull of the quadriceps femoris muscle with the patellar tendon. The Q angle is frequently associated with patellofemoral dysfunction because of its lateral pull on the patella. As the Q angle increases, the lateral pull on the patella also increases, causing lateral patellar tracking. With repetitive motions, this can lead to conditions such as PFPS and chondromalacia patella.[27] A 2002 study by Tauton et al[1] reported an increased Q angle in six percent of subjects with PFPS and patellar tendinopathy.[1] In order to compare this characteristic between individuals, the angle is most commonly measured with a goniometer connecting the line between the anterior superior iliac spine (ASIS) and midpoint of the patella to the line between the midpoint of the patella and tibial tubercle. Also, to obtain accurate measurements, the knee must be fully extended, but not hyperextended.[27]

It is important to establish a normal value for the Q angle in order to identify it as a possible risk for injury as well as to compare values between individuals and/or groups. However, normal values for the Q angle have been inconsistent throughout the literature. Horton et al[27] established 13.5 ± 4.5 degrees as the mean Q angle based on his 1989 study comparing healthy males and females ages 18-33 years. Conversely, this is a wide range in which to consider a normal value. Horton et al[27] cited other sources with normal Q angle defined as different as 10 and 15 degrees.[27] Schulthies et al[34] described 10-14 degrees as normal for males and 14.5-17 degrees for females.[34] Studies do not confirm an abnormal or increased Q angle as the sole cause of risk for patellofemoral injury. Horton et al[27] provided an example from his study stating that 22 percent of healthy female participants had Q angles from 20 to 25.5 degrees and no pathological symptoms.[27] Thus, including Q angle as a baseline measurement may or may not be predictive of chronic running injuries due to inconsistent values throughout current research.

2.6. Gender

In the literature previously discussed, research was mainly conducted comparing injured and healthy subjects; however, other research sought to compare between male and female subjects. It has been reported that women are twice as likely to develop certain overuse injuries such as PFPS, ITBS, and tibial stress fractures compared to males.[1,20,24] Additional differences in injury prevalence related to location have been noted by Taunton et al.[1] Common running related injuries in women more than men included gluteus medius injury (76%), greater trochanteric bursitis (61%), sacroiliac joint injuries (90%), iliopsoas injuries (63%), chondromalacia patellae

(69%), PFPS (62%), and ITBS (62%).[1] A trend is present among these injuries and it reveals that running related injuries in women often stem from the hip and knee. In the same study, men displayed greater incidence of plantar fasciitis (54%), meniscal injuries (69%), patellar tendonitis (57%), Achilles tendonitis (58%), gastrocnemius injuries (70%), and peroneal tendonitis (69%); most of which occur at or below the knee ($P < 0.05$).[1] There is a significant difference between the location of running related injuries between males and females, but no clear explanation for this disparity. Previous literature has attempted to give explanations for these variances by comparing anatomical characteristics, though there is minimal research to explain biomechanical differences.

Thus far, the literature is inconclusive as to the cause of the difference in running injury rates between male and female runners. Additionally, differentiating between male and female running kinematics is a fairly new concept and research is limited. It was stated by Ferber et al[20] that their study in 2003 was the first to examine gender differences in the sagittal, frontal, and transverse planes of the hip and knee joint angles during running. In the study, 20 male and 20 female (n=40) recreational runners age 18-45 were recruited for observation in three joint planes. Females displayed significantly greater hip adduction and knee abduction angles, as well as greater hip internal rotation and knee external rotation. No significant differences were noted between the hip and knee within the sagittal plane ($P > 0.05$).[20]

Similarly, Willson et al[25] conducted a comparative kinematic analysis between males and females during running as a secondary purpose to his study of gluteal muscle activity. Frontal and transverse plane kinematics of the hip and knee were analyzed. The results supported those of Ferber et al[20], displaying a greater hip adduction ($P = 0.001$) and greater knee abduction ($P = 0.011$) in females.[25]

Rather than focusing on running alone, numerous other studies aimed to add other variables such as speed and incline. A study done by Barrett et al[26] focused on gender differences in gait variability of hip, knee, and ankle kinematics during different speeds of a treadmill run. Gait variability was assessed because it was stated that both excessively large and very minimal kinematic changes during running may reveal dysfunction. Furthermore, Barrett et al[26] suggested that lower variability, or very little change in kinematics, may be a risk factor for overuse injury due to a more "localized mechanical stress on anatomical structures."[26(p 63)] Thirty-three healthy subjects, 15 women and 18 men, participated in a kinematic analysis while walking at 5.5 km/hr and running at 8, 10, and 12 km/hr for three minutes each. Only during the higher running speeds were significant differences noted between men and women. Women showed decreased variability within the transverse plane of the hip, knee, and ankle, as well as within the sagittal plane of the ankle at the fastest running speed ($P = 0.051$). No differences emerged during walking. This suggests that women may experience greater stresses on the body than men while running at faster paces. Barrett et al[26] then linked this conclusion to risk factors for ITBS, PFPS, and MTSS in women.[26]

Similar to the study by Barrett et al in 2008, Chumanov et al[24] contributed to the literature with his research including not only varying speeds, but also various inclines during running. Thirty-four healthy, experienced runners volunteered for the study. Three-dimensional, whole body kinematics were assessed while walking at 1.2, 1.5, and 1.8 m/s, as well as running at 1.8, 2.7, and 3.6 m/s. The corresponding surface inclines included 0, 10, and 15 percent grades. In order to examine gender differences, hip, pelvis, and knee joints were evaluated. Results of the analysis displayed a significantly greater peak hip internal rotation ($P < 0.04$) and hip adduction ($P < 0.001$) in women during all speeds and inclines. Lateral pelvic tilt was greater in women during walking only ($P < 0.001$).[24] These results were associated with PFPS and ITBS because hip abductor weakness causes increased frontal plane motion, putting runners at greater risk for injury. This finding is consistent with other literature concluding that women have greater hip adduction during running; however, other variables of the hip and knee in the transverse and sagittal planes are inconclusive. In conclusion, there is still a gap in the literature connecting gender differences in running kinematics to injury risk.

2.7. Fatigue

While kinematic characteristics related to overuse running injuries have been identified and differences in running mechanics between males and females have been recognized, it is unknown whether these characteristics are constant or if a change occurs during running. Prior studies have begun to link changes in running kinematics with fatigue.[8-11,14,15] Chumanov et al[24] cites Derrick et al[9] and Miller et al[14] stating that kinematic adjustments have been observed following an exhaustive run which may lead to an increased risk for running-related injury.[9,14,24] The literature has incorporated fatigue as a variable in different ways, such as through self-selected treadmill speeds based on baseline time trials at maximal effort.[9] Others included setting treadmill speeds to 85 percent of the participants' maximal speed,[8] using isokinetic dynamometer machines to fatigue individual muscle groups,[9] maintaining running speeds at five percent above the participants' anaerobic threshold[11], as well as sustaining running speeds that correspond with the participants' ventilatory threshold.[15] Differences in how the exhaustive run was conducted is due to the availability of various equipment and technology.

Although different fatigue protocols vary throughout the literature, most studies have the same purpose: to determine biomechanical changes during an exhaustive run. For example, Derrick et al[9] included ten injury-free, recreational runners in his study of kinematic adjustments during an exhaustive run. A 3200-meter time trial at maximal effort was used to determine the treadmill test speed for exhaustion. Even though this was a self-selected speed, the average velocity was 3.4 m/s and the average time to fatigue was 15.7 minutes. Kinematic data was collected by knee and rearfoot electrogoniometers at every 30 seconds throughout the run. Results displayed that over the entire run, maximum knee flexion increased 3.8 degrees, but during the latter stages of the run, knee flexion at contact had increased 4.3 degrees.[9] This finding may associate fatigue with injury risk based on conclusions from the study by Miller et al[14] that an increase in knee flexion during running increases iliotibial band friction at the knee.[14] Further results found by Derrick et al[9] revealed an increased rearfoot angle from -6.5 degrees to -7.8 degrees at the end of the run, displaying greater subtalar eversion.[9] Subtalar eversion, or navicular drop, was found by Raissi et al[33] to be a risk factor for MTSS.[33]

Rather than observing lower extremity joint kinematics, a study by Strohrmann et al[8] measured changes in whole body vertical oscillation, trunk forward lean, and heel lift during an exhaustive run. Vertical oscillation was defined as "the difference between maximum and minimum elevation [of the center of mass] during the step cycle"[8(p 986)] Trunk forward lean is the angle between the upper body and line perpendicular with the running surface. Heel lift was defined as the angle between the low leg at maximum height and line perpendicular with the running surface. Twenty-one subjects of various experience levels participated in two separate runs: one on the treadmill and one on an outdoor track. Subjects were instructed to run at 85 percent of their maximum speed for 45 minutes. Each subject wore ETH Orientation Sensor (ETHOS) 3D motion analysis sensors located on two different areas of the body to record kinematic movements. Kinematic values from these sensors were compared among the first, middle, and last five minutes of the run. According to the data collected, kinematics in experienced runners changed less with fatigue. For less experienced runners, vertical oscillation increased significantly with the treadmill run by 8.12 percent ($P = 0.041$). Additionally, trunk forward lean increased in less experienced runners as well; whereas, the expert runners remained more stable overall. Another factor observed by Strohrmann et al[8] was heel lift. Results concluded that heel lift significantly decreased over time for all runners during both runs ($P < 0.01$), which was suggested to be a strong indicator of fatigue. An increase in this kinematic parameter is associated with an efficient running technique and found in more experienced runners.[8]

Similar to both Derrick et al[9] and Strohrmann et al[8], a study by Kellis et al[10] examined running kinematics in the sagittal plane after a fatigue protocol. The study included 15 healthy female runners with a minimum of five years running experience. The fatigue protocol involved using a Cybex Norm isokinetic dynamometer to apply resistance to ankle plantarflexion/dorsiflexion and knee flexion/extension causing muscle fatigue. Before and after the fatigue protocol, 3D sagittal-plane kinematics of the hip, knee, and ankle were recorded during a 10 second treadmill run at 3.61 m/s. In addition to the biomechanical analysis, strength testing and electromyography data were also collected. Results of the biomechanical analysis indicated a significant increase in hip extension angle of three degrees ($P < 0.05$) at toe-off only after the knee muscle fatigue. Furthermore, knee flexion increased at initial contact an average of four degrees ($P < 0.05$) after knee muscle fatigue. Knee flexion also significantly increased at toe-off by an average of three degrees ($P < 0.05$) following the knee and ankle fatigue protocols. For ankle kinematics, plantarflexion increased only after ankle muscle fatigue at initial contact, mid-stance, and swing phases by an average of five, three, and four degrees respectively. It was also noted that kinematic changes were mainly identified during the initial contact and toe-off phases of running.[10] Conclusions of the study suggested that changes in running mechanics are dependent on which muscles are fatigued.

In contrast to Kellis et al[10], a study by Mizrahi et al[11] included only inexperienced male subjects. This study assessed sagittal plane kinematics, but during a long distance run. Anaerobic threshold was determined for each subject in order to incorporate fatigue and a 30-minute treadmill run was completed at a steady pace, five percent above the subjects' anaerobic threshold. Kinematic data was collected every 15 minutes for maximum knee extension, maximum knee flexion just before impact, and maximum hip height. Although no significant changes in hip height were observed, maximum knee extension increased three degrees in the first 15 minutes and an additional 0.4 degrees in the 30^{th} minute. Knee flexion decreased an average of 5.5 degrees by the 30^{th} minute.[11] This finding contradicts the results of Derrick et al[9] which showed an increase in knee flexion over time.

A study done by Abt et al[15] in 2011 revealed differing conclusions as well. Twelve male and female experienced distance runners were included. An individual ventilatory threshold (VO_2 max) and average speed were calculated to ensure fatigue. The average speed was 3.3 m/s and approximate time to exhaustion was 17.8 ± 5.7 minutes. Three-dimensional ankle and knee kinematic data was collected every minute in the frontal and sagittal planes. Results of the biomechanical analysis displayed no significant changes between measurements before and after the exhaustive run ($p<0.05$). Abt et al[15] referred to Derrick et al[9] for an explanation of the differing conclusions, stating that inconsistent results may be due to varying fatigue protocols and data collection methods. He also suggested that greater changes in kinematics may be seen in longer distance runs, rather than shorter runs of greater intensity.[15] Therefore, fatigue may be an important factor for recognizing when lower extremity running biomechanics begin to change.

2.8. Biomechanical Analysis

Throughout the research previously discussed, the primary method of assessing lower extremity biomechanics was three-dimensional (3D) motion analysis. This method is the gold standard for biomechanical analysis; however, it can be expensive, time-consuming, and not practical for most clinical settings. This section will discuss the validity and reliability of two-dimensional (2D) techniques, which can be more widely used as screening tools in clinical settings.[35]

A study conducted by Munro et al[35] tested the reliability of 2D video assessment for knee valgus in the frontal plane in order to investigate anterior cruciate ligament injury risk. They included 20 recreationally active subjects, 10 males and 10 females, who were injury free for at least six months. With markers placed on the center of anterior knee joint, center of anterior ankle joint, and proximal thigh between the anterior superior iliac spine and knee marker, digital video footage was captured and downloaded to an analysis software. Subjects were tested in a single-leg squat, drop jump, single-leg landing, and frontal plane projection angle or knee valgus/varus position. Within-day and between-day reliability was assessed for all tests using intraclass correlation coefficients (ICCs) and 95 percent confidence intervals (95% CIs). Within-day ICCs for both women and men displayed a good result, showing values of 0.59 to 0.88 and 0.79-0.86, respectively. Furthermore, all tests displayed a good to excellent between-day reliability, with values of 0.72 to 0.91 for women and 0.80 to 0.89 for men. This means that 2D technology can produce consistent results within tests during the same day, as well as across multiple days. Increased reliability of the 2D techniques shows the use of these more practical methods of biomechanical analysis for injury prevention screening.[35]

Similar to Munro et al[35], a study by McLean et al[36] also evaluated 2D analysis as a screening tool for anterior cruciate ligament injury. They stated that the 2D methods are more appropriate and efficient for the large-scale screenings needed for injury prevention; however, there was concern whether the results provided by the 2D and 3D techniques would be similar. Ten male and ten female Division 1 basketball players were evaluated for knee joint kinematics using both 2D and 3D analysis techniques during a side jump, side stepping, and shuttle running. The results revealed that knee angles displayed through 2D analysis were, on average, larger than those from 3D analysis. Additionally, moderate correlations existed between 2D and 3D data for the side jump ($r^2 = 0.64$) and side step ($r^2 = 0.58$), but not for the shuttle run ($r^2 = 0.04$). A stronger correlation was observed between 2D and 3D angle data for subjects with more variation in knee valgus angles. Thus, it was shown that 2D methods are valid for detecting frontal plane knee motion.[36]

2.8.1. Dartfish motion analysis software

Two-dimensional kinematic analysis techniques include a video recording as well as a computer software in order to determine specific joint angles and changes in those angles; however, many different software programs exist for this purpose. Norris et al[37] focuses specifically on Dartfish Motion Analysis Software in determining the validity and reliability of the 2D techniques for measuring sagittal plane hip and knee angles during a mechanical lifting task. This software allows joint angles to be examined throughout a movement. In contrast to Munro et al[35] and McLean et al[36], only females were recruited for this study. Maximal lifting capacity was measured for each subject using a back-leg-chest dynamometer system and the joint angles were measured with the Dartfish ProSuite version 4.0.9.0 software and digital camera. Subjects were tested on the first day and again seven to ten days later in order to determine test-retest reliability. To test validity of the software in detecting joint angles, a single image of the video was projected onto a wall and joint angles were measured with a goniometer. Results showed that correlations between 2D and goniometric measurements were 0.95 (P = 0.01) and 0.98 (P = 0.01) for hip and knee flexion, respectively. Intra-rater and inter-rater reliability ICC values for both hip and knee values were shown as excellent and the test-retest ICCs were 0.79 for hip flexion and 0.91 for knee flexion.[37] The overall results of the study confirmed the findings of Munro et al[35] and McLean et al[36] supporting the use of a 2D video analysis for measuring functional movement patterns. Furthermore, Norris et al[37] supports its use for sagittal plane analysis of hip and knee angles during a mechanical lifting task.[35-37]

The previous studies by Munro et al[35], McLean et al[36], and Norris et al[37] focused on functional movements when utilizing the 2D analysis techniques.[35-37] In contrast, a study by Maykut et al[38] concentrated on frontal plane kinematics during treadmill running. The goal of this study was to assess validity and reliability of 2D video analysis compared to 3D analysis of frontal plane kinematics such as contralateral pelvic drop, hip adduction, and knee abduction. Twenty-four collegiate cross country runners (14 males and 10 females) self-selected their treadmill speed for a three to five-minute acclimation period and run. Similar to Norris et al[37], Dartfish Motion Analysis Software was used for the 2D technique. The Dartfish software displayed high reliability with excellent ICC values: hip adduction 0.951 to 0.963, contralateral pelvic drop 0.958 to 0.966, and knee abduction 0.955 to 0.976. Validity for the measurement of hip adduction displayed moderate correlation for the left and right sides of 0.539 (P = 0.007) and 0.623 (P = 0.001), respectively. Further data analysis revealed r^2 values of 0.388 for right side and 0.291 for the left. No significant correlation was found for contralateral pelvic drop measurements, and the correlation for knee abduction measures were inconsistent; however, the

2D measurement of contralateral pelvic drop strongly correlated with the 2D assessment of hip adduction bilaterally (P = 0.0001). The results of this study support the use of 2D software for analyzing hip adduction angles during running assessments if 3D software is unavailable.[38]

2.9. Conclusion

The current literature has attempted to define the cause of altered running biomechanics and how certain kinematic changes relate to injury risk. However, much of the research displays conflicting results because of differing methods and populations included in the studies. To consider the existing research as a whole, Derrick et al[9] poses an intriguing question on cause versus effect of altered kinematics during running: do changes in kinematics stem from failure of the body's optimal biomechanics or from the body's attempt to prevent injury?[9] It may also be important to understand when these biomechanical changes occur. In conclusion, further research is needed to identify the biomechanical causes of chronic running injuries.

CHAPTER 3. METHODOLOGY

The purpose of this study was to evaluate the changes in lower extremity biomechanics throughout a 3.1 mile (5K) run. This study focused on changes in contralateral pelvic drop, hip adduction, knee abduction, and knee flexion. Differences in these kinematic angles were also compared between males and females. A quantitative experiment was conducted using a within-subject and between-subject repeated measures design. The goal of this study was to answer the following research questions:

1. In the course of a 5K run, do observable changes in joint angles occur?
2. What differences are observed in lower extremity running kinematics between males and females?

3.1. Participants

Participants were recruited as a convenience sample via ListServ email and word-of-mouth from the North Dakota State University student population, as well as from the Fargo/Moorhead community. Ten males and ten females (n=20) ages 18-40 years were included based on the following criteria: (1) recreational runners who are not currently competing on a team; (2) those who run a minimum of 15 miles per week for the past three months[21]; (3) experience with treadmill running; (4) ability to run 3.1 miles without stopping. Exclusion criteria for this study were: (1) current lower extremity injuries; (2) lower extremity injuries sustained in the past three months; (3) pain with running; (4) asthma; (5) any cardiovascular conditions; (6) prior surgeries to the lower extremity in the past one year. Once recruited, participants were asked to refrain from running the day of data collection. He or she was also asked to not participate in any races three days prior to data collection. This could have limited the effects of excessive fatigue on lower extremity joint angle values.

Prior to beginning the study, participants completed a Health History Questionnaire and PAR-Q. They also reviewed and signed an informed consent stating the procedures and potential risks of participation. These risks included cardiovascular and muscular fatigue, muscle and joint strain, and tripping on the treadmill. Participants were allowed to wear their preferred running shoe type and any inserts or orthotics they regularly use. Current research was inconclusive on whether or not to allow participants to wear different shoe types. Most studies did not mention if the study controlled the use of shoe type; however, some studies allowed participants to wear only one type of shoe, which was provided by the researchers.[4,9-11,23] Furthermore, all participants were asked to wear compression shorts for optimal measurements of lower extremity joint angles. Upon completion of the study, participants were compensated 20 dollars for their participation.

3.2. Instrumentation

Various types of equipment were necessary for this study, including a treadmill, video camera, and video analysis computer software. A Trackmaster TMX425C treadmill (Full Vision, Inc., Newton, KS) was used for the 3.1 mile (5K) run in order to accurately quantify the participants' running speed and distance. Treadmills are often used in conjunction with biomechanical analysis because it also allows the participant to remain in the camera's field of view to see repeated motions.[4,8-11,14,15,21,24,26,38,39] A Casio Exilim EX-FH20 camera at 30 frames per second was used for recording two-dimensional (2D) video due to the unavailability of three-dimensional (3D) motion analysis technology. Dartfish Motion Analysis Software Version 8 (Dartfish, Fribourg, Switzerland) is a 2D video analysis software that was used to detect joint angles at the hip and knee.

The Dartfish software displayed high reliability for measuring lower extremity frontal and sagittal plane joint angles.[37,38] Validity was shown to have a strong correlation when measuring sagittal plane joint angles.[37] The validity of this 2D analysis software in measuring frontal plane joint angles, specifically hip adduction, has been shown to have a moderate correlation.[38] This means that Dartfish can produce consistent and accurate measurements of lower extremity frontal and sagittal plane joint angles when 3D software is not available.

3.3. Procedures

After receiving approval from North Dakota State University's Institutional Review Board, data collection was conducted in the North Dakota State University Human Performance Laboratory in the Fall of 2016. Each participant attended only one testing session. Immediately upon arrival, participants completed the informed consent, Health History Questionnaire, PAR-Q, and answered the demographic questionnaire. The demographic questionnaire was included to gain additional participant information about age, gender, years of running experience, mileage per week, average running distance, and previous injuries.

The quadriceps angle (Q-angle) of each participant's right leg was then measured. Various methods of measuring Q-angle have been studied, such as supine and standing, demonstrating inconsistent findings throughout the literature.[33,40-43] Studies included in a systematic review showed the reliability of measurement for the supine method to range from low to moderate for inter-tester and intra-tester values[41]; however, another study using the supine method found the reliability to range from moderate to high.[43] It was also noted in the research that using the supine method involved a relaxed quadriceps muscle and no patellar movement, allowing for more consistent measurements.[43] Thus, for this study, the Q-angle was measured with the participant in a supine position. The participant laid face up on a table with knees in full extension, but not hyperextended. The fulcrum of a standard goniometer was placed on the midpoint of the right patella. Then, the proximal arm of the goniometer was placed in line with the right ASIS. The distal arm of the goniometer was positioned in line with the right tibial tuberosity.[41,43] The measurement was recorded before moving on with further procedures.

Following measurement of the Q-angle, the skin was cleansed with an alcohol prep pad. Pieces of white athletic tape were placed on lower extremity landmarks followed by reflective stickers to measure frontal and sagittal plane joint angles. The right side of the participant was chosen to measure lower extremity joint angles in order to maintain consistency with the current literature evaluating lower extremity running biomechanics.[4,10,11,25,37] To measure contralateral pelvic drop, markers were placed on bilateral anterior superior iliac spines (ASIS). Markers placed on the midpoint of the right anterior tibiofemoral joint were used along with the bilateral ASIS markers to measure hip adduction. Markers placed on the anterior midpoint of the medial malleolus of the right tibia and lateral malleolus of the right fibula were used to measure knee abduction.[37] In addition, to measure knee flexion, markers were placed on the right greater femoral trochanter, right lateral femoral epicondyle, and right lateral malleolus (Table 2).[38]

Table 2. Placement of Biomechanical Markers on Lower Extremity Landmarks

Joint Angle	Marker Placement
Frontal Plane	
Contralateral Pelvic Drop	Bilateral ASIS
Hip Adduction	Inferior aspect of patella
Knee Abduction	Anterior midpoint of medial malleolus of right tibia and lateral malleolus of right fibula
Sagittal Plane	
Knee Flexion	Right greater femoral trochanter, right lateral femoral epicondyle, and right lateral malleolus

The Casio Exilim cameras were set on a tripod for video analysis in front (frontal plane) and to the side (sagittal plane) of the treadmill. The distance was then measured between the cameras and the treadmill. The frontal plane viewed the front of the subject inferior to the iliac crests (from the waist to the feet) to observe contralateral pelvic drop, hip adduction, and knee abduction angles. The sagittal plane viewed the subject's right side, also inferior to the right iliac crest to observe knee flexion. This study did not account for upper extremity biomechanics. All joint angle measurements were taken during the stance phase of running gait, which is the period of time between initial contact and toe off of the stance leg.[3]

Before beginning the run, participants were allowed a two-minute warm up and treadmill acclimation period. During this time, participants also self-selected his or her individual treadmill speed (mph). Participants were then allowed a one-minute rest in which he or she performed any habitual routines, such as stretching. If the participant did perform any stretches, these were documented by the researcher. Participants began the run and were allowed to alter the treadmill speed up to 0.5 mph from their original selection during the rest of the run.[21] The incline of the treadmill was kept at zero percent. Throughout the run, the participants were blinded to the analysis periods. In order to accomplish this, the examiner stood behind the participant and gave a hand signal at the beginning and end of each measurement interval. After completing the run, participants were allowed a five-minute cool down jog at their preferred speed on the treadmill. Following all of the running sessions, joint angle measurements were taken using the Dartfish software at the five analysis intervals: 0.9-1.0, 1.4-1.5, 1.9-2.0, 2.4-2.5, and 3.0-3.1 miles. The first 0.5 mile was not measured to account for treadmill acclimation and warm up.[21] The first ten steps for each joint angle of interest within each interval were recorded. Then, the maximum, minimum, and average angle was calculated for each interval.

3.4. Analysis

Contralateral pelvic drop, hip adduction angle, knee abduction angle, and knee flexion angle was measured using the Dartfish software. Contralateral pelvic drop angle was measured by connecting the ASIS bilaterally and drawing a line perpendicular to the ASIS of the stance leg. This angle was then subtracted from 90 degrees. Hip adduction angle was measured by connecting the ASIS bilaterally and drawing a line from the ASIS to the midpoint of the tibiofemoral joint of the stance leg. Knee abduction angle was calculated by a line connecting the ASIS and midpoint of the tibiofemoral joint and a line connecting the midpoint of the tibiofemoral joint and midpoint of the ankle malleoli of the stance leg.[38] Knee flexion angle was calculated by connecting the line between the greater femoral trochanter and lateral femoral epicondyle to the line between the lateral femoral epicondyle and lateral malleolus of the stance leg.[37] This data was then compiled into one document in order to compare joint angles over time and between males and females (Table 3).

Table 3. Analysis of Lower Extremity Joint Angles

Joint Angle	Measurement
Frontal Plane	
Contralateral Pelvic Drop	Angle between line connecting bilateral ASIS and line perpendicular to ASIS of stance leg; Subtract this angle from 90 degrees
Hip Adduction	Angle between line connecting bilateral ASIS and line from ASIS to midpoint of tibiofemoral joint of stance leg
Knee Abduction	Angle between line from ASIS to midpoint of tibiofemoral joint and line from midpoint of tibiofemoral joint to midpoint of ankle malleoli of stance leg
Sagittal Plane	
Knee Flexion	Angle between line from greater femoral trochanter to lateral femoral epicondyle and line from lateral femoral epicondyle to lateral malleolus of stance leg

3.5. Statistics

Statistical analysis was completed using SPSS Software Version 23.0. A two-way, repeated measures ANOVA was conducted in order to capture the within-subject data across time as well as a between-subject comparing differences in gender. The significance level was established at $P < .05$.

3.6. Conclusion

Overall, the purpose of this study was to determine the changes in lower extremity joint angles throughout different stages of a 3.1 mile (5K) run, as well as to compare peak joint angles between males and females during running. Two-dimensional video and Dartfish software was used to record joint angles and conduct a comparative analysis. This data has the potential to add to the current body of research striving to identify predisposing factors to the development of chronic running injuries.

CHAPTER 4. MANUSCRIPT

4.1. Abstract

Objective: To evaluate changes in lower extremity biomechanics throughout a 3.1 mile (5K) run.

Design: Repeated measures, within subject design.

Setting: Human Performance Laboratory at Research Institution.

Participants: Twenty recreational runners (10 males, 10 females; age: 22.5±4.15 years; weight: 162.45±32.35 pounds; height: 69.4±4.2 inches) participated.

Interventions: Participants ran 3.1 miles (5K) on a zero percent incline treadmill at a self-determined pace. Reflective markers were used to collect data during the run.

Main Outcome Measures: Lower extremity joint angles for contralateral pelvic drop, hip adduction, knee abduction, and knee flexion.

Results: Females had a significantly greater incidence of contralateral pelvic drop ($F(1,17)=4.29$, $P = .05$) but did not change over time. The angle for knee abduction declined significantly over the five observations ($F(1,74)=6.09$, $P = .016$). A non-significant decrease in knee flexion was observed over time. No significant results were found for hip adduction angles over time or between gender.

Conclusion: Gender differences and effects of distance can alter lower extremity biomechanics in recreational runners. This research found that running distance affected knee abduction and knee flexion angles. Additionally, gender differences were observed in contralateral pelvic drop angles during running. Many of these biomechanical changes have been correlated with chronic running injuries. Further research is needed to identify predisposing factors to the development of chronic running injuries.

4.2. Introduction

Running has been a popular sport for decades, both recreationally and competitively. The popularity of the sport of running began in the 1970s and has continued to current date as more than 25 million Americans began exercising. Running was the sport of choice for many due to the convenience and health benefits.[1] In 2015, the 5K race remained the most popular, with over 7.6 million participants that year.[29] Because of the growing popularity of running, injury prevalence is also increasing.[2] A quarter to half of all runners will suffer an injury that alters running performance each year.[3] Some of these injuries are acute, or sudden damage to muscle, tendon, ligament, or bone. However, the majority of running injuries are chronic, overuse injuries. Running is a highly repetitive activity and stresses put on the body accumulate with every step.[4,5]

Many researchers have attempted to determine the causes of running related injuries in order to aid in prevention.[1,4-13] Injuries can result from numerous factors, such as training, shoes, running surface, flexibility, previous injury, and malalignment.[1] Moreover, an increased risk for chronic injury has been linked to running longer distances.[4] There is no known numerical data for normative joint angles in the frontal plane during running gait. Thus, there is need for identifying biomechanical aspects of running which contribute to injury or self-limiting pain.[21]

Various overuse injuries have been linked to incorrect running biomechanics. Currently, patellofemoral pain syndrome (PFPS) is the most common injury among runners.[1,5,6,17-20] Patellofemoral pain syndrome is knee pain caused by inefficient kinematics at the knee joint as well as commonly associated with an increase in hip adduction and contralateral pelvic drop.[16] Additionally, those with greater quadriceps angles (Q-angle) are predisposed to developing PFPS.[1] Iliotibial band friction syndrome (ITBS) is the second most common cause of knee pain[5,6,21] and is related to improper kinematics at both the hip and knee joints, such as increased hip adduction[14,22,23] and increased knee flexion.[14]

Gender differences are an important factor to recognize when examining running biomechanics. Numerous studies have concluded that the most common running injuries occur at the knee[1,6,7] with women sustaining more overuse injuries to the lower extremity than men.[8] This may be explained by Barrett et al[26] who suggests that women may experience greater stresses on the body than men while running at faster paces; thus, increasing the risk of developing ITBS, PFPS, and medial tibial stress syndrome in women.[26] Differences in running kinematics between males and females also exist. For example, females typically have increased hip adduction[20,24,25] and knee abduction angles[20,25] during running. It is important to understand gender differences in running biomechanics in order to identify specific causes of such overuse injuries, as well as to predict those who may be predisposed.

Although previous studies have found correlations between overuse injuries and certain running kinematics, there is a gap in the literature for when the onset of biomechanical changes occur during running.[1,5,6,14,17-20,22,23] Additionally, gender differences have not been extensively studied, and limited research exists on the variances in running kinematics between males and females.[20,24-26] Therefore, the purpose of this study was to evaluate the changes in lower extremity biomechanics at the hip and knee joints throughout a 3.1 mile (5K) run. Kinematic differences were also compared between males and females. This study sought to answer the following research questions: (1) In the course of a 5k run, when do observable changes in joint angles occur? (2) What differences were observed in lower extremity running kinematics between males and females?

4.3. Methods

4.3.1. Participants

Participants were recruited as a convenience sample via email and word-of-mouth. Ten males and ten females participated in the research protocol (n=20; Age: 22.5±4.15 years; Weight: 162.45±32.35 pounds; Height: 69.4±4.2 inches). Additional inclusion criteria for this study were: (1) recreational runners who are not currently competing on a team; (2) those who run a minimum of 15 miles per week for the past three months[21]; (3) experience with treadmill running; (4) ability to run 3.1 miles without stopping. Exclusion criteria for this study were: (1) current lower extremity injuries; (2) lower extremity injuries sustained in the past three months; (3) pain with running; (4) asthma; (5) any cardiovascular conditions; (6) prior surgeries to the lower extremity in the past one year. Once recruited, participants were asked to refrain from running the day of data collection. Participants were asked not to participate in any competitive races three days prior to data collection so as to limit the effects of excess fatigue on lower extremity joint angle values.

Prior to beginning the study, participants completed a Health History Questionnaire and PAR-Q. They also reviewed and signed an informed consent, which was approved by the research university's institutional review board, stating procedures that were conducted and the potential risks of participation. These risks included cardiovascular and muscular fatigue, muscle and joint strain, and tripping on the treadmill. Participants were allowed to wear their preferred running shoe type and any inserts or orthotics they regularly use. Furthermore, all participants were asked to wear compression shorts for optimal measurements of lower extremity joint angles. Tables 4 and 5 list the participant demographics including Q angle and running experience.

Table 4. Participant Characteristics					
	Height (cm)	**Weight (kg)**	**BMI**	**Age (yrs)**	**Q-angle (deg)**
Males	170±10	80±6	23±2.5	24.1±5	8.8±1.5
Females	173±5	74±3	22±2.4	20.9±2.2	15.1±2.7

Table 5. Participants' Running Experience	
Average Weekly Running Mileage (miles)	**Number of Participants**
15-20	16
21-25	2
26-30	0
31-40	2
>40	0
Average Running Distance (miles)	
2-3	10
4-5	6
6-7	3
>7	1
Years of Running Experience	
<1	0
1-2	3
2-5	4
5-10	4
>10	9

4.3.2. Protocol

Following completion of the paperwork, the Quadriceps angle (Q-angle) of each participant's right leg was measured with the participant in a supine position.[41,43] Then, the skin was cleansed with an alcohol prep pad and biomechanical reflective stickers were placed on lower extremity landmarks to measure frontal and sagittal plane joint angles. The right side of the participant was chosen to measure lower extremity joint angles in order to maintain consistency with the current literature evaluating lower extremity running biomechanics.[4,10,11,25,37] Table 6 describes the reflective sticker placement for each joint angle measured.

Table 6. Placement of Biomechanical Markers on Lower Extremity Landmarks	
Joint Angle	**Marker Placement**
Frontal Plane	
Contralateral Pelvic Drop	Bilateral ASIS
Hip Adduction	Inferior aspect of patella
Knee Abduction	Anterior midpoint of medial malleolus of right tibia and lateral malleolus of right fibula
Sagittal Plane	
Knee Flexion	Right greater femoral trochanter, right lateral femoral epicondyle, and right lateral malleolus

Casio Exilim EX-FH20 cameras at 30 frames per second were set on a tripod for two-dimensional video analysis in front (frontal plane) and to the side (sagittal plane) of the treadmill. The frontal plane viewed the front of the subject inferior to the iliac crests to observe contralateral pelvic drop, hip adduction, and knee abduction angles. The sagittal plane viewed the subject's right side, also inferior to the right iliac crest, to observe knee flexion. All joint angle measurements were taken during the stance phase of running gait.

Before beginning the run, participants were allowed a two-minute warm up and acclimation period on a Trackmaster TMX425C (Full Vision, Inc., Newton, KS). During this time, participants also self-selected his or her individual speed (mph). Participants were then allowed a one-minute rest in which he or she performed any habitual routines, such as stretching. Participants began the run and were allowed to alter the speed up to 0.5 mph from their original selection, keeping the treadmill at zero percent incline.[21] The examiner stood behind the participant and gave a hand signal at the beginning and end of each measurement interval in order the blind the participants to the analysis periods. After completing the run, participants were allowed a five-minute cool down jog at their preferred speed on the treadmill.

Following all of the running sessions, joint angle measurements were taken using the Dartfish software (Version 8, Dartfish, Fribourg, Switzerland) at the five analysis intervals: 0.9-1.0, 1.4-1.5, 1.9-2.0, 2.4-2.5, and 3.0-3.1 miles. The first 0.5 mile was not measured to account for treadmill acclimation and warm up.[21] The first ten steps of every joint angle of interest within each interval was recorded. Then, the maximum, minimum, and average angle were calculated for each interval. Contralateral pelvic drop, hip adduction angle, knee abduction angle, and knee flexion angle were measured using the Dartfish software. Table 7 explains the methods for each joint angle measurement.

Table 7. Analysis of Lower Extremity Joint Angles

Joint Angle	**Measurement**
Frontal Plane	
Contralateral Pelvic Drop	Angle between line connecting bilateral ASIS and line perpendicular to ASIS of stance leg; Subtract this angle from 90 degrees
Hip Adduction	Angle between line connecting bilateral ASIS and line from ASIS to midpoint of tibiofemoral joint of stance leg
Knee Abduction	Angle between line from ASIS to midpoint of tibiofemoral joint and line from midpoint of tibiofemoral joint to midpoint of ankle malleoli of stance leg
Sagittal Plane	
Knee Flexion	Angle between line from greater femoral trochanter to lateral femoral epicondyle and line from lateral femoral epicondyle to lateral malleolus of stance leg

4.3.3. Statistical Analysis

Statistical analysis was completed using SPSS Software Version 23.0. A two-way, repeated measures analysis of variance (ANOVA) was conducted in order to capture the within-subject data across time as well as a between-subject comparing differences in gender. The significance level was established at $P < 0.05$.

4.4. Results

Twenty participants completed the study; however, only 19 participants were included in the biomechanical analysis because of technology and equipment malfunctions. Means and standard deviations separated by gender and time for each joint angle can be located in Tables 8 and 9 respectively. Joint angle analysis results revealed a significant difference in gender for contralateral pelvic drop during running with females having more contralateral pelvic drop than males ($F(1,17)=4.29$, $P = .05$). However, contralateral pelvic drop did not decrease over time for either females or males. Results of the analysis showed a significant decline in knee abduction in all participants throughout the five intervals during the 5K run ($F(1,74)=6.09$, $P = .016$) (Table 9). There were no effects of gender with knee abduction results. No significant differences were observed between gender or over time for hip adduction. Knee flexion angles decreased throughout the run; however, this result was not significant. No differences were observed between gender for knee flexion angles during running.

Table 8. Average Lower Extremity Joint Angles

Joint Angle	Males (deg)	Females (deg)
Contralateral Pelvic Drop	2.49 ± 1.31	4.70 ± 2.88
Hip Adduction	13.03 ± 2.89	14.93 ± 3.63
Knee Abduction	3.55 ± 3.56	2.30 ± 4.71
Knee Flexion	47.25 ± 4.36	50.61 ± 3.88

Table 9. Average Change in Knee Abduction Angle Over Time

Miles	Males (deg)	Females (deg)
0.9-1.0	3.73 ± 3.27	2.60 ± 4.75
1.4-1.5	3.99 ± 3.25	2.35 ± 4.84
1.9-2.0	3.67 ± 4.04	2.53 ± 4.99
2.4-2.5	3.27 ± 3.53	1.89 ± 4.83
3.0-3.1	3.10 ± 4.37	2.13 ± 5.10

Table 10. Statistical Results for Repeated Measures ANOVA		
Joint Angle	**Gender**	**Time**
CPD Mean	F(1,17)=4.29,p=.054	NS
CPD SD	F(1,17)=3.23,p=.09	F(1,74)=2.82,p=.097
HADD Mean	NS	NS
HADD SD	NS	NS
KABD Mean	NS	F(1,74)=6.09,p=.016
KABD SD	NS	NS
KF Mean	F(1,17)=3.06,p=.098	NS
KF SD	NS	F(1,74)=3.59,p=.062

4.5. Discussion

Results of this study concluded that differences exist between males and females for contralateral pelvic drop angles during running. Females displayed greater contralateral pelvic drop angles, which may be related to anatomical characteristics. Although a gender difference was observed for contralateral pelvic drop, no differences were observed between gender or across time for hip adduction. A decrease in knee abduction angle was shown for all participants over the course of the run. Knee flexion showed a decrease in angles, but this finding was not statistically significant. Furthermore, no gender differences were revealed for knee flexion.

Previous research has compared contralateral pelvic drop angles between males and females during running.[16,24] Those results have demonstrated greater contralateral pelvic drop angles in female runners, specifically those with PFPS.[16] The results of the current study also demonstrated significantly greater contralateral pelvic drop angles in females during the 5K run. In the current study, participants were allowed to run at a self-selected speed, but only healthy participants were included. An increase in contralateral pelvic drop angles has been linked to chronic running injuries, such as PFPS, because excessive frontal plane motions are thought to increase strain on the patellofemoral joint.[14,16,22,23] Therefore, our results compare to previous research suggesting that female runners with greater contralateral pelvic drop during running may have an increased risk for developing PFPS.

Hip adduction is another important lower extremity joint angle to consider when analyzing running kinematics. Increases in hip adduction angles throughout the course of a run have been demonstrated in previous research.[22,23] Additionally, females commonly displayed greater hip adduction angles during running than males.[16,20,24,25] Clinicians should recognize that increases in hip adduction, especially in females, has been correlated with chronic running injuries, such as PFPS and ITBS.[16,20,22-25] The current study's results revealed no changes in hip adduction during running, nor differences between gender. However, there are a few possible reasons for the contradictory results. Previous studies examining hip adduction angles during running have utilized the gold standard, 3D analysis software, unlike the 2D Dartfish Motion Analysis software used in the current study.[16,20,22-25] Although using 2D software was a limitation of this research, prior literature states that Dartfish Motion Analysis can produce reliable and valid measurements of lower extremity frontal and sagittal plane angles when 3D technology is not available.[37,38] Furthermore, most other studies instructed participants to run on a runway instead of using a treadmill.[16,20,22,23,25] This is a limitation that is important to consider because treadmill running cannot be generalized to other surfaces, such as outdoor running.[8] While our results for hip adduction were not consistent with former literature, future research is needed. Similar and valid methodologies should be implemented and specific populations included to identify connections between changes in hip adduction angles during running and predispositions for chronic injury.

Research examining knee abduction angles during running is limited; however, existing research has demonstrated that females have greater knee abduction angles during running than males.[20,25,44] The results of the current study demonstrated a decrease in knee abduction angles for all participants throughout the course of the run but no significant difference was observed between gender. There is an inconsistency between our results and those of previous studies, which could be due to differences in methodologies. As discussed previously, past research used 3D technology and the inclusion of a runway as opposed to a treadmill.[20,25] One study concluded that greater knee abduction motion in females predisposes them to injury during athletic tasks, such as running.[44] A knee abduction angle of five degrees or greater can increase the load on the anterior cruciate ligament (ACL) up to six times than when the knee is aligned properly thus increasing the risk for ACL rupture.[44] Even though the current study's results demonstrated a decrease in knee abduction angles, it is worth noting that three of the female participants displayed a knee abduction angle of greater than five degrees for every interval throughout the run. One potential reason for the discrepancy in results could be that previous research studying knee abduction angles during running did not account for anatomical features of the participants, such as quadriceps angle (Q angle).[44] The current study measured Q angle prior to the run and found that none of the females, including the three who consistently presented with greater than five degrees of knee abduction, exhibited a pathological Q angle. Further research should focus on incorporating anatomical measurements to better understand participants of the study and how pre-existing features may affect lower extremity kinematics.

Knee flexion angles during running have been inconsistent among previous studies. Researchers who have implemented fatigue protocols have found increases in knee flexion across time.[9,14] Our findings demonstrated a decrease in knee flexion angles over time but no gender differences. Over the course of the run, knee flexion angles in females decreased 0.37 degrees and 0.69 degrees in males. Although this finding was not statistically significant, it is similar to the results of previous studies. A decrease in knee flexion angle was found in healthy runners[11,21] as well as in those who had PFPS.[16] One reason why our findings were different from those showing increases in knee flexion may be the inclusion of a fatigue protocol. Our methodology allowed participants to run at a self-selected speed because the purpose was to investigate normative running patterns of recreational runners. In contrast to research that has correlated a decrease in knee flexion to runners with PFPS, others have found that increases in knee flexion can lead to greater risk for ITBS.[14] Because of these contradictory research findings, it is important to continue to explore changes in lower extremity running kinematics in order to understand reasons for the development of chronic running injuries.

4.6. Conclusions

The current literature has attempted to define the cause of altered running biomechanics and how certain kinematic changes relate to injury risk. However, much of the research displays conflicting results because of differing methods and populations included in the studies. It may also be important to understand when these biomechanical changes occur. Additionally, considering the differences in kinematics between male and female runners may be helpful when developing injury prevention programs. Thus, further research is needed for clinicians and researchers to identify the biomechanical causes of chronic running injuries. This study may provide a knowledge base and background for developing methodologies for future research studies involving running analysis, specifically for recreational runners.

CHAPTER 5. DISCUSSION

Running, both competitive and recreational, has been a popular sport for the past few decades.[1] With increases in popularity came increases in chronic, overuse injury rates.[4,5] Various studies concluded that the most common running injuries occur at the knee[1,6,7] and that women sustain more overuse injuries to the lower extremity overall than men.[8] In order to treat these overuse running injuries, the cause must be identified. However, this is not easy because multiple variables play a role in causing injury, such as shoes, running surface, flexibility, previous injury, and anatomical factors.[1] Running longer distances has also been linked to increased injury risk and one reason for this may be altered biomechanics during running.[9-11,14-16] Injuries such as patellofemoral pain syndrome and iliotibial band friction syndrome are common causes of knee pain in runners and have been associated with improper kinematics at the hip and knee joints.[1,5,6,14,16-23]

The current literature has attempted to define the cause of altered running biomechanics and how certain kinematic changes relate to injury risk. However, much of the research displays conflicting results because of differing methods and populations included in the studies. It may also be important to understand when these biomechanical changes occur. Thus, further research is needed to identify the biomechanical causes of chronic running injuries.

The purpose of this study was to evaluate the changes in lower extremity biomechanics at the hip and knee joints throughout a 3.1 mile (5K) run. Kinematic differences were compared between males and females. We sought to answer the following research questions: 1) In the course of a 5K run, do observable changes in joint angles occur? 2) What differences are observed in lower extremity running kinematics between males and females? Ten male and ten female recreational runners wore reflective markers to capture contralateral pelvic drop, knee adduction, knee abduction, and hip adduction. Participants ran 3.1 miles (5K) on a treadmill at a self-determined pace. After the run, hip and knee joint angles were measured at 0.9-1.0, 1.4-1.5, 1.9-2.0, 2.4-2.5, and 3.0-3.1 miles using Dartfish Motion Analysis software (Version 8, Dartfish, Fribourg, Swizerland). A two-way, repeated measures ANOVA was conducted to capture the within-subject data across time and between-subject comparing differences in gender.

5.1. Research Findings

Twenty participants completed the study; however, only 19 participants were included in the biomechanical analysis because of technology and equipment malfunctions. Joint angle analysis results revealed a significant difference in gender overall for contralateral pelvic drop during running with females having more contralateral pelvic drop than males ($F(1,17)=4.29$, $P = .05$). However, contralateral pelvic drop did not decrease over time. Results of the analysis showed a significant decline in knee abduction in all participants throughout the five intervals during the 5K run ($F(1,74)=6.09$, $P = .016$). There were no effects of gender with knee abduction results. No significant differences were observed between gender or over time for hip adduction. Knee flexion angles decreased throughout the run; however, this result was not significant. No differences were observed between gender for knee flexion angles during running.

Previous research has compared contralateral pelvic drop angles between males and females during running.[16,24] Those results have demonstrated greater contralateral pelvic drop angles in female runners, specifically those with PFPS.[16] The results of the current study also demonstrated significantly greater contralateral pelvic drop angles in females during the 5K run. In the current study, participants were allowed to run at a self-selected speed and only healthy participants were included. An increase in contralateral pelvic drop angles has been linked to chronic running injuries, such as PFPS because excessive frontal plane motions are thought to increase strain on the patellofemoral joint.[14,16,22,23] Therefore, our results compare to previous research suggesting that female runners with greater contralateral pelvic drop during running may have an increased risk for developing PFPS.

Hip adduction is another important lower extremity joint angle to consider when analyzing running kinematics. Increases in hip adduction angles throughout the course of a run have been demonstrated in previous research.[22,23] Additionally, females commonly displayed greater hip adduction angles during running than males.[16,20,24,25] Clinicians should recognize that increases in hip adduction, especially in females, has been correlated with chronic running injuries, such as PFPS and ITBS.[16,20,22-25] The current study's results revealed no changes in hip adduction during running, nor differences between gender. However, there are a few possible reasons for the contradictory results. Previous studies examining hip adduction angles during running have utilized the gold standard, 3D analysis software, unlike the 2D Dartfish Motion Analysis software used in the current study.[16,20,22-25] Although using 2D software was a limitation of this research, prior literature states that Dartfish Motion Analysis can produce reliable and valid measurements of lower extremity frontal and sagittal plane angles when 3D technology is not available.[37,38] Furthermore, most other studies instructed participants to run on a runway instead of using a treadmill.[16,20,22,23,25] This is a limitation that is important to consider because treadmill running cannot be generalized to other surfaces, such as outdoor running.[8] While our results for hip adduction were not consistent with former literature, future research is needed. Similar and valid methodologies should be implemented and specific populations included to identify connections between changes in hip adduction angles during running and predispositions for chronic injury.

Research examining knee abduction angles during running is limited; however, existing research has demonstrated that females have greater knee abduction angles during running than males.[20,25,44] The results of the current study demonstrated a decrease in knee abduction angles for all participants throughout the course of the run but no significant difference was observed between gender. There is an inconsistency between our results and those of previous studies, which could be due to differences in methodologies. As discussed previously, past research used 3D technology and the inclusion of a runway as opposed to a treadmill.[20,25] One study concluded that greater knee motion in females predisposes them to injury during athletic tasks, such as running.[44] A knee abduction angle of five degrees can increase the load on the anterior cruciate ligament (ACL) up to six times than when the knee is aligned properly; thus, increasing the risk for ACL rupture.[44] One potential reason for the discrepancy in results could be that previous research studying knee abduction angles during running did not account for anatomical features of the participants, such as quadriceps angle (Q angle).[44] The current study measured Q angle prior to the run and found that none of the females exhibited a pathological Q angle. Further research should focus on incorporating anatomical measurements to better understand participants of the study and how pre-existing features may affect lower extremity kinematics.

Knee flexion angles during running have been inconsistent among previous studies. Researchers who have implemented fatigue protocols have found increases in knee flexion across time.[9,14] Our findings demonstrated a decrease in knee flexion angles over time but no gender differences. Over the course of the run, knee flexion angles in females decreased 0.37 degrees and 0.69 degrees in males. Although this finding was not statistically significant, it is similar to the results of previous studies. A decrease in knee flexion angle was found in healthy runners[11,21] as well as in those who had PFPS.[16] One reason why our findings were different from those showing increases in knee flexion may be the inclusion of a fatigue protocol. Our methodology allowed participants to run at a self-selected speed because the purpose was to investigate normative running patterns of recreational runners. In contrast to research that has correlated a decrease in knee flexion to runners with PFPS, others have found that increases in knee flexion can lead to greater risk for ITBS.[14] Because of these contradictory research findings, it is important to continue to explore changes in lower extremity running kinematics in order to understand reasons for the development of chronic running injuries.

5.2. Clinical Implications

Results and conclusions of the current study can provide clinicians with evidence-based knowledge to add to clinical practice and care. Changes seen in contralateral pelvic drop between males and females is one such result. Females displayed greater contralateral pelvic drop during running when compared to male participants. Based on this result, clinicians can implement different rehabilitation plans according to a runner's specific needs. It is also important to note that similar running kinematics cannot always be expected between males and females. Another result of the current study that proved significant was a decrease in knee abduction over the course of the 5K run. Clinicians should be aware that running kinematics may or may not change over time. It can be recommended to clinicians working with runners to evaluate running mechanics over a longer period of time. This may reveal kinematics adjustments that might not have been visible early on during a run.

Injury prevention is often a motivating factor for continued research in the medical field. Improving our understanding on why injuries occur is crucial to preventing them. The results of the current study were not directly related to running injuries; however, future research based on the current results and recommendations may provide more significant relationship between changes in running kinematics and injury risk. It would be beneficial for clinicians to implement injury prevention programs after performing a kinematic analysis on runners, especially over a longer distance. In the future, a more detailed running analysis may play an important role in physical examinations, especially for those medical professionals who work with recreational and/or competitive runners. This could help prevent chronic running injuries that aren't commonly treated until the patient is no longer able to run.

5.3. Limitations

Limitations of this study included the use of two-dimensional video analysis and software instead of the gold standard three-dimensional analysis system because of the unavailability of three-dimensional technology. A treadmill was used in this study; however, this was a limitation because running on a treadmill cannot be generalized to outdoor running.[8] Additionally, participant height was a limitation that could not be accounted for in this study. Because of the treadmill design and where the safety rails are located, certain reflective markers were difficult to view depending on the height of the participant. This limited data collection for sagittal joint angles for some participants. This study cannot be directly compared to the previous studies' results because we included only healthy participants and did not attempt to correlate injury with biomechanical or surface EMG results. Furthermore, we did not implement a fatigue protocol for the 3.1 mile (5K) run. Thus, we cannot make definite conclusions relating our results to injury risk.

5.4. Recommendations for Future Research

Understanding the differences in kinematics between male and female runners may be helpful when developing injury prevention programs. Further research is needed for clinicians and researchers to make definite conclusions on the relationship between running kinematics and chronic injury risk. This study may provide a knowledge base and background for developing methodologies for future research studies involving running analysis, specifically for recreational runners. In the current study, contralateral pelvic drop, hip adduction, knee abduction, and knee flexion angles were analyzed during running. Different lower extremity angles from the foot and ankle should also be analyzed in future studies.

Additionally, prospective research studies are recommended in order to better identify connections between chronic running injuries and changes in running mechanics over time. This would provide better evidence of a relationship between kinematics and injury risk. Furthermore, developing a universal definition of recreational runner may aid future researchers in studying more specific populations. Continuing research on running kinematics may not only educate medical professionals, but also help those medical professionals to educate runners about running mechanics and injury risks.

5.5. Conclusion

This research was only one of many studying running kinematics. It is still unclear what causes running injuries versus changes in mechanics. In a study by Derrick et al[9], he asked: do changes in kinematics stem from failure of the body's optimal biomechanics or from the body's attempt to prevent injury?[9] Further research in this field will help to answer questions like this and provide all runners with the knowledge and care they need to continue running.

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APPENDIX. DEMOGRAPHIC QUESTIONNAIRE

Age:
- 18-24 years
- 25-30 years
- 31-40 years

Gender:
- Male
- Female

Years of Running Experience:
- < 1 year
- 1-2 years
- 2-5 years
- 5-10 years
- > 10 years

Average Weekly Running Mileage:
- 15-20 miles
- 21-25 miles
- 26-30 miles
- 31-40 miles
- > 40 miles

Average Running Distance:
- 2-3 miles
- 4-5 miles
- 6-7 miles
- >7 miles

Previous Running-Related Injuries:
- Yes (Please explain.) ____________________
- No

Do you where orthotics or shoe inserts?
- Yes (What type?) ____________________
- No

What stretches (if any) do you perform and how often?

____

____

What strength exercises (if any) do you perform and how often?

Please describe any other exercise habits you would like to share.