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Two-Year Injury Incidence and Movement Characteristics Among Division-I Cross-Country Athletes

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ABSTRACT

International Journal of Exercise Science 16(1): 159-171, 2023. While research on running injuries is common, there is a lack of definitive causal relationships between running injuries and gait mechanics. Additionally, there is a paucity of longitudinal research to understand the development of running injuries. The purpose of this study was to assess the incidence of running injuries and investigate movement characteristics as they relate to injury development in Division-I cross-country athletes over a two-year period. Athletes were evaluated at pre- and post-season with three-dimensional kinematic and kinetic gait analyses. A total of 17 female athletes were evaluated, though sample size varied at each time point. Self-reported injury occurrence data was collected via questionnaires and injury reports were obtained from athletic training staff. Sixteen of the athletes reported at least one injury during the study. The percentage of participants self-reporting injury was greater than the percentage of participants who were evaluated and diagnosed by medical staff each year (year one: 67% vs. 33%; year two: 70% vs. 50%). The most common self-reported and medically confirmed injury location was the left foot, with 7 total reports out of 17 participants. Inferential statistics were not feasible due to an inherently limited sample size, thus effect size (Cohen's d_s) was used to assess differences in mechanics between athletes with and without left foot injury. Several variables, including peak ankle plantarflexion, dorsiflexion, and inversion, peak knee abduction, and hip abduction and adduction were associated with moderate-to-large effect sizes (d_s > 0.50). This study demonstrates that injury rates in the literature may be influenced by reporting method. Additionally, this study provides promising information regarding movement characteristics in injured runners and demonstrates the necessity of longitudinal studies of homogenous groups.

KEY WORDS: Biomechanical analysis, overuse running injuries, female NCAA runners, injury reporting

INTRODUCTION

Despite the known health benefits of exercise, runners sustain injuries at alarming rates. Though reporting methods vary, injury incidence rates range from 11% to 85% (8) or 2.5 to 38 injuries per 1000 hours of running. (30) Research has attempted to identify risk factors for running injuries, yet there is little consensus in the literature regarding the cause of running injuries.

(6,8,16) It is also common for runners to consider themselves healthy despite pain and to continue running with pain or injury. (12, 26) This likely relates to the fact that a majority (80%) of running injuries are overuse and develop slowly over time. (14, 26) The lack of consistency in who is reporting injury and the varied definition of injury leads to further complication of reported injury rates. (21)

Although causal relationships have not been established, research has identified various biomechanical variables which may be associated with injury in competitive and recreational runners. These variables include a greater rate of loading of the vertical ground reaction force (3, 9, 10, 16, 19, 34, 35) and changes in joint motion of the lower extremity. (4–7, 17, 18, 23, 24, 33) However, the relationship between these variables and compensation (i.e., changes in gait) due to injury has not been investigated adequately using prospective and longitudinal research designs. Additionally, understanding this relationship is complicated by the nature and extent of injury, population, and study type. Taken together, all these factors likely contribute to the lack of consensus in the literature regarding the relationship between biomechanical variables and running injuries.

A limited number of prospective comparisons of injured and uninjured collegiate runners exists. (5, 13) The main focus of these studies was to analyze mechanics in collegiate runners at the beginning of a season, then compare any differences between runners who became injured versus those who remained healthy. One such study identified higher peak ankle eversion angles, lower eversion range of motion, and lower peak eversion velocity in cross country runners who later became injured. (13) Another study identified greater peak ankle eversion velocity and greater external knee adduction moment in cross country athletes who later sustained an injury. (5) Both studies collected gait data prior to the start of the season but did not collect post-season data. These results provide evidence that a prospective research design may have value in predicting injuries. However, without pre- and post-injury gait data, it is not known if the injuries occurred as a result of mechanics, or if the mechanics were compensatory. Thus, there is still a need for longitudinal data to better understand how a runner may (or may not) change gait patterns in response to an injury.

The criteria for what constitute an overuse injury may differ among athletes, coaches, medical staff, and researchers. Some individuals may define an overuse injury as pain occurring at defined times, pain lasting for specific durations, pain that leads to a decrease in activity, or pain resulting in a medical diagnosis of a specific injury. (21, 29) Furthermore, self-reported injury rates may differ from medically-reported injury rates as runners may not seek medical care for pain they believe they can treat themselves. (11, 26) Previous research has reported that up to 30% of recreational runners do not seek medical care for pain and some individuals continue to run despite pain. (26) Collegiate runners have greater access to sports medicine staff than recreational runners. Visiting a medical professional for injuries may be more convenient for collegiate athletes than the general population, which may lead to more accurate recording of injury rates. However, as the definition of pain will vary by individual, athletes may simply request modalities, such as ice, to treat pain without reporting to their athletic trainer for evaluation, leading to under-reporting of injuries.

There is a need for the collection of longitudinal data including information about training, injury reporting, and biomechanical variables to determine which factors contribute to the development of running injuries and how injury influences mechanics. The primary purpose of this study was to assess differences in injury reporting between self-reported questionnaires and medically-diagnosed injuries. A secondary analysis was conducted to investigate movement characteristics as they relate to injury development in Division-I cross-country athletes. Using pre- and post-season gait analyses, we evaluated movement characteristics of injured and uninjured athletes. We hypothesized that injured athletes would exhibit differences in mechanics that have been previously identified as relating to injury. These include increased frontal plane motion at the ankle and knee, and limited sagittal plane motion throughout the lower extremity (1, 6). We also expected to see differences in injury rates based on reporting method, as athletes may not have sought medical care for all instances of pain.

METHODS

Participants

The study was approved by the Institutional Review Board at the University of Nevada, Las Vegas (protocol #788354). The study met ethical standards instituted by the International Journal of Exercise Science. (20) Data collection occurred at the University of Nevada, Las Vegas in 2016 (year one) and 2017 (year two) at the beginning and end of the fall semesters. Athletes did not complete the gait analysis if they were not cleared to run, either by UNLV Athletics or the sports medicine staff. In year one, nine female NCAA Division I cross-country athletes were recruited for pre-season data collection before the start of the regular season. At the end of the season, two athletes were not cleared to run due to injury, and one athlete left the team. Thus, six athletes returned for post-season collection. Two additional athletes who did not have clearance at pre-season reported for post-season collection only. For year two, nine athletes were recruited at pre-season data collection, and four of these athletes returned for post-season collection. Of those who did not return, one left the team, and four were not cleared to run due to injury. One additional athlete who was not cleared at pre-season reported for post-season collection only.

Overall, there were six athletes with both pre- and post- season gait data in year one and only three athletes with pre- and post-season data in year two. Two athletes were present for all four data collections throughout both years. Table 1 provides information regarding athlete participation and injury status for each year. As the sample size was limited by the team roster and further influenced by injury occurrence, an a priori sample size power analysis was not performed.

Protocol

Athletes first reported to the Sports Injury Research Center at UNLV the week in which they were required to report for official training. Written informed consent was obtained from all participants before data collection. Self-report injury history, including location and duration of pain, and whether the pain influenced training, was collected via an online questionnaire (Qualtrics version 12.17, Provo, UT). A self-selected warm up was completed before performing running trials. To best replicate typical conditions, both the warm-up and the gait collection were performed in the same shoes worn during practice and training runs. As Division-I athletes, participants wore their team-provided shoes for the majority of training and all competitions throughout the season. Twenty-eight retro-reflective markers were attached to the hips, legs, and feet. Participants ran along a 15-meter runway while kinetic and kinematic data were collected bilaterally with a ten-camera three-dimensional motion capture system (200 Hz, Vicon, Oxford, UK) and three embedded force platforms (1000 Hz, AMTI, Watertown, MA).

Participants were asked to run at a 5k training pace, which was monitored using photoelectric timing gates (Lafayette Instruments, Lafayette, IN) placed 4 meters apart surrounding the force platforms. The average of 10 preliminary trials was utilized to determine running velocity, and acceptable trials were those which occurred within ± 5% of the average velocity. Participants ran while at least five successful trials were collected for each limb. A successful trial was defined as full contact of the foot on the force platform without targeting. Participants were not made aware of the location of the force platforms, and their starting position was adjusted by a research team member to ensure a natural stride. At the conclusion of the regular season, athletes completed the same procedure, including an informed consent renewal. Athletes who were unable to run post-season due to injury completed the injury questionnaire and anthropometric measurements but not gait measures.

Injury reports were provided by the team's certified athletic trainer at the end of the season. These reports included clinical diagnoses, rehabilitation notes, and whether the injury led to a loss of training. These data were used to calculate the number of clinically-diagnosed injuries that occurred in the off-season and during the regular season. The questionnaire of self-report injury data included questions about the incidence and location of pain, the date of occurrence, treatment method, and whether the pain affected their training. We utilized the grading system developed by Marti et al., (15) to classify injuries as either grade 1 (maintained full activity despite symptoms) or grade 2 (reduced weekly mileage). The injury data were then compared to determine if there were injuries that were reported by both the athlete and the athletic trainer, or only one of the two.

Marker trajectories were labeled and gap-filled (up to 25 frames) in Nexus software (v.2.6, Vicon, Oxford, UK). Kinetic and kinematic data were exported to Visual3D software (v.6, C-Motion, Germantown, MD) to calculate variables of interest. Kinematic and kinetic data were filtered with a low-pass, fourth order, zero-lag Butterworth filter with cutoff frequencies of 10 Hz and 50 Hz, respectively. A Cardan rotational sequence (x-y-z) was utilized to calculate joint angles so that x represented the ML axis, y the AP axis, and z the vertical axis. Values were interpreted according to right-hand rule. Variables of interest included peak instantaneous vertical loading rate (VILR), sagittal ankle angle at heel strike, sagittal hip angle at heel strike, peak sagittal and frontal angles at the ankle and knee, and peak sagittal, frontal, and transverse angles at the hip. These variables were chosen as a result of previous research findings. (1, 6, 32, 33, 35) Stance phase was determined using a threshold of 20 N vertical ground reaction to identify heel strike and toe-off. A custom Matlab code (v. r2016b, MathWorks, Natick, MA) was used to determine peak instantaneous loading rate from exported kinetic data. The vertical ground reaction forces were inspected to determine the presence of an impact peak. Several participants exhibited impact peaks in only a portion of trials. Therefore, to maintain consistency in the calculation, for all trials the peak VILR was determined as the peak value of the first derivative of the vertical ground reaction force in the first 50ms of stance. (29) Peak VILR was expressed in body weight per seconds (BW/s). All variables were calculated bilaterally.

Statistical Analysis

Injury reporting was descriptively analyzed for both years, but gait mechanics were only analyzed for Year 2. As an exploratory study, injury incidence and reporting will be described qualitatively as inferential statistics would not be meaningful for the small population we were assessing. Additionally, due to the limited sample size, inferential statistics were severely under-powered for the analysis of gait mechanics. Therefore, we aimed to identify subgroups of athletes with similar injuries to analyze gait mechanics. Effect size analyses were utilized to investigate these subgroups. These results, specifically for left foot injury and VILR, are also described qualitatively.

In year two, seven athletes reported left foot and lower leg injuries, which were further supported by medical reports. Thus, gait mechanics were compared between athletes with and without these injuries using Cohen's d_s ((Mean 1 – Mean 2)/pooledSD), and were interpreted as small ($d_s = 0.2$), moderate ($d_s = 0.5$), or large ($d_s > 0.8$). (2)

RESULTS

Subject-specific information regarding injury status and data collection participation is listed in Table 1. Injury incidence rates were determined as the number of participants reporting at least one grade 1 or grade 2 injury during the season. In year one, the medically-reported injury incidence rate during the season was 33%, while the self-report injury incidence rate was 67%. In year two, the medically-reported injury incidence rate during the season was 50%, while the self-report injury incidence rate was 70%. Clinical diagnoses of specific injuries and self-report locations of pain from pre- and post-season are provided in Table 2. In year one, only one of the self-reported instances (hamstring tightness) corresponded with a medically-reported injury. In year two, three self-reported injuries corresponded with a medically-reported injury. Reports of "tightness" from the medical staff were investigated further, and it was clarified that these incidences were considered significant enough to report and treat but were not associated with specific injuries. Instead, these were considered as a result of a lack of proper flexibility maintenance or delayed onset muscle soreness.

Table 1. Injury status and data collection participation by participant and year.

	Year 1		Year 2	
	Pre	Post	Pre	Post
S1	x ▨	x ▨		
S2	x ▨	▨		
S3	x	x	x	x
S4	x	x	x	x
S5	x ▨			
S6	x	x		
S7	x ▨	x ▨		
S8	x	▨	x	▨
S9	x	x ▨	x ▨	▨
S10		x	▨	x ▨
S11		x		
S12			x	
S13			x	x
S14			x ▨	▨
S15			x ▨	▨
S16			x ▨	▨
S17				x

Note: "x" denotes participation & gray shading indicates a medically-reported or self-reported grade 1 or grade 2 injury.

Table 2. Clinical injury diagnoses and self-report locations of pain.

Clinical Diagnoses, Year 1	***n***	**Self-Report, Year 1**	***n***
Bilateral Hamstring Tightness	1	Right Upper Leg	5
Bilateral Calf Tightness	1	Right Foot	3
Iliotibial Band Syndrome, Right	1	Left Upper Leg	1
Knee Injury, Other, Right	1	Left Knee	3
Posterior Tibialis Tendonitis, Right	1	Left Foot	2
Navicular Stress Fracture, Right	1		
Midfoot Inflammation, Left	1		
Year 2	***n***	**Year 2**	***n***
Tibial Stress Fracture, Bilateral	1	Right Upper Leg	1
Lower Leg Injury, Other, Bilateral	1	Right Lower Leg	3
5th Metatarsal Avulsion Fracture, Left	1	Right Foot	1
2nd Metatarsal Stress Fracture, Left	1	Left Upper Leg	2
Navicular Stress Fracture, Left	1	Left Knee	2
Medial Arch Sprain, Left	1	Left Lower Leg	7
Medial Tibial Stress Syndrome, Left	1	Left Foot	7

Seven of the eleven individuals who participated in year two reported either a self-report or medically-reported left foot injury (grade 1 or 2). Due to the high frequency of left foot injuries, this group was investigated further. Of the seven athletes with left foot injuries in year two, none were able to complete both pre- and post-season testing so comparisons between pre- and post-injury mechanics were not possible. However, to begin to elucidate potential movement differences, effect sizes were used to analyze left-limb mechanics in all athletes who reported grade 1 or 2 left foot injuries in year two (n = 7) compared with all athletes who did not (n = 4). The results of this analysis are in Table 3.

Table 3. Left foot injuries, year 2: Injured vs. uninjured mechanics.

	Mean	d_s
Peak VILR (BW)		
Injured	70.98	0.72*
Uninjured	81.60	
Peak Eversion (°)		
Injured	-15.15	0.47
Uninjured	-12.91	
Peak Knee Abduction (°)		
Injured	-3.97	0.16
Uninjured	-4.38	
Peak Hip Adduction (°)		
Injured	10.93	0.82*
Uninjured	13.20	
Peak Hip Internal Rotation (°)		
Injured	10.68	1.54*
Uninjured	6.37	
Hip Rotation Range of Motion (°)		
Injured	9.55	0.72*
Uninjured	7.67	

* *Indicates a moderate or large* d_s

DISCUSSION

All but one of the 17 individuals in this study experienced at least one self-reported grade 1 or grade 2 injury over the course of two years. The yearly incidence rates in this study (33–70%) were within the range of rates provided in the literature (11–85%). (8, 16, 32) Overall, we observed that self-reported injury rates were higher than medically-reported injury rates. Injury reporting inconsistencies may be related to several factors. Athletes may feel more comfortable disclosing instances of pain on a questionnaire, particularly when the questionnaire is for research purposes only. Additionally, because the athletes were reporting instances of pain and not specific injuries, they may have over-reported injuries. We did, however, ask if the pain altered their training, classifying these injuries as grade 2. Over the course of this study, including the off-season, the majority (65%) of self-report instances of grade 2 injuries did not correspond with medical reports. That is, it appears athletes were managing pain and altering their training on their own without seeing sports medicine personnel. Inconsistencies in injury reporting may represent a larger issue, particularly for grade 2 injuries which caused athletes to alter their training. It is possible that reporting inconsistencies, such as those discovered in this study, may influence injury rates in the literature. Indeed, according to commonly-referenced systematic reviews, the method of reporting injuries and the definition of injury is not consistent among investigations. (8, 21) The results of the current study demonstrate that the method of reporting injuries should be a consideration when analyzing injury rates in the literature.

Along with variance in reporting methods and definition of injury, injury rates may also be influenced by the population investigated. Several studies have noted that weekly training mileage (8, 16, 24) and level of experience (24, 30) may increase injury risk. In the current study, all participants were on the same training schedule throughout the season. The team's mileage did change throughout the season, which may account for increased tissue load, but would not directly explain why some athletes experienced specific injuries while others did not. We did not account for any activities outside of cross-country, which might have influenced tissue load. During both years, there were more self-reported and medically-reported injuries at post-season than at pre-season. This may be due to an increase in training mileage and intensity associated with the competitive season and mandatory practices.

Additionally, participants' experience with this level of training may further influence injury rates. (24) The injury incidence rate for athletes with at least two years' experience (67% in year one and 50% in year two) was less than athletes in their first or second year (100% in year one and 88% in year two). More experienced runners may be better able to identify their injury threshold, particularly when transitioning to a Division-1 level sport. Experience with training loads expected at a more elite level may lead to lower injury occurrences in the third- and fourth-year athletes.

A secondary aim of this study was to evaluate movement characteristics of injured and uninjured athletes. Although inferential statistics were not feasible, effect size analyses demonstrated moderate to large effects. Despite the limitations in sample size, these moderate to large effect sizes may represent potential differences that could be clinically meaningful. (27) The reported injury types varied among athletes in this study. We would not expect that movement alterations resulting from a foot injury would be the same as movement alterations resulting from a hip injury. Thus, combining all injured participants, regardless of injury location or type, may not accurately represent the biomechanical changes that may occur as a result of injury. This demonstrates the complexity and individualization of running injuries, even in a seemingly homogenous group of participants. Therefore, to conduct a thorough biomechanical analysis, we focused on specific injuries that were commonly reported.

Seven athletes experienced injuries to the left foot during year two. Three of these injuries were diagnosed by the team athletic trainer and included medial arch sprain, navicular stress fracture, and fifth metatarsal avulsion fracture. The remaining four were classified as either grade 1 or grade 2 self-reported foot injuries. We observed that the athletes suffering from a foot injury exhibited greater ankle eversion and hip rotation, and limited hip adduction. These differences were supported with moderate-to-large effect sizes. Previous research suggests that increased hip internal rotation may be associated with patellofemoral pain and tibial stress fractures. (19)

Indeed, seven athletes also experienced lower leg injuries, including two medically-diagnosed cases of medial tibial stress syndrome and one instance of bilateral tibial stress fractures.
Most of the reported foot injuries were self-reported and, therefore, did not have a medical diagnosis to confirm a specific injury or determine exact location. However, during the study there were two incidences of navicular stress fracture, thus further inspection of these participants' data was performed. At pre-season, both athletes exhibited several measured variables of gait mechanics that were beyond one standard deviation from the group mean. These included a greater peak instantaneous loading rate (group mean = 71.1 ± 22.5 BW/s), greater peak ankle dorsiflexion (group mean = 113.9 ± 2.3°), greater peak hip extension (group mean = 11.6 ± 7.1°), greater peak hip adduction (group mean = 0.9 ± 2.79°), and lesser hip flexion angle at heel strike (group mean = 27.7 ± 7.1°). By the post-season data collection, however, most variables were within the group norm. Importantly, these changes occurred with a decrease in symptoms reported, which further highlights the relationship between injury occurrence and mechanics.

Research regarding biomechanical changes after a navicular stress fracture is scarce, but a recent study (1) demonstrated that foot kinematics differ in runners who had sustained a navicular stress fracture compared to healthy runners. Specifically, runners who had a history of navicular stress fractures exhibited less plantar flexion, greater rearfoot eversion excursion, greater rearfoot eversion velocity, and less forefoot abduction excursion than runners without a history of navicular stress fracture. (1) Although research has yet to examine changes occurring at proximal joints in individuals with navicular stress fractures, there is support that altered hip mechanics are associated with distal injuries. (6) In the current data set of athletes with navicular stress fractures, the observed deviations were more prominent on the uninjured limb, indicating that the athlete may have been compensating for the injury. While some movement asymmetry is present in healthy gait, an excess may increase risk of injury. (34, 35)

In addition to differences associated with left foot injuries, we also noted differences in kinetics among athletes. Though vertical instantaneous loading rate did not differ between injured and uninjured athletes, the vertical ground reaction force (vGRF) profile was of interest among several athletes. We observed that several athletes who suffered left foot injuries in year 2 presented with inconsistent and highly variable vGRF profiles in the left limb. Data from pre-season collection included three athletes with variable and/or inconsistent vGRF profiles (Figure 1). Of these three athletes, two experienced left foot injuries during the season and one athlete left the team for reasons unknown to the research team. The two injured athletes did not participate in post-season collection, as they were both prescribed protective walking boots. One athlete sustained a stress fracture of the second metatarsal, while the other experienced an avulsion fracture of the fifth metatarsal. The athlete who sustained a stress fracture of the second metatarsal exhibited a vGRF profile with a consistent impact transient but appeared to have additional peaks occurring immediately after (Figure 1a). This athlete participated in data collection in year one before sustaining the stress fracture, and the kinetic data demonstrated a more typical vGRF profile. However, the athlete was treated by the athletic trainer for left foot injuries between year one and year two. Therefore, it is possible that the atypical vGRF in pre-season year two was influenced by the injuries sustained between seasons and may have predisposed the athlete to the metatarsal stress fracture. The athlete who experienced a fifth metatarsal avulsion fracture did not exhibit a clear impact transient but demonstrated inconsistent vGRF profiles, particularly during the loading response, between trials (Figure 1c). This athlete was not on the team during year one, so pre-injury data were not available for comparison. Additional data points, such as those collected as part of a longitudinal study, would be useful to determine the influence of impact kinetics in the development and progression of running injuries. Although assessing foot strike pattern and impact mechanics was not an aim of the current study, the potential interactions among impact kinetics, gait mechanics, and running injuries should be considered.

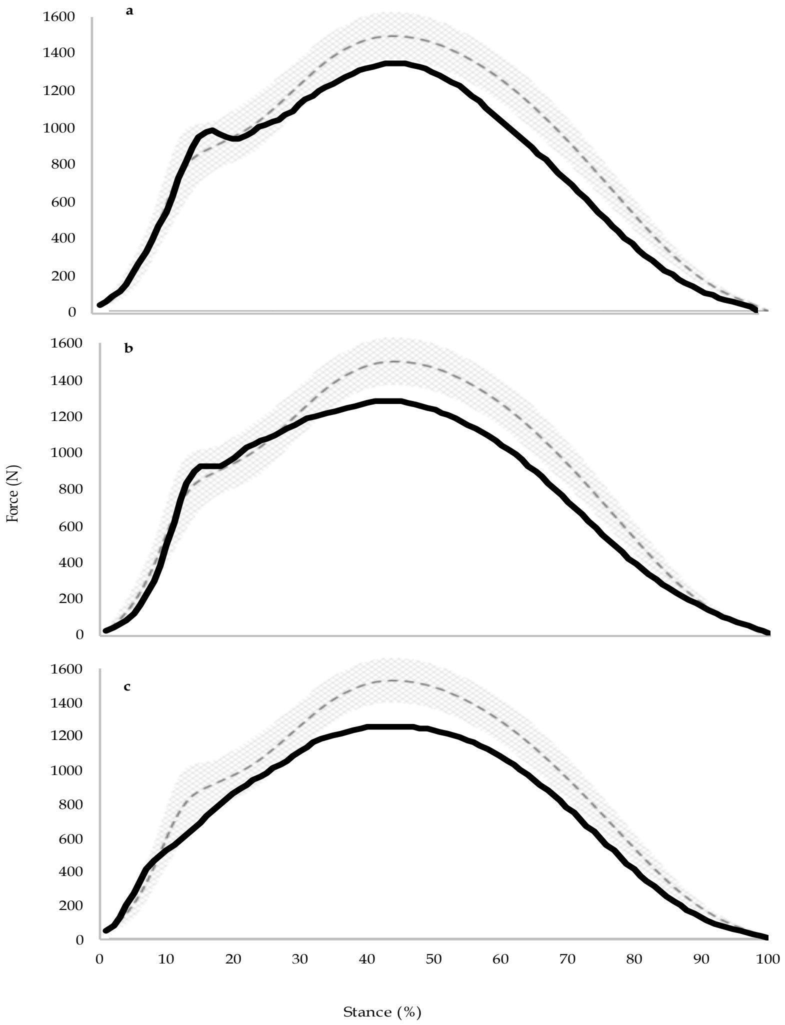

Figure 1. Ensemble vertical ground reaction force versus time curves of three athletes (a-c) who sustained foot injuries during Year 2. The dotted line and shaded region represent the group mean and standard deviation, respectively. The y-axis represents force in Newtons and the x-axis represents time normalized to stance phase. Each line represents one representative trial collected while running at a preferred pace.

Within the literature, some evidence suggests that force parameters, particularly vertical loading rate, may be influential in the development of overuse running injuries such as tibial stress fractures. (32, 33) A recent systematic review (32) confirmed a potential relationship between loading rate and stress fracture incidence, but not other running-related injuries or other force parameters, including impact peak or active peak. The authors surmise that different injury types have different etiologies, and force parameters may be more influential for the development of bony injuries than soft-tissue injuries. (32) Like other research regarding running injuries, further research regarding force parameters and injury incidence should involve well-defined groups, clear injury definitions, and a longitudinal approach.

The current study provides evidence that injury rates reported in the literature may be influenced by reporting methods, as the self-reported injury rate was greater than the medically-reported injury rate. This information is important for researchers and clinicians who rely on injury reporting methods to differentiate and study the effects of running injuries. Additionally, it was observed that training load and intensity, especially combined with experience at these loads, may influence injury risk. Although it has been previously hypothesized, our data also confirm the complicated and individualized nature of movement patterns that may contribute to or result from injuries. Despite the homogenous group of highly competitive female runners, injury mechanics were not able to be observed across all injured runners. This may be due to a variety of injuries observed, the individual definition of injury, or the individual response to injury. This elucidates the difficulty of assigning causes to running injuries and highlights the importance of future large-scale studies. These studies must include clear injury definitions and reporting criteria and most importantly, must focus on movement mechanics in a large group of runners with a given injury.

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