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FOOTWEAR SELECTION, FOOT TYPE, AND RUNNING BIOMECHANICS OF MALE DISTANCE RUNNERS WITH PREVIOUS RUNNING RELATED INJURY: A CASE SERIES

by

DIEGO CASTRO-DIAZ

(Under the Direction of Jessica Mutchler)

ABSTRACT

With the rise in popularity of running, running shoe companies have researched and designed several models aimed at the purpose of providing comfort and aiding in the decrease of running related injuries. Technology was developed for running shoes to control forefoot and rearfoot impact forces and rearfoot motion during running. However, there is no overwhelming evidence supporting the notion that footwear corresponding to foot type leads to a decrease in running injuries. Thus, the purpose of this study was to describe footwear selection, foot type, and running biomechanics in previously injured male distance runners. Six total participants completed this case series. Cases 1 and 3 were recreational runners, Cases 2, 4, and 5 were professional athletes, and Case 6 was an assistant coach for a professional sport team. All participants had a history of lower extremity running related injury within the last year, but no current injury preventing them from running 10+ miles per week. Each participant completed the Disablement for the Physically Active Short Form-8, a questionnaire on shoe selection and injury history, Foot Posture Index (FPI), dorsiflexion range of motion (DFROM) using the weight bearing lunge test and walking and running trials in the equipment outfitted biomechanics lab. Running kinematic and kinetics were calculated along with descriptives of FPI, DFROM, and survey data for analysis between cases. The two cases that had Achilles/shank injuries also had clinically significant asymmetry with reduced DFROM in the affected limb. Case 3 was the only Highly Pronated Foot Type and with footwear not recommended for foot type. Case 3 lacked dorsiflexion at absorption and lacked appropriate foot progression into eversion. As a result that also had the highest vertical ground reaction force. Case 4 had similar injuries to Case 3, but sought care and had close to normal dorsiflexion range of motion. Injury history may affect long-term dorsiflexion range of motion if not rectified and have more influence on biomechanics than foot type.

INDEX WORDS: Running, Footwear, Foot type, Running Biomechanics, Running Injuries.

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by

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Fulfillment of the Requirements for the Degree

MASTER OF SCIENCE

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DEDICATION

I dedicate this thesis to Consuelo and Pablo, my mother and father. You gave me the love, support and encouragement to achieve success in any endeavor. This accomplishment is yours as much as it is mine.

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I want to thank my committee members Drs. Mutchler, Wilson, Munkasy and Siekirk for providing me with a truly incredible academic experience at Georgia Southern. Even from my time as an undergraduate student, you all have fueled my curiosity, challenged me to work harder, and to think more critically. Without you all I would not be where I am today. I would also like to thank my cohort for being part of this academic journey. I will always cherish the time we spent growing as professionals. I want to thank my girlfriend Erin for being supportive throughout my time in graduate school. I would also like to thank my pets Ziggy and Harriet for their patience and emotional support which enabled me to on this thesis in good spirit.

TABLE OF CONTENTS

Page

LIST OF TABLES

Page

CHAPTER I

INTRODUCTION

Since the rise in popularity of running in the 1970's, running shoe companies have researched and designed several models aimed at the purpose of providing comfort and aiding in the decrease of running related injuries. Technology was developed for running shoes to control forefoot and rearfoot impact forces during running, as well as stiffer midsoles and a varus wedge to control rearfoot motion during running (Butler et al., 2006). The development in shoe technology is aimed to reduce injuries stemming from overuse. However, there is no overwhelming evidence supporting the notion that footwear corresponding to foot type leads to a decrease in running injuries.

There are extrinsic and intrinsic factors that are believed to predict running-related injuries. The intrinsic factors that are believed to predict running-related injuries are impact forces and foot pronation. Impact forces were assumed to be associated with injuries such as fatigue fractures, tendonitis, and cartilage damage (Clements et al., 1981; Frederick et al., 1981; Nigg et al., 1977; Nigg et al., 1986). It was suggested that shoes should be constructed to reduce impact forces in the first 30ms-50ms of ground contact. Since then, impact forces from a foot strike have been shown to be unrelated to running injuries (Nigg & Murtlock. 1987).

Foot pronation is the simultaneous movement of foot eversion, abduction, and dorsiflexion. Excessive total pronation is assumed to relate to overloading medial structures at the ankle joint, such as the tibialis posterior and plantar fascia.

Researchers have speculated on the relationship between the abnormal kinematics of the rearfoot and patellofemoral pain syndrome. The movements in the foot and lower leg are linked by tibial rotation, therefore an abnormal foot alignment may alter the mechanics of the patella-femoral joint and result in pain. It has been suggested that running shoes should be built to provide mediolateral stability and rearfoot control. Instability is assumed to relate to overuse injuries such as anterior medial compartment syndrome or IT-Band syndrome (Krahl, 1977; Nigg & Leuthl, 1980; Schuster, 1978; Segesser & Nigg, 1980; Subotnick, 1981). Motion control shoes are a mainstream development in shoe technology that aims to control the movements of the rearfoot during locomotion in sports to reduce injuries stemming from overuse (Hamill et al., 1992). This supports the idea that motion control of the foot should be considered in treating PFPS as there is a biomechanical link between the rearfoot and shank movements. However, evidence has suggested that foot pronation may to not be an injury risk factor (Nielsen et al., 2014).

Underpronation, also known as over-supination, is when the foot contacts with the outer side of the heel with little or no normal pronation. There is pressure of the smaller toes on the outside of the foot during push-off, possibly causing large transmissions of shock through the lower leg. Over-supination at takeoff is speculated to be associated with Achilles tendon problems (Cheung et al., 2006; Clements et al., 1981; Stacoff & Kaelin., 1983). It is suggested that running shoes should be built to provide guidance to avoid over-supination of the foot during the take-off phase.

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It is unclear whether footwear creates the adjustments that are intended for the designated foot type even when runners have experienced a previous running related lower extremity injury. It is also of interest whether a runner whose habitual footwear is associated with their foot type has significant differences in foot and ankle kinematics and kinetics compared to a runner whose habitual footwear is not the recommended footwear for their foot type. As mentioned previously, habitual shoes that are motion-controlled footwear, which incorporates stiffer midsoles, and a varus wedge are often recommended for an overpronated foot type. Habitual shoes that are cushioned footwear, typically with rearfoot foam and inserts in the forefoot and rearfoot to absorb impact during running are often recommended for an under pronated foot type (Butler et al., 2006). The recommended footwear for foot-types in-between over and under pronated are neutral or stability shoes. Stability shoes usually control or limit rearfoot eversion and medial plantar pressure (Ryan et al., 2011).

Therefore, the purpose of this study was to describe footwear selection, foot type, and running biomechanics in previously injured male distance runners to explore similarities and patterns using a case series approach.

CHAPTER 2

METHODS

Participants

There were six total participants in this case series. Cases 1 and 3 were recreational runners, Cases 2, 4, and 5 were professional athletes, and Case 6 was an assistant coach for a professional sport team. Further details on personal and running background for each individual can be seen in Table 1. All participants had a history of lower extremity running related injury within the last year, but no current injury preventing them from running 10+ miles per week. Individuals were excluded from the study if they answered “Yes” on the PAR-Q+ for a condition that physical activity would be contraindicated and/or had a current injury that prevented study completion. Runners with no previous injury history and those that require an orthotic insole would also be excluded. All participants were recruited from a convenience sample via verbal recruitment and advertisements placed in university buildings and community boards. Before recruitment began, the study was approved by the University’s Institutional Review Board. Participants scheduled the first study session once the inclusion criteria have been confirmed. Once the informed consent was read and signed, the study procedures began.

Procedures

Each participant who passed eligibility attended a screening and familiarization session prior to their test session. This session included the completion of the Disablement for the Physically Active Short Form-8 (DPA SF-8) questionnaire (Casanova et al., 2021), a questionnaire on shoe selection and injury history (Andrade & Santos, 2022), evaluation of the Foot Posture Index (FPI), and walking and running practice trials in the equipment outfitted biomechanics lab. The walking and running familiarization trials were used to mark each cases starting position and gain comfort with the set running velocity of 3.5m/s-4 m/s. The starting position was the best location for the participant to start their walk/run and naturally land in the center of the target force platform without stuttering, slowing or looking down. A five-minute dynamic warm-up with shuttles, high knees, skips, squats, and lunges, preceded the walking and running familiarization.

The test session occurred as soon as the day following the familiarization session, but not on the same day to reduce testing fatigue. The test session began with the same guided warm-up to prepare them for the activity. The weight bearing lunge test immediately followed and their dorsiflexion range of motion for both limbs were recorded (Powden et al., 2015). Participants completed five successful walking trials per target limb with no minimum speed, and five successful running trials per target limb at a velocity of 3.5m/s-4 m/s. Participants had approximately 10+ meters to reach the approach speed. A successful trial is defined as landing with the entire foot inside the force platform without visible disturbance to the natural gait cycle (stuttering, slowing down, looking down, etc.). Total number of test trials varied per individual due to gait variations and location of force platforms. For example, if a participant landed with their right foot in one force platform and their left foot in another force platform within the same trial, that trial counted for each limb. Therefore, a range of 5-10 walking and 5-10 running trials per participant was required for data collection and processing. After the collection was completed, participants began a minimum five-minute cooldown, where they walked around the room and stretched before leaving the testing facility.

Participants were asked to wear their habitual running shoes to both sessions. Habitual shoes must have been worn regularly by the participant and not new from a box. Participants were asked to provide an estimate of length of wear (i.e. days, months, years), average frequency (number of days a week), and total miles run in the shoes. Pictures of the shoes were also collected to confirm the type of footwear (cushioned, motion-control, stability, neutral, etc.). Footwear type will be discussed further in data processing.

Instrumentation

Foot posture was evaluated using the FPI (Pollock et al., 1977), a six-item foot posture assessment tool, where each item was scored between -2 and +2 to give a sum between -12 (highly supinated) and +12 (highly pronated). To be considered under pronated the foot must have met a minimum score of -1. To be considered overpronated the foot must have met a minimum score of +6. Neutral feet are ranged between 0 and +5. Each foot was given their own separate score and was evaluated separately. Items include: talar head palpation, curves above and below the lateral malleoli, calcaneal angle, talonavicular bulge, medial longitudinal arch, and forefoot to rearfoot alignment. The FPI-6 scores predicted 64% of the variation in the static ankle/subtalar position during quiet double limb standing. The same FPI-6 scores predicted 41% of the variance in ankle/subtalar position at midstance (Redmond et al., 2001). The independently reported inter-tester reliability of the original eight item FPI has ranged from 0.62 to 0.91, depending on population, and intra-tester reliability ranges from 0.81 to 0.91 (Evans et al., 2003). In this study, the same evaluator performed all FPI assessments and had three years of experience with testing foot posture, under the supervision of an experienced athletic trainer.

Static dorsiflexion range of motion was assessed using the weight-bearing lunge test (WBLT). Participants were barefoot, the foot of the test-leg positioned so that the first toe and mid-point of the calcaneus were in a straight line perpendicular to the wall. Their hands were instructed not to be placed on the wall for support. The opposite leg and foot were positioned comfortably at the side, on the floor. The player lunged forwards keeping the knee in line with the second toe to touch the wall with the knee. The foot progressed gradually away from the wall until the furthest point at which the knee could touch the wall with the heel on the floor was identified. If the heel was raised from the floor, the foot was progressed forwards until the heel made contact with the floor. Knee contact with the wall and heel contact with the floor were monitored visually. Maximum dorsiflexion range-of-motion was the maximum distance, in centimeters, between the tip of the first toe and the edge of the wall whilst keeping the knee in contact with the wall and the heel on the floor, with no visible tibial rotation. Only one trial was performed for each leg as per previous work (Simondson et al., 2012; Venturini et al., 2006).

High inter-rater reliability for the WBLT from one trial has been reported for uninjured individuals, with an intraclass-correlation-coefficient (ICC) of 0.98-0.99 and standard-error-of-measurement (SEM) of 0.3 cm (Venturini et al., 2006). High inter-rater reliability was also reported in those with ankle trauma with an ICC of 0.97, and SEM of 1.4 cm (Simondson et al., 2012). The WBLT was selected for measuring dorsiflexion due to the functional nature of the test and supported reliability in previous literature. Due to the hours of experience needed to accurately use a goniometer, the WBLT is more reliable for novice clinicians (Hankemeier and Thrasher, 2014). In this study, the same evaluator performed all WBLTs and had two years of experience with this measure.

Motion analysis was conducted using a three-dimensional motion analysis system (Vicon MX system, Oxford Metrics Ltd, Oxford, England) with 19 cameras (7 ×Vero, 4 MX T10, 4 x MX T20 and 4x Bonita) operating at a sampling frequency of 100 Hz. Ground reaction forces was collected using multiple floor embedded force platforms (AMTI, type BMS400600, USA) at a sampling frequency of 1000 Hz. Specific anatomical landmarks were created by a markerless motion analysis system (Theia Markerless, Inc. Kingston, Canada).

Speed was controlled using timing gates (Lafayette Timing Gait System, Lafayette Instrument, Lafayette, IN, USA) placed 1 meter from force platform.

Data Processing

Only running trials were included in the analysis of this study. Walking trials were processed separately for a separate research question not being explored in this thesis. 3-D joint coordinates were filtered with a 20 Hz low-pass, fourth-order zero-lag Butterworth filter. Four phases of the gait cycle were identified via ground reaction force (GRF) data. Initial contact and toe-off were determined using a 10N threshold from the vertical GRF data. The absorption and propulsion phases were determined using the antero-posterior GRF data. Absorption phase started at initial contact and ended when the force ascended to zero. Propulsion phase began when antero-posterior GRF reached zero and ended at toe-off. This post-processing was performed using a custom code through Visual 3D (Visual3D, Version: 6.00.27, C-Motion Inc., Germantown, MD). Visual 3D was used to identify the maximum values of eversion, inversion, plantar flexion, and dorsiflexion for each phase of gait and for each trial. The global means and standard deviations for each measure was then calculated and exported to a purposely developed Microsoft Excel (Microsoft Corporation, Redmond, Washington, USA) template for analysis.

Kinematic data was reported in degrees. Kinetic data was reported as newtons per kilogram for participant normalization.

Data Analysis

Means and standard deviations for all kinematic and kinetic measures were calculated from the five running trials on each limb and reported for each case individually. Data from the questionnaires, FPI, and dorsiflexion measures are reported via descriptive tables. Individual cases were compared to identify any observable similarities or patterns associated with injury history, shoe selection process, perceived disability, foot characteristics, habitual footwear use, and running kinematics and kinetics.

Table 1

Personal and Running Background

ID	Demographics			Running Background				
	Age	Weight (Kg)	Height (m)	Running Experience	Frequency of Training	Distance Covered In Training (Km)	Professional Guidance	Dominant Limb
1	23	89.36	1.803	12-18months	3 to 4	>15	No	Left
2	28	79.54	1.803	>24 months	5 to 6	>15	Professional	Left
3	23	70.1	1.7	>24 months	3 to 4	>15	No	Right
4	27	89.09	1.905	>24 months	5 to 6	>15	No	Right
5	25	70	1.75	>24 months	7	>15	Professional	Right
6	28	81	1.8	>24 months	5 to 6	>15	No	Right

CHAPTER 3

RESULTS

The running related injury history by case can be viewed in Table 2. The answers to select questions related to shoe selection process by case can be viewed in Table 3. Table 4 provides a description of each habitual footwear by case. Results of perceived disability and foot characteristics, including foot type and dorsiflexion scores can be viewed in Table 5.

Means and standard deviations of the frontal plane kinematics can be seen in Table 6. Means and standard deviations of the sagittal plane kinematics can be seen in Table 7. Means and standard deviations of the kinetic data per case can be seen in Table 8.

Table 2

Running Related Injury History

ID	Injured in last year?	How many injuries?	Seek professional for care/guidance?	Injured body part?	Affected Limb?	Same body part injured more than once?
1	Yes	3	Did not seek professional help	Foot/Toe	Left	Yes
2	Yes	1	Sought Physical Therapist and Running Coach	Hip/Pubis	Left and Right	No, only one injury
3	Yes	1	Did not seek professional help	Shank/Achilles Tendon	Left	No, only one injury
4	Yes	1	Physical Therapist	Shank/Achilles Tendon	Right	Yes
5	Yes	2	Physical Therapist	Knee	Left	No, only one injury
6	Yes	1	Did not seek professional help	Foot/Toe	Left	No, only one injury

Table 3

Shoe Selection Process

ID	Use of specific shoes for running?	Selection of shoe?	Foot type known?	How did they discover their foot type?	What is your foot type?	Consider their foot type in the choice of shoes?	Wears foot orthoses?	Influence/ guidance of the choice of shoes?
1	Yes	Characteristics	Yes	Professional Evaluation	Pronated	No	No	Internet
2	Yes	Comfort	No	Do not Know	Do not Know	No	No	No one
3	Yes	Price	No	Do not Know	Do not Know	No	No	No one
4	Yes	Comfort	No	Do not Know	Do not Know	No	No	Internet
5	Yes	Characteristics	No	Do not Know	Do not Know	Yes	No	Fellow Runners
6	Yes	Characteristics	Yes	Professional Evaluation	Pronated	Yes	No	No one

Table 4

Shoe Descriptions

ID	Shoe Selection	Type	Pronation	Heel-Toe Drop
1	Saucony Endorphin Speed 2	Maximalist, Cushioned	Neutral arch support, Neutral pronation and Supination	8mm
2	Adidas Solarglide	Maximalist, Cushioned	Neutral arch support, Neutral pronation and Supination	10mm
3	Sketchers Hyperburst	Maximalist, Cushioned	Neutral arch support, Neutral pronation and Supination	6mm
4	Puma Deviate Nitro	Maximalist, Cushioned	Neutral arch support, Neutral pronation and Supination	10mm
5	Hoka Clifton 8	Maximalist, Cushioned	Neutral arch support, Neutral pronation and Supination	5mm
6	Brooks Ghost 14	Maximalist, Cushioned	Neutral arch support, Neutral pronation and Supination	12mm

Table 5

Foot Characteristics and Perceived Disability

ID	Foot Posture Index		Dorsiflexion Range of Motion		Disablement in the Physically Active Scale Short Form-8	
	FPI_L	FPI_R	DFROM_L	DFROM_R	Physical Summary	Quality of Life Score
1	3 (N)	4 (N)	12	9.5	8	0
2	1.5 (N)	2.5 (N)	10.5	11.5	8	0
3	10 (HP)	10 (HP)	2.7	7.8	0	0
4	1.5 (N)	0 (N)	11	9	3	1
5	5 (N)	5 (N)	9.5	9	3	2
6	3.5 (N)	6.5 (P)	14.5	13	0	0

Note. N indicates Neutral; P indicates Pronated; HP indicates Highly Pronated

Table 6

Frontal Plane Ankle Kinematics

Variables		Participant	Left Limb		Right Limb	
			Mean	STD	Mean	STD
Angle at Initial Contact (deg)		1	5.67	1.58	2.78	1.50
		2	3.70	1.21	3.64	0.59
		3	9.27	0.36	8.85	0.95
		4	1.59	1.50	4.50	0.97
		5	3.56	0.87	6.10	2.21
		6	4.35	1.14	6.99	2.10
Absorption Phase	Eversion (deg)	1	-2.29	1.06	-4.19	0.90
		2	-3.96	0.39	-3.79	0.71
		3	-0.68	1.14	1.29	1.01
		4	-7.92	0.96	-4.19	1.39
		5	-2.51	1.27	-3.23	1.15
		6	-5.45	1.17	-2.05	1.25
	Inversion (deg)	1	5.73	1.63	3.89	1.00
		2	3.82	1.34	3.80	0.54
		3	9.36	0.49	9.55	1.28
		4	1.88	1.26	5.15	1.29
		5	3.80	0.68	6.10	2.21
		6	4.68	0.59	7.26	1.91
Propulsion Phase	Eversion (deg)	1	0.54	1.75	-3.43	0.81
		2	-1.80	0.72	-2.42	0.89
		3	0.79	1.19	2.68	0.21
		4	-4.73	3.19	-3.70	1.00
		5	-1.62	1.32	-2.48	1.41
		6	-3.75	0.60	-0.97	1.27
	Inversion (deg)	1	3.48	0.77	3.11	0.69
		2	1.16	0.48	2.28	0.87
		3	5.59	0.28	7.46	1.18
		4	1.39	1.29	2.32	1.08
		5	7.52	1.82	5.57	0.58
		6	2.46	0.73	4.03	0.77
Angle at Toe Off (deg)		1	3.34	0.72	2.52	0.54
		2	0.70	0.80	0.96	1.59
		3	5.06	0.58	5.71	1.14
		4	-0.82	1.61	-1.30	1.51
		5	7.13	1.38	5.12	0.75
		6	-0.30	1.74	2.06	1.23

Table 7

Sagittal Plane Ankle Kinematics

Variables		Participant	Left Limb Mean	Left Limb STD	Right Limb Mean	Right Limb STD
Angle at Initial Contact (deg)		1	1.26	1.42	1.67	1.11
		2	0.85	1.59	10.61	0.66
		3	-10.40	0.74	-6.85	0.90
		4	6.56	1.85	3.29	2.82
		5	3.55	2.16	1.17	2.29
		6	11.71	0.89	8.77	2.06
Absorption Phase	Plantarflexion (deg)	1	-0.63	1.36	-0.11	1.04
		2	-1.00	1.63	1.17	2.35
		3	-10.94	0.60	-7.13	0.70
		4	1.34	1.73	0.60	2.71
		5	2.99	1.74	0.68	1.72
		6	4.43	1.17	1.93	1.53
	Dorsiflexion (deg)	1	18.04	0.96	18.51	0.54
		2	19.49	0.73	23.97	0.57
		3	17.12	1.26	17.99	0.48
		4	21.12	2.01	20.07	1.12
		5	18.62	1.43	19.29	0.42
		6	26.61	1.61	23.44	1.58
Propulsion Phase	Plantarflexion (deg)	1	-21.95	1.99	-24.37	1.42
		2	-23.23	1.47	-26.04	2.32
		3	-28.62	1.77	-23.06	1.26
		4	-32.44	2.58	-30.28	2.48
		5	-27.24	2.93	-23.87	0.96
		6	-16.12	2.86	-21.85	1.29
	Dorsiflexion (deg)	1	19.83	1.31	20.36	0.98
		2	20.84	0.94	24.90	1.07
		3	18.46	1.03	18.56	0.18
		4	23.01	2.31	22.53	1.18
		5	19.20	0.91	19.66	0.23
		6	28.72	1.43	24.00	2.00
Angle at Toe Off (deg)		1	-21.95	1.99	-24.23	1.26
		2	-23.17	1.39	-26.04	2.32
		3	-28.60	1.76	-23.06	1.26
		4	-32.26	2.60	-30.22	2.41
		5	-26.82	2.38	-23.75	0.81
		6	-16.12	2.86	-21.85	1.29

Table 8

Maximum Running Ground Reaction Forces

Variables		Participant	Left Limb Mean	Left Limb STD	Right Limb Mean	Right Limb STD
Vertical (N/kg)		1	25.52	0.47	26.31	0.39
		2	28.02	0.61	27.62	0.41
		3	32.24	0.63	30.67	0.90
		4	24.04	0.50	25.40	0.31
		5	29.84	0.78	30.29	0.59
		6	26.43	0.58	30.39	1.41
Anteroposterior	Propulsion (N/kg)	1	4.05	0.21	4.23	0.30
		2	3.88	0.29	3.63	0.21
		3	4.33	0.21	3.49	0.57
		4	4.12	0.19	4.77	0.41
		5	4.07	0.37	4.27	0.07
		6	3.83	0.41	4.52	0.39
	Braking (N/kg)	1	-2.97	0.29	-2.78	0.29
		2	-4.00	0.45	-5.43	0.56
		3	-2.38	0.88	-1.77	0.83
		4	-2.85	0.34	-3.11	0.41
		5	-2.29	0.56	-2.26	0.44
		6	-4.61	0.74	-5.26	0.35
Mediolateral	Medial (N/kg)	1	0.26	0.09	0.09	0.03
		2	0.15	0.10	0.41	0.20
		3	0.43	0.24	0.33	0.09
		4	0.40	0.21	0.27	0.27
		5	0.81	0.16	0.53	0.24
		6	0.69	0.27	0.02	0.01
	Lateral (N/kg)	1	-1.28	0.53	-1.64	0.36
		2	-1.11	0.34	-1.04	0.22
		3	-1.20	0.25	-1.10	0.21
		4	-0.89	0.31	-0.88	0.39
		5	-0.53	0.11	-0.60	0.18
		6	-0.17	0.05	-2.37	0.51

CHAPTER 4

DISCUSSION

Achilles/Ankle Injuries

Case 3 and Case 4 had shank/Achilles injuries and both injured limbs had clinically significant less dorsiflexion range of motion compared to the unaffected limb. This was not observed in any of the other cases whose injuries were in the foot/toe, hip/pubis, and the knee. Clinical significance is defined as a limb difference greater than 1.9 cm, which is comparable to a 4.7^{o} change in limb difference (Powden et al, 2015) The normative values for DFROM is 12 cm (Hoch and McKeon, 2011).

Initial Contact

When the foot first touches the ground, it becomes unlocked and has more freedom of motion to adapt to various terrains. It then locks to become rigid that helps propel the leg forward as it leaves the ground. The ankle joint is a synovial articulation between the inferior aspects of the tibia and fibula and the superior surface of the talus. There are no muscles that directly attach to the talus so no pure plantar flexors or dorsiflexors are present in the foot (Riegger CL., 1988). The ankle is often described as a pure plantar flexor and dorsiflexor as it is uniaxial although it is oblique. This factor results in pronation and supination. As the foot dorsiflexes while in a fixed position causes internal rotation of the tibia and pronation of the foot(Inman V.T., 1976). The subtalar joint is a gliding articulation that is inferior to the talus and superior to the calcaneus. It is closely associated with the talocalcaneonavicular joint, which is a complex of synovial joints between the talus superiorly and inferior to the navicular, calcaneus, and the spring ligament. A major portion of inversion and eversion happen at this articulation (Grant A, 1983).

The expectation at initial contact is that if an individual who heel strikes or strikes at midfoot they would be in a neutral or slight dorsiflexed position at the prescribed running speed. All cases were in a neutral or slight dorsiflexion position. Typically, long-distance runners initially contact the ground heel first or with the foot flat, whereas sprinters commonly land on the midfoot (Mann et al, 1981). In a study of 753 distance runners, 80% were rearfoot strikers and the others midfoot. Faster runners were often midfoot strikers (Burdett R.G., 1982). At the time of heel strike, rapid dorsiflexion at the ankle joint, along with hip and knee flexion, helps absorb the force of impact (Mann et al, 1981). Case 3 was the only one in a plantarflexed position. This is comparable to sprinters that move at higher speeds as the tibial position allows the ankle to be in a more neutral or slightly dorsiflexed position. Sprinters are typically moving at speeds greater than 4 m/s and Case 3 was between the target velocity of 3.5 m/s-4 m/s.

Absorption

The absorption phase should see low plantarflexion but mostly peak dorsiflexion (Novacheck T.F., 1998). This was observed in all subjects except Case 3. He maintains a plantarflexed position and had the lowest dorsiflexion of the group. This is still comparable to a sprinter as maximum dorsiflexion during the stance phase is typically lower in sprinters than runners as the plantarflexed position at initial contact and the shorter duration of the absorption period. Inversion occurs in the subtalar joint when the calcaneus is brought toward the midline, and eversion of the hindfoot occurs throughout the first 15% of the stance phase, at which time inversion begins. This motion at the subtalar joint is passed through the talus and calcaneus to the navicular and cuboid bones (Chan and Rudins, 1994). This was observed in all cases expect Case 3.

Propulsion

Vertical forces approach 275% of body weight during running (Mann et al., 1981). Localized forces may be as high as 13 times body weight at the ankle and 10 times at the Achilles tendon (Burdett R.G., 1982). During running, the impact peak is smaller than the second peak, which is associated with propulsion (Cavanagh et al., 1982), because more force is generated with propulsion than with impact. With midfoot or forefoot strikers, the initial impact peak generally flattens out and dissipates (Czerniecki J.M., 1988). There should also be a transition from a deep dorsiflexion to a high peak of plantarflexion. All cases met their wide transition from dorsiflexion to plantarflexion. Case 3 had the lowest transition as they peaked in dorsiflexion at 18.46 deg. Everyone else hit the normal range of 20-25 degrees. Case 3 did not hit 20 degrees of dorsiflexion in any of the phases of contact.

Foot Pronation

Pronation is the combination of dorsiflexion, eversion and foot abduction. What is expected of an individual who is highly pronated to have greater peak foot eversion compared to other foot types, especially if the subject is in a shoe that does not limit their eversion such as a motion control or a stability specific shoe. There is also greater rearfoot eversion as there is an increase in FPI score (Chuter V.H., 2010). Case 3 was the only individual who was highly pronated, and eversion was not observed during any phase of gait. At initial contact the rearfoot is typically inverted and pronation occurs as the limb is loaded during the absorption phase and have peak eversion. Case 3 maintained a level of foot inversion throughout each phase of contact, especially in the previously injured left limb. The lack of eversion is likely due to the lack of peak foot dorsiflexion. They did not get into the foot dorsiflexion that was expected to make the full foot progression or transition. They are not able to get into the peak eversion that would be typically seen in pronated or neutral runners (Novacheck, 1997).

Observations

The Achilles' tendon and its insertion are frequent sites of chronic injury in athletes. Pain along the course of the tendon is the most frequent presenting complaint. The Achilles' tendon is one of the anatomic structures that stretches during the 1st half of stance phase and recoils later in a spring-like fashion. It stores energy as it is stretched and efficiently returns 90% at the time of push off (Cavanagh P.R., 1982). If initial contact is on the forefoot, the eccentric function of the gastrosoleus: Achilles' tendon complex is exaggerated as the heel is lowered to the ground. The gastrosoleus generates large ankle plantar flexor moments during running compared to those generated during walking. As mentioned, because there are few other structures involved, peak Achilles' tendon forces have been estimated to be in the range of 6±8 times body weight (Cavanagh P.R., 1982). Peak forces do not occur at initial contact, but in midstance. They are generated by the powerful contraction of the gastrosoleus not by the shock of initial contact with the ground. These injuries are due to the active muscle forces of midstance not to the passive impact forces at the time of initial contact. Shoe wear and the type of running surface are much less important factors in the genesis of this type of injury than is commonly believed. Shoe wear may play a role in decreasing locally increased stress if you are running on an uneven surface or if you are a hyper pronator. Again, if the shoe can control the position of the hindfoot, the localized stresses both along the medial aspect of the Achilles' tendon and further up the kinetic chain may be decreased.

As Case 3 has the lowest dorsiflexion, it is expected that they would have higher vertical ground reaction force. It was observed that Case 3 had the highest N/Kg vertical ground reaction force out of all the cases. They also had low absorption forces. To confirm that this was not a cause due to different anthropometrics, Case 3's data was compared to Case 5 as they were very similar to height, weight, shoe type and heel-to-toe drop. Case 5 had a lower heel to toe drop so it is expected that there is a greater peak vertical force. Case 3 and Case 5 did not have similar foot patterns. Case 3 is the only one with a large dorsiflexion asymmetry and his right, unaffected limb had scores that were closer to the rest of the group than his injured left limb. Case 3 is the only one that is highly pronated, and they are the only one that is not in their recommended footwear for their foot type. Based on industry recommendations they should be in footwear that is motion controlled or provides stability. Case 3 wore a neutral, maximalist cushioned shoe that is similar to the rest of the cases.

This study had several limitations. Participants were running in a controlled lab setting with a known intention to land in a force platform along their path. A convenience sample was used of local runners with a minimum of 10+ miles a week and a history or running related injury. This led to a small sample of male distance runners with various weekly training loads and experience. The habitual shoes, although similar, still had varying features. Previous running-related injuries also varied and minimal details were collected on the individual restrictions each participant experienced following injury and return to running.

CHAPTER 5

CONCLUSION

The two cases that had Achilles/shank injuries also had clinically significant asymmetry (>=2cm) with reduced dorsiflexion range of motion in the affected limb. Other injuries did not fit this pattern. Case 3 was the only one with a Highly Pronated Foot Type. They were the only participant with footwear not recommended for foot type as well as the only participant with plantarflexion at initial contact. During running, pronounced forces—the vertical force, fore and aft shear, medial and lateral shear, and torque— develop between the foot and the ground (Root et al., 1977). Case 3 lacked dorsiflexion at absorption and lacked appropriate foot progression into eversion. As a result that also had the highest vertical ground reaction force. All differences were greater in the injury-affected left limb and the right limb were like the other cases in the right limb. Injury history may affect long-term dorsiflexion range of motion if not rectified and have more influence on biomechanics than foot type. Case 4 had similar injuries to Case 3, but he sought care and had close to normal dorsiflexion range of motion.

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APPENDIX A

EXTENDED INTRODUCTION

Purpose

The purpose of this study was to describe footwear selection, foot type, and running biomechanics in previously injured male distance runners.

Independent Variables

1. Phases of Gait (4)
    a. Initial Contact
    b. Absorption/Braking
    c. Propulsion
    d. Toe Off

Dependent Variables

1. Kinematics - degrees
    a. Max Inversion
    b. Max Eversion
    c. Max Dorsiflexion
    d. Max Plantarflexion
2. Kinetics – N/kg
    a. Max Vertical GRF
    b. Max & Min A/P GRF
    c. Max & Min M/L GRF

Limitations

1. Controlled running in lab setting.

2. A convenience sample was used.
3. Habitual shoes have varying characteristics.
4. Previous injuries varied

Delimitations

1. Age 18-30
2. Physically Active: RUns at least 10 miles a week with no current injuries preventing them from doing so.
3. No neurological conditions.
4. No use of orthotics.

Assumptions

1. FPI had minimal tester error and no participant bias.
2. Participants gave maximum effort on WBLT
3. Participants were as truthful as possible in their answers when completing the questionnaires.

APPENDIX B

REVIEW OF LITERATURE

Over the past century, there have been drastic changes in shoe designs where what we considered dress shoes in today's age were used as athletic shoes. More modern shoes are now more technical and have much more engineering involved and contain descriptions as "lightweight," "support," and "cushioning." There has been research looking into the epidemiology of running injuries over the past 4 decades and a few suggestions were the changes in running population, change in definition of running injury, and sport shoes. There is limited research about shoes and their relationship with foot type although there are several shoes on the market catered to different foot types. Each foot type outside from the neutral stance is considered an abnormality and there is a belief to be an increased risk of injury. The purpose of this literature review is to investigate the different research of the different articles looking into the epidemiology of running injuries, what influences them and how footwear and foot type play a role in them.

Running-Related Injuries

A meta-analysis was conducted to assess the trend of running-related injuries over the past 40 years and what was found was that there was no trend in either direction. There could be several reasons for this, but what was mentioned was: Changes in running population. Change in definition of injury, sports shoes and sport injuries, sport inserts/ orthotics and sport injuries, hardness of a shoe sole, and perceived comfort.

Running became extremely popular in the 1970s. Regularly active males dominated it. Over time, women would be more included and recreational runners would pour in and become a large majority of the running population. The definition of running injuries also changed how they became reported and altered the reported instances. Technological advances in running shoes and orthotics are meant to aid in foot comfort and decrease injury risk, but even as specialized shoes became more common, there still is no trend even after 1995 (Nigg & Morlock, 1987) that show a decrease in injury.

There are intrinsic and extrinsic factors that are believed to predict running injuries. The extrinsic factors were weekly mileage and training, injury history, and training environment. The increase in weekly mileage and training is associated with an increase in risk of running-related injuries (Pollock et al., 1977) . If an athlete has sustained a previous injury, they are more likely to sustain another injury (Rudszki, 1997) . The athlete's acclimation to their training environment does have an inverse relationship to their risk of running-related injuries (Bovens et al., 1989).

The Intrinsic Factors that are believed to predict running injuries are Impact forces and Foot pronation Foot pronation is the simultaneous movement of foot eversion, abduction, and plantarflexion. Excessive total pronation is assumed to relate to overloading medial structures at the ankle joint (posterior tibial tendonitis and plantar fasciitis). Due to the rotation of the tibia, excessive pronation is assumed to be connected to patellar tendonitis and Ilio-Tibial band syndrome. A few researchers (Buchbinder et al., 1979; Busseuil et al., 1998; Clement et al., 1981; Eng & Pierrynowski, 1994; Hintermann et al., 1994; Ilahi & Kohl., 1998; Johnson, 2001; Klingman et al., 1997; Powers et al., 1997; Powers et al., 2002; Tiberio, 1987) have speculated on the relationship between the abnormal kinematics of the rearfoot and PFPS. It has been proposed that movements in the foot and lower leg are linked by tibial rotation, therefore an abnormal foot alignment may alter the mechanics of the patellofemoral joint and result in pain. Epidemiological studies (Newell, 1984; van Mechelen, 1992) have found that the knee is the body part most prone to running injuries. The estimated rate of injury for runners is between 37% and 56% (Cook et al., 1990) and that PFPS dominates among knee ailments. Motion control is a mainstream development in shoe technology that aims to control the movements of the rearfoot during locomotion in sports (Hamill et al., 1992) to reduce injuries stemming from overuse. There appears to be a biomechanical link between the rearfoot and shank movements, which supports the idea that motion control of the foot should be considered in treating PFPS.

Benno M. Nigg (1987) gave three general conclusions about running shoes:

1.) Shoes should be built to reduce impact forces in the first 30ms-50ms of ground contact. Impact forces were assumed to be associated with injuries such as fatigue fractures, tendonitis, and cartilage damage (Clements et al., 1981; Frederick et al., 1981; Nigg et al., 1977; Nigg et al., 1986).

2.) Running shoes should be built to provide mediolateral stability and rearfoot control. Instability is assumed to relate to overuse injuries such as anterior medial compartment syndrome or ilio-tibial band syndrome (Krahl, 1977; Nigg & Leuthl, 1980; Schuster, 1978, (Segesser & Nigg,1980; Subnotnick, 1981).

3.) Shoes should be built to provide guidance to avoid over supination of the foot during the take-off phase. Over supination at takeoff is speculated to be associated with Achilles tendon problems (Cheung et al., 2006; Clements et al., 1981; Stacoff & Kaelin, 1983).

Since then, impact forces from a foot strike have been shown to be unrelated to running injuries (Nigg, & Morlock,1987). Foot pronation was also proven to not be an injury risk (Nielsen et al, 2014). In relation to running shoes and injury, shoe conditions that are more comfortable are associated with a lower movement-related injury frequency than shoe conditions that are less comfortable (Bovens et al., 1989). Shoe conditions that are more comfortable are associated with less oxygen consumption than shoe conditions that are less comfortable (Mundermann et al., 2001).

Foot Posture and Kinematics during Locomotion

In analyzing gait patterns, a neutral gait is when the foot lands on the outside of the heel, then rolls inward to absorb shock and support body weight. In a normal heel-toe gait pattern, pronation at the subtalar joint (STJ) takes place from heel strike to midstance. Foot pronation is defined by the combined 3-dimensional movements of calcaneal eversion, abduction of forefoot and dorsiflexion of the foot. Pronation of the STJ is accompanied by knee flexion and internal tibial rotation. These series of actions play a key role in absorbing the shock when the heel encounters the ground. Also, pronation of the STJ unlocks the midtarsal joints and allows the forefoot to adapt to uneven terrains (Hamill et al., 1992; Klingman et al., 1997; Livingston, Mandigo, 2003; Tiberio, 1987). Shortly after pronation, STJ re-supinates and reaches its neutral position during mid-stance before heel lifting and full knee extension (Tiberio, 1987). Supination of the STJ re-locks the midtarsal joints, which turns the foot into a rigid lever for push-off. This mechanism reduces the stress on the soft tissue of the foot (Livingston, Mandigo, 2003; Stacoff et al., 1989). Supination of the STJ also causes the head of talus to dorsiflex and slide laterally. Because of the unique architecture of the mortise of the talus that has a wider anterior measurement, dorsiflexion of the talus will force the tibia to rotate externally (Hintermann et al.,

1994) between heel-off and end of stance phase. The above sequence of kinematics assumes that the runners land on their heels. However, heel landing is not the only style of running. There are other landing styles such as the mid-foot landing or forefoot landing, which have different lower limb controls and kinematic sequences. One article examined the kinematics of the lower limbs with an altered pattern of landing on the forefoot. Forefoot landing refers to landing on structures other than the calcaneus and most forefoot runners land on the fifth metatarsal (Stacoff et al., 1989). In this situation, the forefoot everts rapidly after it touches the ground. Because of the time lag in the chain of movements, torsion results between the forefoot and rearfoot via the transverse tarsal and tarso-metatarsal joints, thus rearfoot pronation occurs and reaches a peak immediately before the foot pushes off.

It has been suggested that the rearfoot movement at touchdown was much larger in forefoot runners (Stacoff et al., 1989). It is therefore speculated that forefoot runners are at higher risk of overuse injuries because of their larger foot pronation movements (Stacoff et al., 1989). However, there is yet no available literature to support this proposition.

There are two types of deviations when there is excessive movement of the foot where it rolls either inward or outward as the foot makes contact. They are known as overpronation (foot eversion) and under pronation (foot inversion). Overpronation is when your foot lands on the outside of the heel, then rolls inward excessively, transferring the center of pressure to the inner edge of the foot instead of the ball of the foot. The first and second metatarsal do much of the work as the foot pushes off. This is common in individuals with low arches or flat feet. Underpronation is when your foot contacts the outer side of the heel with little or no normal pronation. There is pressure on the smaller toes on the outside of the foot during push off. This can cause a large transmission of shock through the lower leg. This is common in individuals with high or rigid arches.

The Foot Posture Index is a diagnostic clinical tool aimed at quantifying the degree to which a foot can be in a pronated, supinated, or neutral position. Its intention is to be a simple method of scoring various features of a person's foot posture into a single quantifiable result which in turn will give an overall foot posture. It is a six-item weight bearing test that requires the subject to stand in a relaxed, double limb support position. This position has been reported to approximate the position to which the foot functions during a gait cycle. FPI has a fair to moderate association in some parameters of dynamic foot function in both individuals with and without Patellofemoral Pain Syndrome (Barton et al, 2014).

The six criteria that is assessed by the FPI are: Talar Head Palpation, Supra and infra lateral malleolar curvature, calcaneal frontal plane position, prominence in the region of the talonavicular joint, congruence of the medial longitudinal arch, and abduction/adduction of the forefoot on the rearfoot. Each criterion is graded 0 for neutral, a minimum score of -2 for straightforward signs of supination, and +2 for positive signs of pronation. The final FPI score will be a whole number between -12 and +12. Once the FPI had been reduced to its final six-item form the validity was evaluated further. Six item FPI scores were compared with contemporaneous EMT data obtained during quiet standing and during normal walking. The FPI-6 scores predicted 64% of the variation in the static ankle/subtalar position during quiet double limb standing. The same FPI-6 scores predicted 41% of the variance in ankle/subtalar position at midstance.

Relationship with Foot Type and Running Injury

Nielsen et al., conducted a 1-year prospective cohort study investigating if running distance to the first running-related injury varies between foot postures in novice runners wearing neutral shoes (Nielsen et al, 2014). The novice runners are defined as healthy individuals between 18 and 65 years, no lower extremity injuries at least 3 months prior to the start of the study and ran less than 10 kilometers in the previous year. While categorizing them using FPI-6, all participants were given a GPS watch and the same model of neutral running shoes. During a 1-year follow up, there were no significant differences in injury risk among all the foot types compared to a neutral foot posture after 250km of running. In addition, the incidence- rate difference per 1000km of running revealed that pronators had a significantly lower number of injuries than neutral foot types.

When prescribing running shoes based on the subject's foot type in women runners, Ryan et al. (2011) discovered significant main effects ($p<0.001$) for footwear condition in both the neutral and pronated foot types. The motion control shoe reported greater levels of pain in all VAS items. In the neutral foot group, the runners who wore neutral shoes reported greater values of pain while running compared the runners in the stability shoe. In the pronated foot group, runners in the stability shoe reported greater values of pain while running than the neutral shoe.

Three studies investigated the effects of assigning shoes based on the shape of the plantar surface and if it influenced injury risk in Basic Military Training for the Army, Air Force, and the Marine Corp (Cavanach & Lafortune, 1980; Knapik, Brosch, Venuto, et al., 2010; Knapik, Trone, Swedler, et al., 2010). The trainees were split into an experimental group and a control group. The experimental group were assigned motion control, stability, or cushioned shoes for plantar shapes based on low, medium, or high arches. The control group received stability shoes regardless of plantar shape. They were to wear these shoes during Basic Military Training. The multivariate cox regression controlling for other risk factors showed little difference in injury risk between the groups among men or women. This is a complementary to an army study where they tracked their subjects in the same medical surveillance system, calculated injury incidences in an identical manner, and replicated the same randomized design with the control group receiving a single stability shoe and the experimental group receiving a shoe based on plantar shape. The differences had to do with the brands and models of the shoes and the nature of the training environment. These studies evaluated injuries as the outcome measure. Shoe comfort and shoe wear were not evaluated. Only 3 shoes were evaluated in the Air Force study although the Army study evaluated 19 different shoes using similar techniques.

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APPENDIX C

IRB APPROVAL DOCUMENT

GEORGIA SOUTHERN UNIVERSITY
RESEARCH INTEGRITY

Institutional Review Board (IRB)
PO Box 8005 • STATESBORO, GA 30460
Phone: 912-478-5465
Fax: 912-478-0719
IRB@GeorgiaSouthern.edu

To:	Castro-Diaz; Diego Mutchler, Jessica; Wilson, Samuel
From:	Georgia Southern Institutional Review Board
Approval Date:	April 5, 2024
Expiration Date:	March 31, 2025
Subject:	Status of Application for Approval to Utilize Human Subjects in Research Expedited

After a review of the following proposed research project, it appears that (1) the research subjects are at minimal risk, (2) appropriate safeguards are planned, and (3) the research activities involve only procedures which are allowable.

Protocol #:	**H24205**
Title:	**Running Biomechanics Between Footwear and Foot Type in Previously Injured Runners**
Maximum Number of Subjects:	**45**
Purpose of Study:	The purpose of this study is to investigate whether footwear creates the adjustments that are intended for the designated foot type even when runners have experienced previous lower extremity injuries.

Therefore, as authorized in the Federal Policy for the Protection of Human Subjects, I am pleased to notify you that the Institutional Review Board has approved your proposed research **with the understanding that you will abide by the following conditions**:

COVID Safety Precautions Required	Precautions will be taken in accordance with current Georgia Southern policies to reduce the risk of the spread of communicable diseases (including COVID-19). Researchers will monitor the current transmission risk assessment by state and county using the COVID Data Tracker provided by the CDC and increase COVID safety measures as appropriate; follow the COVID safety guidelines of the organization whose facility they are am using to conduct research; and any shared devices or equipment will be sanitized using standard sanitation methods.
Incentives:	No monetary incentives are approved for this protocol.
Special Conditions:	None.

If at the end of this approval period there have been no changes to the research protocol; you may request an extension of the approval period. In the interim, please provide the IRB with any information concerning any significant adverse event, whether or not it is believed to be related to the study, within five working days of the event. In addition, if a change or modification of the approved methodology becomes necessary, you must notify the IRB prior to initiating any such changes or modifications. At that time, an amended application for IRB approval may be submitted. Upon completion of your data collection, you are required to complete a Research Study Termination form to notify the IRB, so your file may be closed.