Lower Extremity Kinematics in Runners with Plantar Fasciopathy: A Case-Control Study

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Abstract* — The potential link between kinematic variability in runners' lower extremity movement patterns and plantar heel pain is the focus of this study. Plantar heel pain affects approximately 10% of the population with plantar fasciopathy being the leading cause in runners. The study recruited 30 participants, 15 healthy and 15 with foot pain lasting more than 2 months. Spherical reflective markers were placed on key landmarks and segments of the lower extremity to track the movement of hips, knees, ankles, and foot. The data generated were analyzed using a custom script in RStudio and compared. The knee rotation angle showed a significant reduction in variability in the injured group, and the ankle eversion velocity also exhibited a large difference in mean variability between the groups. The examination of the heel demonstrated statistical significance in both the heel strike and heel whip, with both showing a reduction in the injured group and large differences in mean variability, with heel strike and heel whip. The results of this study can be used to improve the current treatment plans and protocols in place for this injury.

***Index Terms* — Biomechanics, Gait Analysis, Plantar Fascia, Plantar Fasciopathy, Running-Related Injuries**

I. Introduction

In the general population approximately 10% of the over 2 million people will seek medical treatment for plantar heel pain [1]. Running is the most popular form of exercise for Americans, a common cause of plantar heel pain. The leading cause of a runner's plantar heel pain is plantar fasciopathy [2]. Plantar fasciopathy is the thickening or scarring of the connective tissue on the bottom of the foot – the plantar fascia (Figure 1). While most patients show improvement with conservative treatment, many require more aggressive intervention to resolve their symptoms.

To improve treatment, current research has identified risk factors which include: obesity, excessive pronation, prolonged standing, and contracture of the gastrocnemius and soleus muscles along with their tendons. (Figure 1) [2-3].

In individuals with risk factors, degenerative changes begin to take place in the plantar heel. Through the use of ultrasound, plantar fascial thickness is visible along the calcaneal attachment (Figure 1) [4].

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This thickness can be a source of symptoms in those suffering from plantar heel pain. Studies of runners with plantar heel pain have demonstrated an increase in ground contact time, pressure, and impulse of the foot [5]. In a study conducted by Yildiz et al. differences were found in those with and without plantar fasciitis. Patients with heel pain appear to contact the ground earlier with their midfoot and forefoot, most likely in an attempt to reduce the load on the heel, alleviating pain [6].

Current research, however, has not investigated the potential link between kinematic variability in runners' lower extremity movement patterns in this medical condition. We hypothesize that an increase in this kinematic variability is present in those with plantar fasciitis. Our research was conducted using 3D gait analysis of the participant's running kinematics. The participants' kinematics were marked using reflective markers and captured using high-speed infrared cameras. These cameras tracked the marker moment in the 3D space and the data were then analyzed. This analysis involved 35 markers, 7 segments, and 44 additional segmental moment patterns for this study. The variability in segmental movement, degree of change, and velocity are among the factors that we investigated.

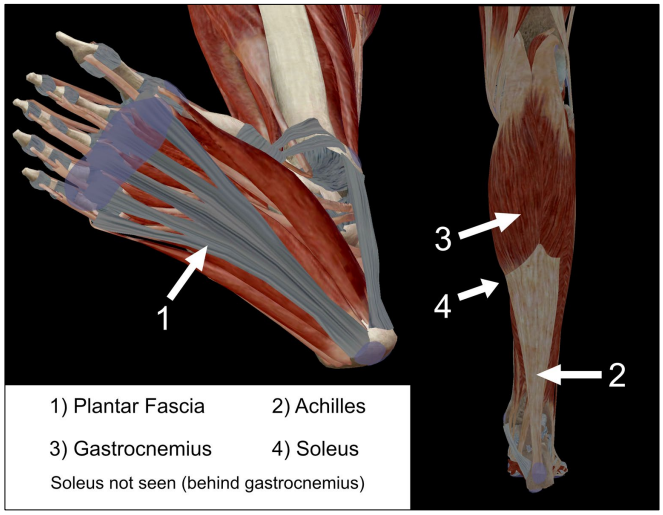

Figure 1: Diagram of foot and calf anatomy
1) Plantar Fascia: Connective tissue originating from the bottom of the heel to the base of the toes. 2) Achilles: Tendon connecting the calf muscles (Gastrocnemius and Soleus) to the back of the heel. 3) Gastrocnemius: Superficial calf muscle connecting from the back of the Femur to the Achilles. 4) Soleus: Deep calf muscle connecting from the back of the knee to the Achilles. [Adapted from Visible Body Human Anatomy Atlas 7 [11]]

Plantar fasciopathy not only affects runners but also impacts the larger population as a whole, currently millions of Americans [1]. With so many affected, it is important to further investigate the medical condition to link cause and effect. We hypothesize that runners with plantar heel pain would demonstrate increased variability across all segmental movements in all directions. Identifying biomechanical differences will elucidate the source of plantar heel pain and lead to improvement in the treatment of the condition. With this improvement, patients will be able to return to the activity they enjoy, especially runners.

II. Background

A. Plantar Heel Pain

Plantar fasciosis, a condition that is often wrongly identified as plantar fasciitis, are actually two distinct medical issues. Plantar fasciitis can be separated into two terms: "Plantar" meaning the sole or arch of the foot, and "fasciitis", the inflammation of the fascia. Plantar fasciosis is the breakdown of the fascia causing scar tissue formation. The plantar fascia extends from the heel (calcaneus) to the base of the toes [4]. To view this connective tissue diagnostic imaging is the primary method used. The most efficient and cost-effective method of imaging the plantar fascia is through the use of diagnostic sonography. Diagnostic sonography, more commonly known as ultrasound, is the process of using high frequency sound to create an image [8]. This form of imaging is less expensive when compared to other forms, including MRI. Imaging reveals the presence of inflammation and irritation, which is the major source of discomfort in this condition.

B. Gait Analysis

Gait analysis is the observation or recording of movements during walking or running. Running gait analysis can provide information related to both kinetics and kinematics of lower extremity movement. Kinetics is the study of forces, torques, moments, and impulses. Kinematics is the study of the positions and motion of objects. An observer or computer system monitors the displacement of markers at particular intervals of time. The computer system we use tracks markers in a 3D space using 3 high-speed infrared cameras. These cameras are manufactured by Vicon (Hauppauge, USA) and emit infrared light that reflects off the markers placed on the subject. As the subject moves, data is gathered by the software 3D Gait (Gait Analysis Systems Inc., Calgary, Canada) at which time 3119 different calculations are conducted [10]. Among these calculations' marker movement, rotational movement, and velocity are broken into anatomical segments including the pelvis, thigh, shank (lower leg), ankle, and foot. The segmental movements are then calculated and placed into time series plots.

C. Lower Extremity Biomechanics

The movements are measured during each running stride. These movements include adduction/abduction, extension, hip drop, rotation, flexion, eversion, heel strike, heel whip, and vertical oscillation (Figure 2). These movements are related to the three cardinal planes used in biomechanics (Figure 3). The coronal plane (sometimes called the frontal plane) divides the body front to back. Next, the sagittal plane divides the body left and right. Lastly, the transverse plane divides the body top to bottom [10]. Movements can occur in one, two, or three of the cardinal planes. For example, foot pronation occurs in all three while ankle dorsiflexion (up down movement) occurs in on plane. These movements are tracked over the time frame of each stride and is called stance phase or gait cycle (Figure 4).

The three cardinal planes are not a part of every movement pattern however, most require two or more to perform the action. The foot has 28 bones and 33 joints allowing for a large degree of movement [10]. From understanding how the lower extremity moves, insight is gained into atypical movements and their impact on a variety of injuries.

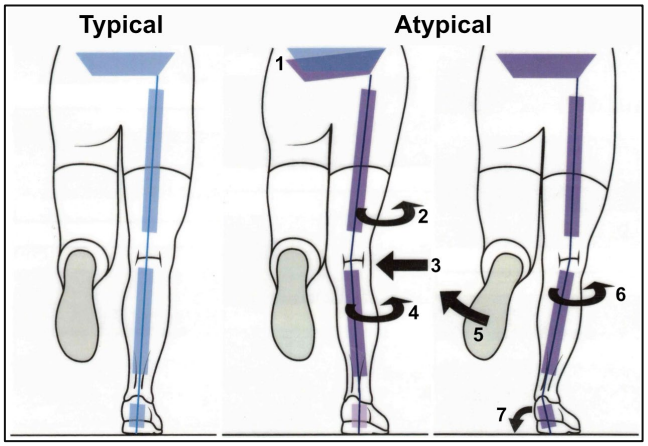

Figure 2: Diagram of normal and abnormal gait.
(1) Hip Drop, (2) Hip Internal Rotation, (3) Knee Adduction, (4) Shank Internal Rotation, (5) Heel Whip, (6) Knee Internal Rotation, (7) Ankle Eversion. [Adapted from The Running Injury Clinic, University of Calgary [12]]

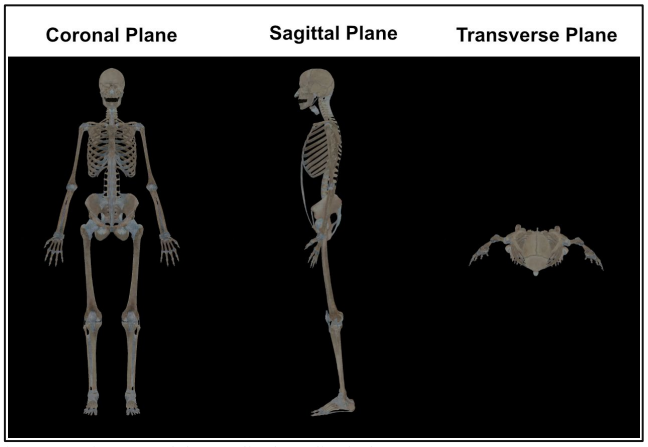

Figure 3: Diagram of the medical cardinal planes.
Coronal plane dividing the body front to back. Sagittal Plane dividing the body left to right. Transverse plane dividing the body top to bottom. [Adapted from Visible Body Human Anatomy Atlas 7 [11]]

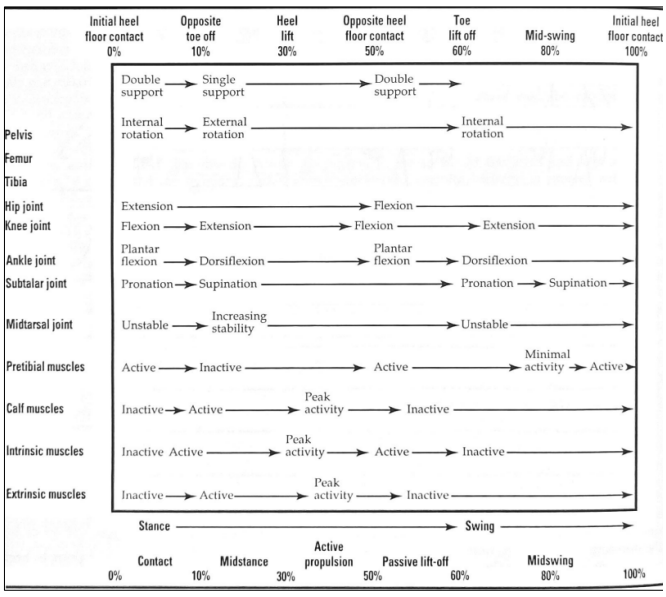

Figure 4: Diagram of the gait cycle biomechanics.

Bone, joint, and muscle groups movements during each gait cycle. Cycle beginning at initial heel contact and ending at this contact of following stride. Cycle is broken into segments and percentage of gait cycle. Movement types are identified for each bone, joint, or muscle group and the portion of the gait cycle they are present. Adapted from Clinical Biomechanics of the Lower Extremities [10]

III. Methods

A. Participants

We recruited 15 healthy (mean ± st dev, age: 35.5 ± 8.10, BMI: 22.5 ± 2.75, gender: 7 male, 4 female) and 15 study (mean ± st dev, age: 40.1 ± 6.98, BMI: 23.9 ± 2.28, gender: 5 male, 10 female) participants. Healthy individuals reported no lower-extremity injury or surgery in the last 2 years. Study participants were selected based on foot pain, both unilateral or bilateral, lasting greater than 2 months while not impacting training rigor or volume. Individuals apart of this group had no surgical intervention with no lower-extremity surgery in the last 2 years. Participants were screened for BMI greater than 18 while not exceeding 30, and age from 18 to 50 [7]. Prior to participation intake forms were filled out providing medical and running history. Consent for participation was gathered for all participants. A minimum of 13 participants per group was determined to reach a power of 0.80 and alpha of 0.05.

B. Data Collection

A total of 35 spherical reflective markers (B&L Engineering, Santa Ana, California, diameter: 9.5 mm) were placed on key landmarks and segments of the lower extremity by an experienced and board-certified physician. Individual markers were used to identify hips, knees, ankles, and feet. Ridged shells with mounted markers were used to identify the sacrum, thigh, and shank (Figure 5). Participants were instructed to use their normal running shoe. The instrument 3D Gait (Gait Analysis Systems Inc., Calgary, Canada) in conjunction with 3 Vicon Cameras (Hauppauge, USA, 240 fps, 0.3 megapixel) were used to track these markers [13]. 3D Gait was celebrated before every participant and markers clarity was verified before data capture. Participants were given 3–5-minute warm-up periods at a standard 6 mph (10 min/mi) pace before 3D Gait began the data capture process. A standard of 25-35 strides was confirmed after each trial.

Figure 5: Joint and segmental marker placement. Proper segmental and joint marker location. Segmental group markers on sacrum, two thigh groups, two shank (calf) groups, and two-foot groups. Joint markers on hips, knees, and ankles. Adapted from The Running Injury Clinic, University of Calgary [12]

C. Data Processing

Data sets were generated for segmental markers and were tracked for 5000 frames (~25 seconds) in the three cardinal directions. From these data sets, 3D Gait generated new data sets for the 22 traced moment patterns for both left and right anatomical sides.

D. Data Analysis

Analysis of the data was conducted using a custom script in RStudio (2021.09.1+372, Boston, USA). Analysis was separated into a segmental analysis in the three-dimensional space followed by an analysis of each separate moment pattern. A p-value of 0.05 (CI 95%) was determined for statistical significance and calculated using a student's t-test of variability calculations. P-values and T-statistics were gathered from the student's t-test. A p-value greater than 0.05 was set for statistical significance. A T-statistic greater than 1.5 was determined set to reject the null hypothesis. A data normality test was conducted and nonnormal data was then normalized using a logarithmic transformation.

E. Segmental Analysis

Analysis of the five segments (sacrum, thighs, shanks, and feet) were conducted in the standard cardinal system (x, y, and z directions). Variability was calculated per subject and segment in each of these directions. Data apart of the study group were separated into injured and uninjured limbs and analyzed separately when compared to the control data. A student's t-test was then conducted by group and axis. Planes with significance were then plotted for visual analysis.

F. Movement Pattern Analysis

Analysis of the 22 measured moment patterns by 3D Gait were analyzed. Peak rotation and velocities were identified for each stride. Variability calculation was conducted by subject

for these values. The study group participant data was separated into injured and uninjured limbs and analyzed separately when compared to control data. A student's t-test was conducted by group and moment pattern. Movement patterns with significance were then plotted and group trend lines were included. This was then followed by a visual analysis.

IV. Results

Segmental

Participants with plantar heel pain were observed to have a lower mean variability in the foot's vertical movement when compared to those without the condition (right, left; 21, 18; Table 1). These findings were contrary to the initial hypothesis which suggested that the injured participants would demonstrate increased variability across all segmental movements in all directions.

TABLE 1
COMPARISON OF 3D SEGMENTAL MOVEMENT

	Right		Left	
	T-Stat	p-Value	T-Stat	p-Value
Pelvis				
X	-0.25	0.80	-0.38	0.72
Y	-0.11	0.91	**2.00****	0.06
Z	0.51	0.62	-0.10	0.93
Thigh				
X	-0.70	0.95	-0.10	0.92
Y	-0.56	0.58	0.07	0.94
Z	0.09	0.93	-0.44	0.67
Shank				
X	0.19	0.85	0.26	0.80
Y	0.97	0.35	-0.03	0.97
Z	0.59	0.56	1.10	0.29
Foot				
X	-0.31	0.76	-0.53	0.61
Y	0.47	0.64	-0.57	0.58
Z	**21.00****	0.40	**18.00****	0.39

* Significant difference between groups ($p < 0.05$)

** T-statistic value significance between group ($T > 1.5$)

Movement Patterns

A. Hip

The study found no statistically significant difference in the seven hip movement patterns as presented in Table 2. However, an increased T-statistic in the rotation angle was observed (Eversion Angle: T = 1.57, 1.57; Rotation Angle: T = 19.00) indicating a large deviation in the mean angle. Differences between the control and injured groups were noted at various points during the stance phase of the adduction peak velocity using visual analysis. Specifically, a decrease was observed just after the 50% mark in the injured group, as shown in Figure 6. Additionally visual differences were noted in the hip extension angle, pelvis drop velocity, and hip rotation velocity (Figure S1). These movements did not reach statistical significance ($p > 0.05$), but increased or delayed movements were identified when comparing the injured and control groups.

TABLE 2
COMPARISON OF HIP MOVEMENT PATTERNS

	Right		Left	
	T-Stat	p-Value	T-Stat	p-Value
Abduction Angle	1.42	0.17	1.42	0.83
Abduction Velocity	1.05	0.31	1.05	0.72
Eversion Angle	**1.57****	0.14	**1.57****	0.18
Pelvic Drop Velocity	0.57	0.57	1.38	0.18
Pelvic Drop Angle	-0.46	0.65	0.21	0.84
Rotation Angle	0.08	0.93	**19.00****	0.39
Rotation Velocity	0.71	0.49	0.23	0.82

* Significant difference between groups ($p < 0.05$)

** T-statistic value significance between group ($T > 1.5$)

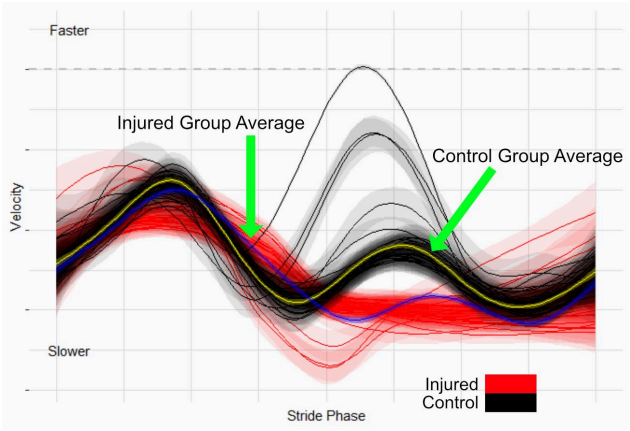

Figure 6: Time series plot of hip adduction velocity (see Table 2 row 2).

Control and study group data plotted measuring hip internal velocity change over stride phase. Control data individually plotted in black with group average plotted in yellow. Study participant data individually plotted in red with group average plotted in blue. Using visual analysis of the time series data differences between the injured group and control group were identified. Reduction in study groups velocity identified over the 50% stance phase point. Statistical significance was not reached in this movement pattern contrary to results of visual analysis.

B. Knee

In the five movement patterns examined, a statistically significant difference was identified only in the knee rotation angle (Table 3). An increased T-statistic in the rotation angle (T = 2.67) and abduction velocity (T = 1.53) was found indicating an increased deviation on the mean angle of the groups. Visual analysis revealed differences between the control and injured groups at various points of the stance phase of the adduction peak velocity. Specifically, an increase was observed over the entire stance phase of the knee rotation angle (Figure 7). Additionally visual differences were noted in the knee abduction velocity (Figure S2). Abduction velocity did not reach statistical significance ($p > 0.05$), but increased or delayed movements were identified when comparing the injured and control groups over the stance phase.

TABLE 3
COMPARISON OF KNEE MOVEMENT PATTERNS

	Right		Left	
	T-Stat	p-Value	T-Stat	p-Value
Abduction Angle	-0.54	0.60	0.43	0.67
Abduction Velocity	-0.42	0.68	**1.53**	0.15
Flexion Angle	-0.82	0.44	0.64	0.53
Rotation Angle	**2.67**	**0.02**	-0.07	0.95
Rotation Velocity	-1.27	0.23	0.22	0.83

* Significant difference between groups ($p < 0.05$)

** T-statistic value significance between group ($T > 1.5$)

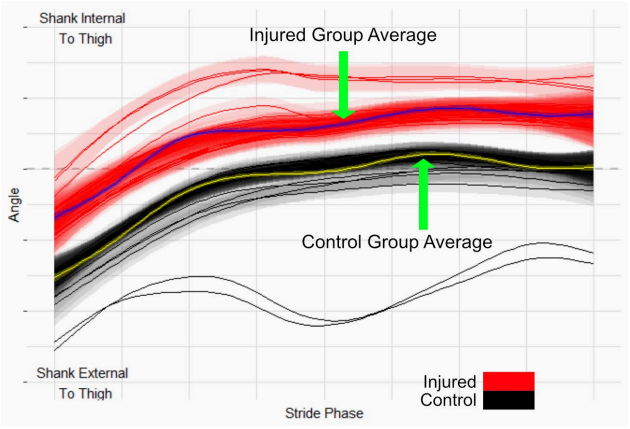

Figure 7: Time series plot of hip adduction velocity (see Table 2 row 2).

Control and study group data plotted measuring hip internal velocity change over stride phase. Control data individually plotted in black with group average plotted in yellow. Study participant data individually plotted in red with group average plotted in blue. Using visual analysis of the time series data differences between the injured group and control group were identified. Reduction in study groups velocity identified over the 50% stance phase point. Statistical significance was not reached in this movement pattern contrary to results of visual analysis.

C. Ankle

In the ankle movement patterns, no statistically significant difference was found between the control and study groups (Table 4). However, an increased T-statistic was identified in the eversion velocity (T = 1.60) indicating a large deviation in the mean angle. Visual analysis revealed differences between the groups at varying points of the stance phase of the rotation peak velocity. An increase in the knee rotation angle was observed over the entire stance phase (Figure 8). In using visual analysis, the injured group had an increased rotation velocity in the beginning of the stance phase compared to the control group (Figure S3). Rotation velocity did not meet statistical significance ($p > 0.05$), but these observations indicate large differences between the injured and control groups.

TABLE 4
COMPARISON OF ANKLE MOVEMENT PATTERNS

	Right		Left	
	T-Stat	p-Value	T-Stat	p-Value
Eversion Angle	0.15	0.88	0.25	0.81
Eversion Velocity	**1.60**	0.13	0.44	0.67
Rotation Angle	-0.29	0.78	-0.03	0.98
Rotation Velocity	-1.00	0.35	1.25	0.23

* Significant difference between groups ($p < 0.05$)

** T-statistic value significance between group ($T > 1.5$)

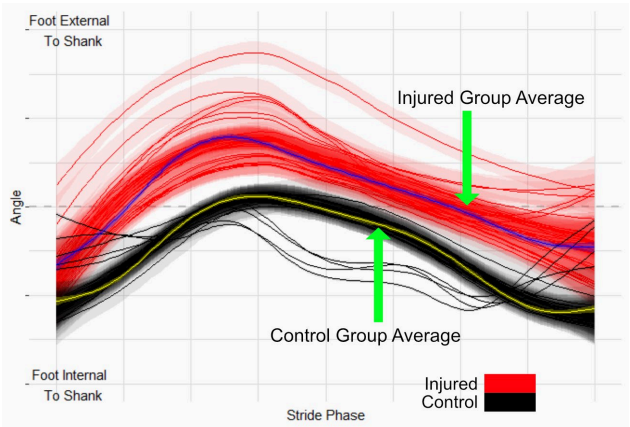

Figure 8: Time series plot of ankle rotation angle (see Table 4 row 1).

Control and study group data plotted measuring hip internal velocity change over stride phase. Control data individually plotted in black with group average plotted in yellow. Study participant data individually plotted in red with group average plotted in blue. Increase in study groups angle identified over the entire stance phase. Statistical significance was not reached in this movement pattern contrary to results of visual analysis.

D. Heel

In the heel movement patterns, statistical significance was identified in the two heel movement patterns (Table 5). An increased T-statistic was found in both the heel strike (T = 2.36) and heel whip (T = 2.27) angle. Using visual analysis, differences were noted between the control and study groups over the entire stance phase of the heel whip angle (Figure 9). Additional differences were observed in the heel strike angle (Figure S4). The control group demonstrated an increase over the mid stance phase then reduced at the completion of stance phase.

TABLE 5
COMPARISON OF HEEL MOVEMENT PATTERNS

	Right		Left	
	T-Stat	p-Value	T-Stat	p-Value
Heel Strike	**2.36**	**0.03**	1.40	0.18
Heel Whip	-1.42	0.20	**2.27**	**0.04**

* Significant difference between groups ($p < 0.05$)

** T-statistic value significance between group ($T > 1.5$)

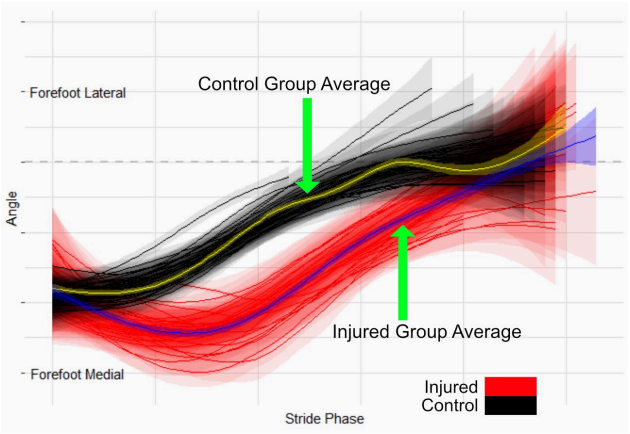

Figure 9: Time series plot of heel whip angle (see Table 5 row 2).

Control and study group data plotted measuring heel whip angle change over stride phase. Control data individually plotted in black with group average plotted in yellow. Study participant data individually plotted in red with group average plotted in blue. Using visual analysis of the time series data differences between the injured group and control group were identified. Decrease in study groups angle identified over the entire stance phase.

E. Functional

No statistically significant difference identified (Table 6) in the four functional movement patterns. However, an increased T-statistic in the vertical oscillation was found (T = 1.58). Visual analysis revealed differences between the control and study groups at the beginning stance phase of the progression angle, reducing near the end of the stance phase (Figure 10). Additionally, it was observed that the control group's stride rate was elevated compared to the injured group (Figure S5).

TABLE 6
COMPARISON OF FUNCTIONAL MOVEMENT PATTERNS

	Right		Left	
	T-Stat	P-Value	T-Stat	P-Value
Progression Angle	0.96	0.35	1.31	0.21
Stride Rate	0.65	0.52	0.60	0.56
Stride Width	0.61	0.55	0.11	0.91
Vertical Oscillation	**1.58**	0.13	0.74	0.47

* Significant difference between groups ($P < 0.05$)

** T-statistic value significance between group ($T > 1.5$)

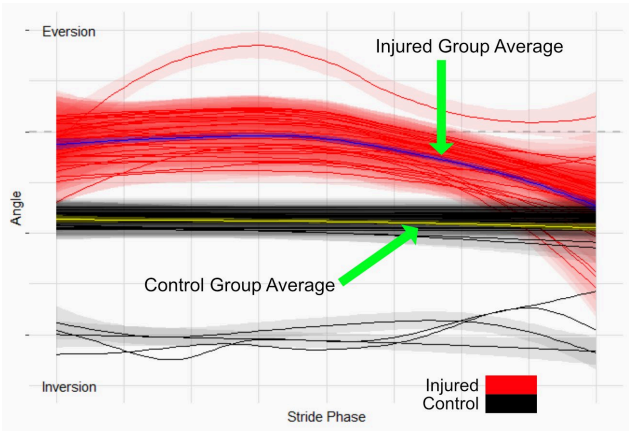

Figure 10: Time series plot of progression angle.

Control and study group data plotted measuring hip internal velocity change over stride phase. Control data individually plotted in black with group average plotted in yellow. Study participant data individually plotted in red with group average plotted in blue. Increase in study groups velocity identified at the start of stride phase and decreasing as it progresses. Statistical significance was not reached in this movement pattern contrary to results of visual analysis.

V. DISCUSSION

Approximately 2 million Americans in the general population suffer from plantar heel pain [1]. Heel pain affecting runners is primarily plantar fasciopathy [2]. We hypothesized that an increase in variability in running biomechanics would be present in those with the pathology. 3D gait analysis was used to gather running data from 30 participants (15 injured, 15 uninjured). Knee rotation angle, heel strike, and heel whip ($p < 0.05$) in the injured group were identified to have increased variability when analyzed against control (Table 3 & 5). In identifying this variability, we can improve current treatment protocols and plans, improving patient care.

No significant differences were identified in the segmental 3D moments (Table 1). In analyzing the T-Statistic a larger difference in the groups mean variability was identified in the vertical foot direction or z-axis (right, left; 21, 18). This

indicates a stiffening in the injured group related to reducing pressure and therefore pain.

In the movement patterns statistical differences were found. In the knee rotation angle ($p = 0.02$) the injured group had a reduction in variability ($T = 2.67$; Table 3). Limb stiffening to protect the body from further injury is the primary cause of this reduction in variability. In the ankle eversion velocity, a large difference in mean variability ($T = 1.60$) was found (Table 4). The injured group had a reduced variability compared to the control group. In the examination of the heel both the heel strike ($p = 0.03$) and heel whip ($p = 0.04$) were found to have statistical significance. Both also had large differences in mean variability with heel strike ($T = 2.36$) and heel whip ($T = 2.27$) showing a reduction in the injured group (Figure 5). In the functional outcomes no significant differences were identified (Figure 6).

In the article by Chang R. et. al. they identified greater rearfoot motion in healthy individuals supporting our findings if increased vertical foot movement [7]. Reduction therefore would be primary due to the body's natural response to protect the area from further injury and damage. This would then lead to a reduction in knee moment again reducing variability. This is supported as patients with plantar heel pain will walk on the lateral edge of the foot or toes to alleviate pain [8]. In previous studies it was reported suggested that lower extremity movement patterns in those with plantar heel pain had reduced rearfoot transverse motion [3]. Contrary to this study a reduction in heel whip (transverse motion) was found to be reduced in the injured group.

This study was conducted on individuals with chronic plantar heel pain (symptoms > 3 months). Therefore, we cannot conclude that the variation in identified factors is a cause of plantar heel pain. To discover this this study would need to be conducted over the time that plantar heel pain develops. Each of the studies' movements are complex with a multitude of factors that can change these measurements. Markers placed on the skin were used as opposed to other methods such as bone pinned markers to remain non-invasive. Errors regarding marker placement were minimized to the best of our ability using physician experience and when needed marker checking software. This software would come with its own error as it uses calculated average placement for markers.

While 3D gait analysis is a powerful tool in understanding human moment it also has limitations in its ability. Gait analysis requires participants to run on a treadmill. This in many cases does not match road, track, and trail running which can alter biomechanics. 3D gait analysis also lacks the ability to gather information in some areas. These include muscle and joint function as well as neurological function. Participants' shoes were additionally not standardized. Current research into the impact of shoes on biomechanics is additionally conflicting.

To better improve the treatment, prevention, and diagnosis of plantar heel pain research into kinematics is required. Understanding the role of kinematics in individuals with plantar heel pain is important because it can help identify the specific mechanics that may be contributing to the pain. By analyzing the movement patterns of the foot and ankle, healthcare professionals can determine if certain factors, such as overpronation or limited dorsiflexion, are contributing to the development of heel pain. This information can then be used to develop more targeted and effective treatment plans for patients.

Using the results found in our study we can further improve the current treatment plans and protocols in place for this injury. We can also develop new protocols focusing of areas lacking in flexibility and strength. Future research can continue to investigate causes after injury has occurred. To gain better understanding of the biomechanics leading to injury studies should perform this analysis as plantar heel pain develops. In using this information, we can continue to gain a better understanding of running-related injuries and the differences in movement they cause.

APPENDIX

Additional plots, graphs, and information not included in this paper are available upon request. Supplementary information included after references.

ACKNOWLEDGMENT

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VI. SUPPLEMENTARY

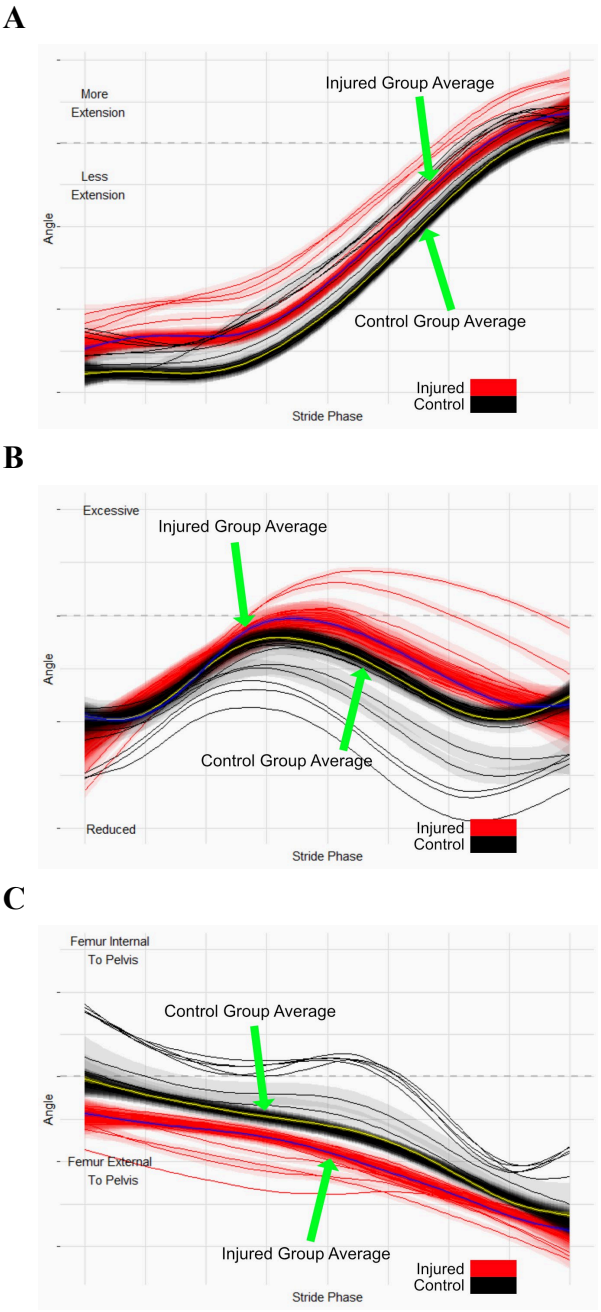

Figure S1: Time series plot of hip eversion angle (see Table 2 row 3, 4, & 7).

(A) Control and study group data plotted measuring hip eversion angle change over stride phase. Increased in study groups angle identified over the entire stance phase. (B) Control and study group data plotted measuring pelvic drop velocity change over stride phase. Increased in study groups velocity identified starting at the midpoint of the stance phase. (C) Control and study group data plotted measuring hip rotation velocity change over stride phase. Decreased in study groups angle identified over the entire stance phase. Control data individually plotted in black with group average plotted in yellow. Study participant data individually plotted in red with group average plotted in blue. Using visual analysis of the time series data differences between the injured group and control group were identified.

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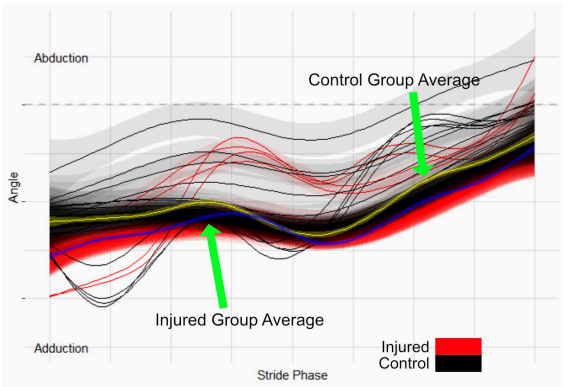

Figure S2: Time series plot of knee abduction velocity (see Table 3 row 2).

Control and study group data plotted measuring knee abduction velocity change over stride phase. Control data individually plotted in black with group average plotted in yellow. Study participant data individually plotted in red with group average plotted in blue. Using visual analysis of the time series data differences between the injured group and control group were identified. Decrease in study groups angle identified over most of the stance phase.

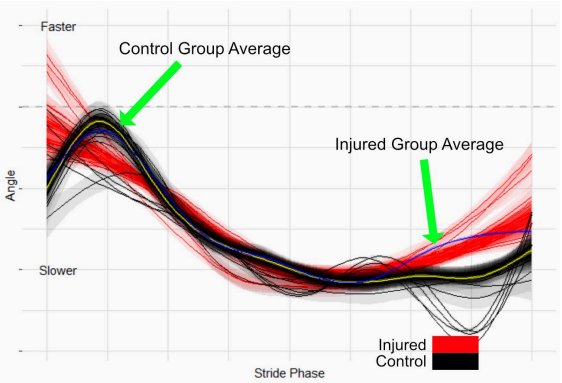

Figure S3: Time series plot of ankle rotation velocity (see Table 4 row 2).

Control and study group data plotted measuring ankle rotation velocity change over stride phase. Control data individually plotted in black with group average plotted in yellow. Study participant data individually plotted in red with group average plotted in blue. Using visual analysis of the time series data differences between the injured group and control group were identified. Increased in study groups angle identified over the start and end of the stance phase.

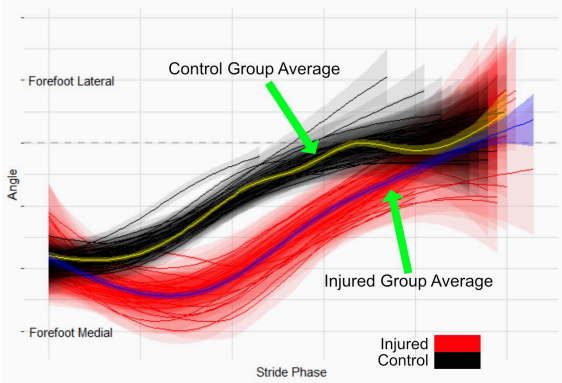

Figure S4: Time series plot of heel strike angle (see Table 5 row 1).

Control and study group data plotted measuring heel strike angle change over stride phase. Control data individually plotted in black with group average plotted in yellow. Study participant data individually plotted in red with group average plotted in blue. Using visual analysis of the time series data differences between the injured group and control group were identified. Decreased in study groups angle identified over the entire stance phase.

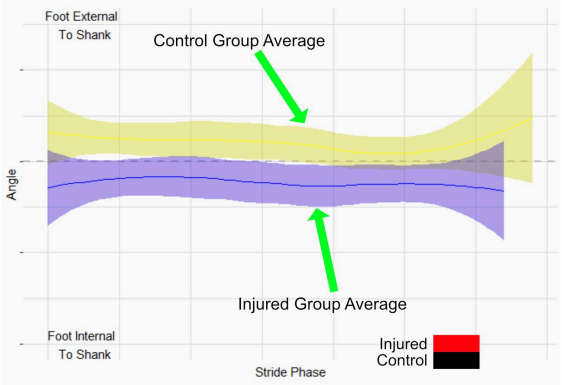

Figure S5: Time series plot of stride rate (see Table 6 row 2).

Control and study group data plotted measuring stride rate change over stride phase. Control data individually plotted in black with group average plotted in yellow. Study participant data individually plotted in red with group average plotted in blue. Using visual analysis of the time series data differences between the injured group and control group were identified. Decreased in study groups angle identified over the entire stance phase.