Session 15: Sports Injuries

Co-Moderators: Joseph Hamill, PhD (University of Massachusetts) and Robert Turner, PT, DPT (HSS)

1:30PM *15-1:* Arnold, John, et al. Development and evaluation of the Running Shoe Comfort Assessment Tool (RUN-CAT)

1:40PM *15-2:* Becker, James, et al. Metatarsal Loading In Runners Who Habitually Use Rearfoot or Mid/Forefoot Strikes

1:50PM *15-3:* Bruening, Dustin A., et al. Foot Mechanics in Drop Landings

2:00PM *15-4:* Casillas, Christopher. & Becker, James. Relationship Between Arch Height and Metatarsal Loading in Runners

2:10PM *15-5:* Deeble, John, et al. Mechanical analysis of barefoot and shod treadmill running using a smartphone application

2:20PM *15-6:* Henderson, Adrienne, et al. Midfoot Angle Changes During Running After an 8-Week Intervention Program

2:30PM *15-7:* Houston, Megan, et al. Association Between Concussion and Ankle Sprain History in Collegiate Athletes

2:40PM *15-8:* Johnson, Wayne, et al. The differences in time to stability, foot muscle size and toe flexor strength between gymnast, cheerleaders and non-athletes

2:50PM *15-9:* Wearing, Scott C., et al. Do Achilles Tendon Properties differ with Habitual Foot–strike Running Patterns?

3:00PM *15-10:* Matias, Alessandra B.et al. Foot kinematics of forefoot and rearfoot strikers on recreational runners using the Rizzoli's foot model

3:10PM *15-11:* Veloso, Antonia, et al. Joint moment contributions to forward and upward acceleration of body CG are affected by the foot to ground contact model

Development and evaluation of the Running Shoe Comfort Assessment Tool (RUN-CAT)

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INTRODUCTION: Footwear comfort is an important aspect of running shoe prescription which can improve running performance [1], and reduce the incidence of foot-related complaints or injury [2,3]. Although existing tools are useful for evaluating footwear comfort [4-6], to the authors' knowledge, none have been developed in a systematic fashion that incorporates items deemed meaningful by runners, is reliable and sensitive to differences between footwear models, and has established thresholds for clinically meaningful changes. Therefore, the aim of this study was to develop a new running footwear comfort assessment tool for use in clinical and research settings addressing these requirements.

METHODS: A four-phase development process was used: (i) a survey of 282 runners to identify meaningful items of footwear comfort, (ii) field testing of runners (n=100) who assessed the comfort of three different shoes (ASICS Nimbus 18, Contend 4 and Onitsuka Tiger), (iii) item reduction using bootstrap aggregation and weightings from multiple regressions relative to overall comfort to identify a final set of items, and (iv) a reliability study (n=30) to establish standard error of measurement (SEM), minimal detectable difference (MDD_{90}) and minimal clinically important difference (MCID) for the component items and final comfort index. Ethical approval for this research was granted by the UniSA HREC (ID 35827).

RESULTS: Of 19 initial items relating to different aspects of footwear comfort, after item reduction, four weighted items were included in the final comfort assessment tool: heel cushioning, shoe stability, forefoot cushioning and forefoot flexibility. Reliability of the overall comfort index (within-day and between-day) was excellent (ICC 0.98 and 0.95, respectively) with all four component items also displaying good reliability (ICC >0.70). The SEM of the component items ranged from 4.3-4.9 mm, and subject nominated MCID values ranged from 9.3-9.9 mm on a 100 mm VAS. The SEM and MDD_{90} for the final comfort score was 2.0 and 4.6 points, respectively. The overall comfort index was different between two of the three shoes based on the mean score (Nimbus: 82, Contend: 78, Tiger: 46, $p<0.001 – 0.053$).

DISCUSSION: This study presents the development and initial evaluation of a new assessment tool (RUN-CAT) for evaluating the comfort of running footwear. The RUN-CAT demonstrates excellent reliability, acceptable measurement error and good discriminative ability between footwear models. Comfort perception is presented as a composite score for overall rating using weightings derived from four individual items (heel cushioning, shoe stability, forefoot cushioning and forefoot flexibility). The identification of these comfort items as predictors of overall comfort is largely in agreement with other recent findings [6], although features in this study were more specific to different aspects of the footwear. Based on the data from this study, group changes in running footwear comfort exceeding 11 mm were both larger than error thresholds and deemed to be clinically important to runners. The RUN-CAT will benefit from further evaluation and expanded testing with different cohorts and footwear models to fully elucidate its clinical utility.

SIGNIFICANCE/CLINICAL RELEVANCE: (1-2 sentences): The selection of running footwear may be improved using the RUN-CAT, with group changes greater than 5 points above measurement error and 11 points considered clinically meaningful. Footwear design features may also be altered to optimize comfort which can be measured with the RUN-CAT.

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Metatarsal Loading In Runners Who Habitually Use Rearfoot or Mid/Forefoot Strikes

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INTRODUCTION: There currently is a debate in the scientific community regarding whether switching from a rearfoot strike (RFS) or a mid/forefoot (FFS) pattern might be an appropriate strategy for preventing running injuries [1,2]. Making a recommendation either way requires a detailed understanding of the differences between these foot strike patterns. While numerous studies have compared ground reaction forces, joint kinematics, and joint kinetics [3], to date relatively little is known about how metatarsal loading varies with foot strike pattern. Thus, the purpose of this study was to compare metatarsal loading in habitual RFS and FFS runners during treadmill running. We hypothesized that peak loads applied to the metatarsals would be similar between foot strikes but that loading rates would be higher in runners who use a FFS.

METHODS: 30 habitual RFS runners (sex: 19M, 11F, age: 33.1 ± 12.5 years, weekly mileage: 44.8 ± 17.1 miles) and 20 habitual FFS runners (sex: 14M, 6F, age: 27.3 ± 10.4 years, weekly mileage: 48.9 ± 13.6 miles) participated in this study. All participants were injury free at time of testing. The procedures were approved by the IRB and all participants provided informed consent. In-shoe plantar pressure was collected at 100 Hz while participants ran on a treadmill. Prior to data collection, a pressure insole was trimmed to fit the insole from each participants' shoes and calibrated using step calibration. Participants wore their own shoes. Plantar pressure software was used to identify six regions including all the metatarsals (AllMets) and each individual metatarsal (M1, M2, M3, M4, and M5, respectively). Peak force, percent stance when peak force occurred, maximal loading rate, and impulses were calculated for each region. All forces were normalized to body mass. Differences between RFS and FFS groups were compared using *t*-tests and effect sizes (Cohen's *d*).

RESULTS: Peak forces were higher in the FFS group than the RFS group in the AllMets (p = .021, d= 0.729, Figure 1A), M1 (FFS: 0.44 ± 0.19 BW, RFS: 0.34 ± 0.10, p = .039, d= 0.658), and M3 (FFS: 0.36 ± 0.11 BW, RFS: 0.29 ± 0.08, p = .034, d= 0.214) regions. The percent stance when peak force occured was not different between groups for any of the six regions. Loading rates were higher in the FFS group for the AllMets (p = .029, d = 0.704), M1 (p=.042, d=0.652), and M5 (p = .034, d=.064) regions (Figure 1B) while impulses were higher in the FFS group for the AllMets (p = .006, d = .801), M1 (p = .035, d = 0.639), M3 (p = .019, d = 0.710), and M5 (p = .017, d = 0.694) regions (Figure 1C).

DISCUSSION: Peak plantar forces, loading rates, and impulses are higher in the metatarsals in runners who habitually FFS than those who habitually RFS. It is likely that habitual FFS runners have adapted to these higher loads. Thus, if differences persist when a habitual RFS runner switches foot strike pattern then these individuals would be exposed to higher loads. This might help explain studies reporting metatarsal stress injuries after individuals switch to a FFS pattern [4,5].

SIGNIFICANCE/CLINICAL RELEVANCE: Recommendations regarding switching from a RFS to a FFS pattern should be made cautiously as habitual FFS runners experience higher loads in the metatarsals.

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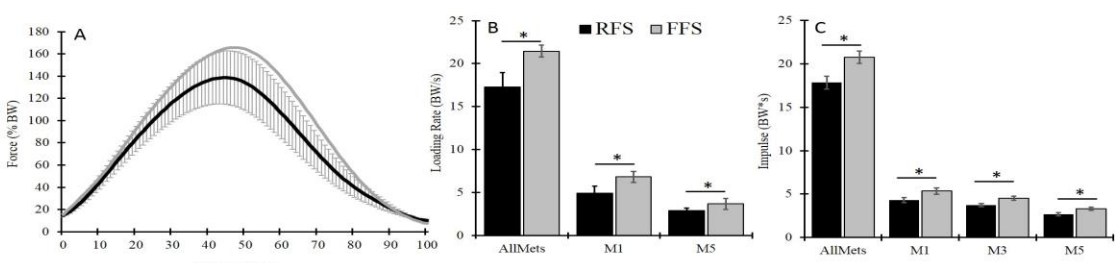
FIGURES: Vertical force in the AllMets region (A), peak loading rate in the AllMets, M1, and M5 regions (B), and impulse in the AllMets, M1, M3, and M5 regions (C).



Foot Mechanics in Drop Landings

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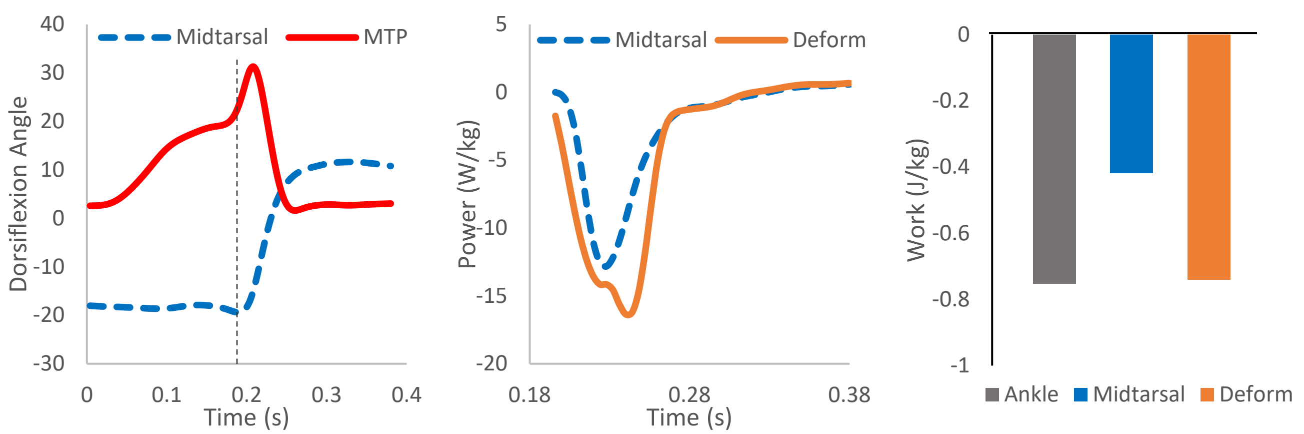
INTRODUCTION: Tools to quantify foot mechanics have increased in recent years, providing much needed insight into foot and ankle function during walking and running. A non-locomotor task, such as a drop landing, may provide a unique perspective to further study foot function. Landing mechanics are sequentially reversed from locomotion, with ground contact moving from distal to proximal. Landing forces are also higher, potentially amplifying stresses to foot structures such as the medial longitudinal arch. The purpose of this study was to investigate the mechanics of the foot during drop landings using two recent models: a multi-rigid segment foot model [1] and a deformable foot model [2].

METHODS: Forty-eight females (age = 20±2 yr, ht = 1.6±0.1 m, wt = 57±6 kg) participated after signing ethics committee approved consent forms. Twenty-eight markers were attached to the dominant leg and foot according to a three segment kinetic foot model [1]. Subjects performed one legged barefoot drop landings from a height of 0.4 m. Hanging from wooden rings, subjects dropped onto two adjacent force platforms, so that the hindfoot and forefoot contacted separate plates. Angles, power, and work were calculated for the modeled foot joints [1] while total power distal to the rearfoot segment was calculated from a deformable foot model [2].

RESULTS & DISCUSSION: The midtarsal joint was plantarflexed at the start of the drop, with a slight increase in plantarflexion just before contact (Left Figure). Upon contact, it quickly underwent 27° of dorsiflexion excursion, much greater than has been found in walking and running [2]. The metatarsophalangeal (MTP) joint extended approximately 20° during the drop and an additional 10° just after contact. MTP motion just prior to impact corresponded with Midtarsal plantarflexion, suggesting some engagement of the windlass mechanism to tension the plantar fascia in preparation for landing. During landing, the MTP joint returned to a neutral position as the Midtarsal joint (and ankle) dorsiflexed. Across the impact phase, the Midtarsal joint performed -0.42 J/kg of work, 56% as much as the ankle (-0.75 J/kg), while the total deformable structures distal to the rearfoot performed work similar in magnitude to the ankle (-0.74 J/kg) (Right Figure). These structures include the Midtarsal and MTP joints, as well as elastic and viscoelastic soft tissues. A comparison of Midtarsal joint and Deformable Foot power (Middle Figure) show in particular the influence of the heel fat pad, as a second power peak is visible in the Deformable power when the rearfoot contacts the ground.

SIGNIFICANCE: A dynamic drop landing task amplifies joint motion and loading in the foot when compared to locomotion. Various foot tissues made substantial contributions to impact absorption comparable in magnitude to the ankle joint. The role of these tissues may have implications in athlete and pathology treatments that limit foot mobility, such as footwear or taping.



Figures: Left = Representative Midtarsal and MTP joint angles, plotted from start of drop to lowest position of the center of mass (vertical line indicates ground contact). Middle = Midtarsal joint power and Deformable Foot power, plotted from initial contact to lowest position of the center of mass. Right = Group mean Ankle, Midtarsal, and Deformable foot work done during the same time period.

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Relationship Between Arch Height and Metatarsal Loading in Runners

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INTRODUCTION: Metatarsal stress fractures are common injuries among runners. While the cause of these injuries are multifactorial, arch height has been suggested to play a role in which metatarsal gets injured. Previous authors have reported that high arched individuals experience more 5th metatarsal stress fractures while low arched individuals experience more second and third metatarsal stress fractures [1]. However, studies on plantar loading have reported that low arched individuals have higher forces on the lateral forefoot compared to the medial forefoot, suggesting that low arched individuals would be at higher risk for 5th metatarsal stress fractures [2]. One explanation for this discrepancy is that there currently are few studies in the literature evaluating relationships between arch height and plantar loading during running, and those that do exist typically lump multiple metatarsals into one region. Therefore objective of this study was to determine whether there is a relationship between arch height and loading among each of the metatarsals.

METHODS: 30 runners (sex: 23M, 7F, foot strike: 14 RFS, 16 FFS, weekly mileage: 48.3 ± 16.3 miles) participated in this study. All participants were injury free at time of testing. The procedures were approved by the IRB and all participants provided informed consent. Arch height index assessment was performed on each participant. [3] Participants then ran on a treadmill with an in-shoe plantar pressure system sampling at 100 Hz. Prior to data collection, a pressure insole was trimmed to fit the insole from each participants' shoes and calibrated using a step calibration. Participants wore their own shoes. Plantar pressure software was used to identify each individual metatarsal region (M1, M2, M3, M4, and M5, respectively). Maximal force in each metatarsal was calculated in each region for ten gait cycles. All forces were normalized to body mass and averaged. Both their left and right feet were analyzed (total n=60 feet analyzed). Linear regressions were used to determine the relationship between arch height index and peak force for each metatarsal region.

RESULTS: There was a weak relationship between higher arches and increased force under M1 (R^2 = 0.166, p = 0.001). However, there was not a relationship between arch height and peak force under M2 (R^2 = 0.042, p = 0.114), M3 (R^2 = 0.017, p = 0.317), M4 (R^2 = 0.002, p = 0.739), or M5 (R^2 = 0.001, p = 0.845).

DISCUSSION: Our results show no relationship between arch height and plantar forces under the second, third, or fifth metatarsals, the most common locations for metatarsal stress fractures. Since increased plantar loads are thought to be related to metatarsal stress fracture development [2], this calls into question whether there is a relationship between arch height and metatarsal stress fracture location. Future prospective studies on plantar loading in individuals who sustain metatarsal stress fractures are required to address relationships between plantar loading and injury.

SIGNIFICANCE/CLINICAL RELEVANCE: (1-2 sentences): The use of arch height to assess risk of stress fractures to specific metatarsals is not supported by these results.

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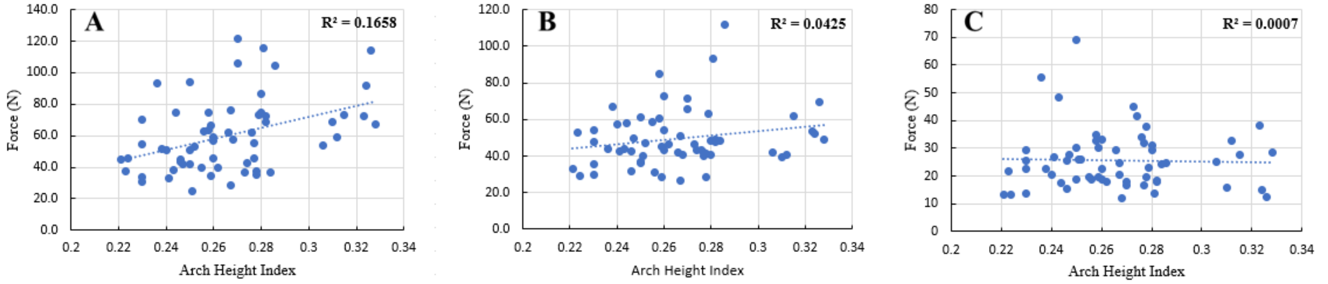
FIGURE 1: Linear regressions comparing arch height to peak plantar forces under M1 (A), M2 (B), and M5 (C).



Mechanical analysis of barefoot and shod treadmill running using a smartphone application

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Disclosures:None.

INTRODUCTION: There is much deliberation in literature over the possible conditioning benefits of barefoot running activity[1-3] with equivocal findings. Furthermore, if footwear conditions affect optimal movement patterns of the lower limb they may affect magnitudes of between-leg symmetry and potentially injury incidence[4, 5]. The increase of smart phone applications is a relatively new, but potentially valid method for analysing the mechanical variation between footwear conditions[6]. The aim of this study was to employ a smart phone app to analyse between-leg asymmetry and mechanical variables between shod conditions.

METHODS: Twenty-five undergraduate sports students (Age, 20 ± 0.8 yrs; Height, 179 ± 7cm; Body Mass, 79 ± 12kg) volunteered based on regular physical activity (5 ± 2hrs per week) which included running and were injury free and had no previous experience of barefoot running. All participants completed PAR-Q and informed consent documents and all testing was approved by the St Mary's University Ethics Committee. Participants performed two, randomised 1-minute bouts of treadmill running at 4 $m \cdot s^{-1}$ in two conditions, shod and barefoot separated by 5 minutes rest. A smart phone application (Runmatic[6] at 240fps) was used to calculate (based on 8 consecutive steps) multiple biomechanical measures after recording the final 15 seconds of each bout from the rear of the treadmill; these were contact time (s), flight time (s), step frequency (Hz), relative max force (BW) and leg stiffness (kN/m), furthermore to compare a percentage of between-leg asymmetry. Paired samples T-Test and Wilcoxon tests were used to examine for significant difference (p set at 0.05) between footwear conditions, based on whether the data was normally distributed via Shapiro-Wilk analysis.

RESULTS: Contact time significantly decreased in the barefoot condition (from 0.22 to 0.21s), while step frequency (from 2.92 to 3.03Hz) and leg stiffness significantly increased (15.4 to 18.2kN/m) during the barefoot condition. Flight time, and relative max force significantly increased in the barefoot condition. There was a greater, but insignificant, score of asymmetry in the barefoot condition (4.5 ± 3.85% vs 3.3 ± 3.4%).

DISCUSSION: Contact time decrease and step frequency and leg stiffness increase during the barefoot condition follow that seen in other literature. Flight time and relative max force significantly increased in the barefoot condition which could be an artefact of suboptimal acute changes to the condition, though much research highlights an increase in force during initial barefoot contact though flight time would expect to reduce in line with increased step frequency. Asymmetrical gait has multiple research publications and suggestions that footwear may reduce asymmetry[7] is a tentative finding from this study since research also highlights the subject specific nature of lower limb mechanics across footwear conditions[5,8].
The immediate response to the footwear condition after 30 seconds of treadmill acclimatization may not be a true representation of adaptation to the given condition; furthermore the use of low homogeneity in the participants may have increased variation in acute response to barefoot running. Additionally, grouping participants into 'foot type' categories may provide more interesting results particularly with proxies of force and stiffness that the application calculates.

SIGNIFICANCE/CLINICAL RELEVANCE: (1-2 sentences): The Runmatic smartphone application seems a valid tool to measure acute changes in footwear conditions or monitor adaptations in mechanical variables and/ or symmetry in treadmill running following intervention with a clinical or performance focus.

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Midfoot Angle Changes During Running After an 8-Week Intervention Program

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Disclosures: None

INTRODUCTION: The medial longitudinal arch has been called the central core of the foot. Its structure, movement, and integrity during running gait largely depends on the function of intrinsic and extrinsic foot muscles. There are many injuries that can be associated with a dysfunctional medial longitudinal arch[1]. Improving the strength of the foot muscles could help improve arch function during running. The purpose of this study was to observe changes in arch deformation after eight weeks in a foot strengthening exercise group (FSG), a group walking in minimalist shoes (MSG), and a control group (CG).

METHODS: 24 healthy college age subjects (age 22.6±2.6 years, height 174.4±10.3cm, weight69.0±13.0kg) were recruited and randomly assigned to either FSG (n=9), MSG (n=7) or CG (n=8) and monitored over 8 weeks. All subjects were recreational runners with an average weekly running mileage of 15 to 30 miles for the last 6 months prior to participation. Exclusion criteria included any lower extremity injury within the last 3 months or if they had run in barefoot or minimalist shoes at least 3 times within the previous 3 months. All runners, regardless of group assignment, maintained their pre-study mileage in traditional running shoes throughout their participation in the study. FSG subjects followed a series of progressive exercises designed to strengthen the intrinsic muscles of the foot while MSG subjects were given a pair of minimalist shoes to use while walking. These subjects started walking 2,500 steps daily, increasing their daily walking step count to 7,000 steps a day by the end of the 8-week study. Biomechanical data was collected at the beginning of the study and again at week 8. To do this passive-reflective motion capture markers were placed on participants' right and left feet and ankles according to the Oxford Foot Model. Subjects ran at a self-selected pace on a treadmill while data was collected for at least 10 strides.

Data was processed within Visual 3D where peak midfoot angles were extracted and averaged within each trial. Paired t-tests were used to compare group means at week 0 and week 8 with alpha set at 0.05.

RESULTS: While all groups experienced a decrease in midfoot angle, only the FSG group experienced a significant change. See table below.

DISCUSSION: The results suggests that the foot exercise intervention resulted in more arch control during running than the MSG or CG. The FSG may have been the only group to experience a significant reduction in arch drop because the exercises were targeted for the muscles that control the medial longitudinal arch whereas the minimalist shoes were less targeted. The MSG group also started at a daily step count that is roughly equivalent to walking 1 mile which could be considered a small distance when compared their daily running mileage. A limitation of this study was the small sample size which would help strengthen the significance in the FSG.

SIGNIFICANCE/CLINICAL RELEVANCE: It is possible for patients to reduce the amount of arch deformation during running by using targeted foot exercises. This could help with patients who have over-use injuries associated with dropped arches.

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ACKNOWLEDGEMENTS:

FIGURES AND TABLES:

	Week 1	Week 8	p-Value
CG	10.8401	9.9399	0.332
FSG	11.4583	7.5893	**0.045***
MSG	9.0624	8.7442	0.401

Average midfoot angles for weeks 1 and 8. Significance shown by *.

Association Between Concussion and Ankle Sprain History in Collegiate Athletes

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Disclosures: The authors have no conflicts of interest to disclose.

INTRODUCTION: Ankle sprains and concussions are common injuries sustained by collegiate athletes. Multiple studies have determined that athletes who sustain a concussion are at greater risk for lower extremity musculoskeletal injuries. A positive association between concussion and lower extremity musculoskeletal injury has also been identified when examined retrospectively over the course of a collegiate athletic career. Despite these recent findings, few studies have specifically examined the association between concussion and ankle sprain injury history or factors which may impact this relationship such as number of concussions or gender. Therefore, the purpose of this study was to examine the association between concussion and ankle sprain history; as well as, the influence of number of concussions and gender on this relationship.

METHODS: A sample of 468 National Collegiate Athletic Association student-athletes (200 Males, 268 Females; 19.5±1.3y, 173.9±10.5cm, 71.9±13.6kg) were recruited from 17 sports at either the Division I or III level. Institutional Review Board approval was attained and voluntary completion of the study packet was deemed consent to participate. Participants provided demographic, injury history, and athletic participation information through a survey. Participants were asked to describe all injuries that they could recall over their lifespan. For this study, analysis was limited to reported ankle sprains and concussions. Chi-square analyses with corresponding odds ratios examined the relationship between concussion and ankle sprain history. Additional analyses were completed by stratifying athletes with a single or multiple concussion history and within each gender. For all analyses, Fisher's exact tests were used to determine statistical significance ($p<0.05$).

RESULTS: Athletes with a history of concussion reported a greater ankle sprain history rate compared to athletes with no history of concussion (OR=2.07, $p<0.001$). Further examination determined that athletes with a history of multiple concussions (OR=2.56, $p=0.003$) and those who reported a single concussion (OR=1.78, $p=0.040$) had a greater association with ankle sprain history compared to athletes with no concussion history. Females with a history of concussion were more likely to report a history of ankle sprain compared to females with no concussion history (OR=2.54, $p=0.001$). However, males with a history of concussion were not more likely to report a history of ankle sprain when compared to males with no history of concussion (OR=1.41, $p=0.360$). A summary of the data is reported in Table 1.

DISCUSSION: Overall, there was a positive association between concussion history and ankle sprain history among collegiate athletes. Athletes with a concussion history were twice as likely to report an ankle sprain history compared to athletes with no history of concussion. Athletes who reported more than one concussion or females that reported a history of concussion were 2.5 times more likely to report an ankle sprain history.

SIGNIFICANCE/CLINICAL RELEVANCE: Collegiate athletes who reported a history of concussion were up to 2.5 times more likely to have a history of ankle sprain. Although the underlying mechanism(s) for the relationship between concussion and ankle sprain has not been established, this association should be taken into consideration during the management of these injuries. Concussion and ankle sprain injuries may share common sensorimotor or neurocognitive impairments which increase susceptibility to additional injuries over time. Future research should consider examining the effects of sensorimotor training following concussion and neurocognitive training following ankle sprain.

Table 1. Association between concussion history and ankle sprain history in collegiate athletes

	Groups	**n**	**Rate of Ankle Sprain History**	**Odds**	**Odds Ratio**	**Odds Ratio 95% CI**	**p-value**
Entire Sample	History of Concussion	115	58.0%	1.40	2.07	1.35, 3.18	<0.001*
	No History	353	40.0%	0.67			
	History of 1 Concussion	66	54.5%	1.20	1.78	1.05, 3.02	0.040*
	No History	353	40.0%	0.67			
	History of >1 Concussion	49	63.0%	1.72	2.56	1.38, 4.75	0.003*
	No History	353	40.0%	0.67			
Males	History of Concussion	36	50.0%	1.00	1.41	0.68, 2.91	0.360
	No History	164	41.0%	0.70			
Females	History of Concussion	79	62.0%	1.63	2.54	1.48, 4.35	0.001*
	No History	189	39.0%	0.64			

The differences in time to stability, foot muscle size and toe flexor strength between gymnast, cheerleaders and non-athletes

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INTRODUCTION: There has been recent speculation that the intrinsic foot muscles may play a larger role in lower extremity control and injury than previously believed. It has been suggested that training in less supportive footwear or barefoot may lead to an increase in intrinsic and extrinsic foot muscle size and strength. Our purposes were: 1) to compare intrinsic and extrinsic foot muscle size and strength in gymnasts (who predominately train barefoot), cheerleaders (who perform similar movements to gymnasts and predominately train shod), and weight matched non-athletes; and 2) to measure time to stability (TTS) after drop landings among the groups.

METHODS: Forty-eight women participated and signed IRB approved consent forms. Three groups were recruited: collegiate gymnasts (Gym), (n=16, age= 19.4 yr, ht= 159.3 ± 4.9cm, wt= 56.7 ± 4.3kg), collegiate cheerleaders (Cheer), (n=16, age= 20.3 yr, ht= 161.9 ± 5.4cm, wt= 58.7 ±7.1kg), and non-athletes (CON) (n=16, age= 21.5 yr, ht= 167.2 ± 5.8cm, wt=57.2 + 5.7kg). Sizes of 3 intrinsic (abductor hallucis, flexor digitorum brevis, quadratus plantae) and 3 extrinsic (tibialis posterior, fibularis longus and fibularis brevis) foot muscles were measured using ultrasound imaging (GE LogiqP6 with ML6-15 linear probe). The muscles were measured using protocols previously used and shown reliable. Toe flexor strength was assessed from the first toe (GT) individually, and the lateral toes (LT) together using a customized dynamometer. The subject completed three trials of a maximal contraction for 3 seconds. Subjects then performed 3 drop landing trials of each of 4 conditions – double and single leg, shod and unshod. We defined TTS as the time when the sequentially averaged medial-lateral ground reaction force during landing remained within one-quarter standard deviation of the overall series mean. The mean of the 3 trials for each condition were compared using ANOVA comparisons with alpha set at 0.05, weight was a significant co-variate.

RESULTS: Gym had significantly larger muscles in all 6 muscles compared to the CON group (p<0.002) and significantly larger fibularis longus (p<0.001) and fibularis brevis (p=0.048) muscles compared to the Cheer. Cheer had significantly larger muscles than the CON group in the abductor hallucis (p=0.028), quadratus plantae (p<0.001), tibialis posterior (p<0.001), and near significance in the flexor digitorum brevis (p=0.055). Gym had significantly greater GT strength compared to CON (p<0.001) and Cheer (p=0.018) and LT strength significantly greater than CON (p<0.001), but not Cheer (p=0.286). Cheer also had significantly greater strength compared to CON in both toe flexion tests (p<0.001). CON had significantly longer times to stability than both Gym and Cheer in all conditions (p<0.006). Gym and Cheer did not differ in time to stability in any of the conditions (p>0.08).

DISCUSSION: Athletes performed significantly better in the strength and TTS tests than CON. Gym had the greatest GT flexion strength and overall largest muscle sizes normalized to weight. Many factors likely affect drop landings to achieve shorter TTS beyond the size and strength of foot muscles that are worth considering. These athletes routinely perform tumbling and landing maneuvers that require high levels of motor control, hours of practice, and fitness. There does seem to be significant training effects in these athletes' foot muscle development compared to the CON group. Training barefoot may have a larger influence on strength and muscle size increase compared to training or performing activities of daily living shod. Limitations to our study may be small sample sizes and similarity in the training of between the athletes.

SIGNIFICANCE/CLINICAL RELEVANCE: Stronger and larger foot muscles appear to contribute to decreased TTS. Our data supports strengthening of foot muscles to improve performance.

Table 1. Between-group comparison (mean±SD) of intrinsic and extrinsic foot muscle size, strength and time-to-stability.

	Strength (kg)		**Muscle Size (cm^2)**						**Time to Stability (s)**			
	GT	LT	AH	FDB	QP	TP	FL	FB	BD	BS	SD	SS
CON	3.3±.8	2.8±.9	1.6±.4	1.5±.4	1.2±.3	1.5±.2	3.9±.7	3.1±.6	.49±.16	.46±.17	.39±.17	.47±.24
Cheer	4.5±1	3.9±1	1.9±.6	1.7±.4	1.7±.5	1.8±.2	4.2±.8	3.3±.6	.36±.09	.35±.1	.32±.07	.35±.09
Gym	5.2±3	4.0±2	2.1±.5	1.9±.3	1.7±.3	1.9±.3	4.8±1	3.5±.7	.35±.12	.31±.06	.27±.08	.37±.1

CON=non-athlete control, Cheer=Cheerleader, Gym=Gymnast; GT=great toe, LT=lateral toes; AH=Abductor Hallucis, FDB=Flexor Digitorum Brevis, QP=quadratus plantae, TP=Tibialis Posterior, FL=fibularis longus, FB=fibularis brevis; BD=barefoot double foot landing, BS=Barefoot single foot landing, SD=shod double foot landing, SS=shod single foot landing

Do Achilles Tendon Properties differ with Habitual Foot–strike Running Patterns?

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INTRODUCTION: There is a 52% lifetime incidence of Achilles tendinitis in runners.[1] It has been suggested that a stiffer tendon is a healthier tendon. The capacity of foot–strike running patterns to influence the mechanical properties of the Achilles tendon is controversial.[2,3] This study used transmission–mode ultrasound to investigate the influence of habitual running foot–strike patterns on Achilles tendon properties during walking and running.

METHODS: Axial transmission velocity of ultrasound, a measure of the instantaneous elastic modulus of tendon, was measured in the right Achilles tendon of 15 runners with an habitual rearfoot foot–strike (RFS) and 10 with an habitual forefoot–strike (FFS) running pattern during barefoot walking (1.1 ± 0.1 ms^{-1}) and running (2.0 ± 0.1 ms^{-1}). Basic gait parameters, ankle motion and vertical ground reaction force were simultaneously recorded at 120Hz. Statistical comparisons between habitual foot–strike patterns were made using repeated measure ANOVAs.

RESULTS: Mean (±SD) gait characteristics and ultrasound velocity in the Achilles tendon during walking and running are summarized in Table 1. FFS was characterized by significantly shorter stance duration (-4%), greater ankle dorsiflexion (+2°), and higher peak vertical ground reaction force (+20% bodyweight) than RFS during treadmill running ($P<.05$). Both groups adopted a RFS pattern during barefoot walking, with only the relative timing of peak dorsiflexion (3%) and ground reaction forces (1–2%) differing between groups ($P<.05$). Peak force loading rates were 22–23% lower in FFS than RFS during walking and running ($P<.05$). Peak ultrasound transmission velocity in the Achilles tendon was significantly higher during walking (≈100 ms^{-1}) and running (≈130 ms^{-1}) in FFS than RFS ($P<.05$).

DISCUSSION: Despite adopting a similar heel-toe gait pattern during walking, ultrasound transmission velocity in the Achilles tendon was systematically higher during both walking and running in habitual FFS than RFS; indicating the Achilles tendon had a higher material stiffness in those with a habitual FFS running pattern.

SIGNIFICANCE/CLINICAL RELEVANCE: Habitual footfall patterns during running may influence the mechanical properties of the Achilles tendon in recreational runners. A stiffer tendon in FFS may aid rapid force development as well as offer protection against injury.

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Table 1. Mean (±SD) gait characteristics and ultrasound velocity in the Achilles tendon during walking and running

Gait Condition	Walk		Run	
Habitual foot-strike pattern when running	**RFS**	**FFS**	**RFS**	**FFS**
n	15	10	15	10
Stance Phase Duration (%GC)	63 ± 1	64 ± 2	45 ± 4	41 ± 3 *
Swing Phase Duration (%GC)	37 ± 1	36 ± 2	55 ± 4	59 ± 3 *
First Ground Reaction Force Peak (BW)	1.10 ± 0.06	1.17 ± 0.07	−	−
Ground Reaction Force Minimum (BW)	0.84 ± 0.09	0.85 ± 0.09	−	−
Second Ground Reaction Force Peak (BW)	1.13 ± 0.08	1.14 ± 0.08	2.13 ± 0.22	2.32 ± 0.20 *
Peak Loading Rate (BWs^{-1})	33.5 ± 9.2	26.2 ± 6.2*	65.0 ± 14.2	50.3 ± 18.8*
Peak Ankle Dorsiflexion (°)	5 ± 1	6 ± 2	9 ± 2	11 ± 4 *
Peak Ankle Plantarflexion (°)	-6 ± 2	-7 ± 4	-12 ± 4	-11 ± 3
Minimum Ultrasound Velocity 1 (ms^{-1})	1972 ± 111	2085 ± 112	2066 ± 103	−
Peak Ultrasound Velocity 1 (ms^{-1})	2189 ± 100	2311 ± 70 *	2212 ± 104	2353 ± 78 *
Minimum Ultrasound Velocity 2 (ms^{-1})	1908 ± 143	1994 ± 137	1900 ± 138	1996 ± 130
Peak Ultrasound Velocity 2 (ms^{-1})	2091 ± 122	2181 ± 71*	2099 ± 105	2216 ± 113 *

* Statistically significant difference between RFS and FFS groups ($P < .05$); RFS, Rearfoot foot–strike running pattern; FFS, Forefoot foot–strike running pattern; %GC, percentage of gait cycle; BW, normalized to body weight

Joint moment contributions to forward and upward acceleration of body CG are affected by the foot to ground contact model

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INTRODUCTION: Induced acceleration analysis (IAA) is based in the dynamic coupling effect caused by the multiarticulated nature of the body, meaning that when a muscle contracts it produces acceleration, not only in those segments that are spanned by that muscle but on all body segments of the chain, due to the intersegmental forces [1] . IAA has being used to ascertain the contribution of the different muscle groups to the forward progression and vertical acceleration applied to the body center of gravity (CG) in gait[2] and more recently in sports activities [3] where maximal effort is demanded from the athletes. Nevertheless the IAA results are sensitive to the type of constraints and particularly to foot to ground modeling. The purpose of our work was to explore the different contribution and synergist's action of the ankle plantar flexors moment in relation to a free or a fixed foot contact simulation in hopping and sprinting.

METHODS: For the sprinting data 1 male national elite sprinter performed a sprint start from blocks and for the hopping data 1 national elite male triathlete performed a series of 10 unilateral hopping's. Motion and ground reaction forces of the first step after leaving the blocks in sprinting, and the 10 hopping's were captured at a sampling frequency of 200Hz using an optoelectronic system of 8 infrared cameras (Qualisys Oqus 300 & QTM software), synchronized in time and space with a force plate. The best trial for each movement was selected for analysis in Visual 3D (C-Motion software). A biomechanical model, composed by 8 rigid segments (HAT, pelvis, bilateral thighs, shanks and feet) was built, and optimized through inverse kinematics. The contribution of all joint moments and gravity to the horizontal and vertical acceleration of the participant's center of mass was computed through an induced acceleration analysis, the dynamic equations of motion can be expressed in the following form (eq.1):

$$\ddot{\theta} = M^{-1}(\theta)\tau + M^{-1}(\theta)C(\theta,\dot{\theta}) - M^{-1}(\theta)G(\theta) \quad \text{(eq.1)}$$

Where $\ddot{\theta}$ is the joint acceleration term, M^{-1} is the inverse inertia matrix (where the segments inertial parameters and CM positions are taken into account), τ is the joint moment's term, C and G are the Coriolis and Gravitational terms, respectively. Given equation 1, C and G terms are set to zero allowing us to obtain the accelerations produced by each of the joint moments and the generated GRF [1]. In this study two different contact models were used to establish the connection between the foot and the environment. In the first one, here designated as free-foot system, the foot–floor interface was modeled using a hinge joint with the axis of the hinge passing through the center of pressure in a direction parallel to the medio-lateral axis of the foot. In the second model, called fixed-foot system, the foot was constrained to the floor so that no motion of the foot was permitted. The free foot model was used when the foot to ground sagittal angle was changing and the fixed foot was used when this angle deed not varied.

RESULTS: As expected, different contributions of the lower legs joint moments of force were perceived when using the two types of foot contact model. In hopping, when free foot was used the main contributor to vertical acceleration were the ankle plantar flexors nevertheless when the fixed foot model was used, the foot/ground angle was fixed, the contribution of knee extensors was predominant and a synergistic action of ankle and knee extensors was reveled, with the ankle plantar flexors being responsible for fixing the foot to ground interaction and allowing the transfer of knee extensors action to the body CG upward acceleration. In sprinting a comparable synergistic action was observed when using a fixed foot model when no movement between foot and ground was computed but in this case between the hip extensors and plantar flexors, allowing the hip extensors to propel the CG forward.

DISCUSSION: The results we obtained showed that the IAA is sensitive to the foot to ground contact modeling solution and this was especially relevant to understand the major role of the ankle plantar flexors of guaranteeing the rigidity of the foot to ground contact probably due to a quasi-isometric behavior of these muscles and so contributing to the transfer of mechanical power developed by hip and/or knee extensors to the ground during an important phase of stance in explosive sports movements.

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Foot kinematics of forefoot and rearfoot strikers on recreational runners using the Rizzoli's foot model

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INTRODUCTION: Several studies investigated and compared biomechanical patterns of different foot strikes, mostly regarding kinetic and kinematic of the lower limbs; even though those studies rarely report foot kinematics either for not using a multi-segment foot model or for analyzing shod running [1]. The few biomechanics-related variables described in running focuses on plantar arch dynamics and rearfoot kinematics. The literature has showed lower limb kinematic differences when comparing rearfoot (RS) and forefoot strikers (FS) for knee and ankle`s range of motion (ROM) and their angles at the initial contact, vertical loading rates, running economy [1,2]. However, the literature lacks information about how the foot moves during running, and which adjustments the foot joints performs during each foot strike technique. Therefore, our aim was to investigate forefoot, midfoot and rearfoot kinematics and compare them between naturally RS and FS strikers in recreational long-distance runners.

METHODS: Kinematic data of twenty healthy long-distance recreational runners of both sexes was assessed using 8-camera motion capture system (Vero - VICON) at 200 Hz, while they ran barefoot on an AMTI™ force-sensing tandem treadmill at self-selected speed at 1kHz. The Rizzoli's Foot Model (IOR foot) marker protocol was used [2]. Runners' foot strike pattern was identified using both kinematic and kinetic online data and slow-motion sagittal plane video recorded of each runner [3]. The maximum angle and the ROM of 12 foot-related variables were analyzed across 10 steps for each 10 runners from each group (RS and FS). Groups were not different in body mass (64.5±12.6kg), height (168.5±7.7cm), age (41.0±5.9yr.), self-selected running velocity (9.8±1.9km/h), and foot posture index (2.0±4.4). Groups were compared using t-test for each kinematic variable ($p<0.05$). (Ethic committee HC-FMUSP 031/15).

RESULTS: Differences between groups were found for the range of the angle between the first metatarsal to the ground ($p=0.006$), the second metatarsal to the ground ($p=0.001$) (Figure 1). Difference between groups was also found between the midfoot and metatarsus in the sagittal plane ($p=0.05$). No other differences were found.

DISCUSSION: Results revealed smaller range of motion of toes joints in the FS runners compared to RS runners. Possibly a greater foot strength developed by FS strikers enables a better control and damping of the body weight during the stance phase leading to a more controlled foot motion during running. Modelling foot kinetics using foot kinematic and ground reaction forces might help understanding the mechanisms that generated such foot mechanics differences. Increasing the sample size would reveal more differences because we had some results borderline to significance. Other analysis would also be possible, such as measuring the stance in two phases.

SIGNIFICANCE/CLINICAL RELEVANCE: This study proposes a better comprehension of the foot segments motion and its variability among runners with different strike strategies. Investigating normal foot kinematic patterns, variability and differences between FS and RS strikers are the basis for many clinical and surgical interventions in this population, and they might also be used as controlling variables of effectiveness.

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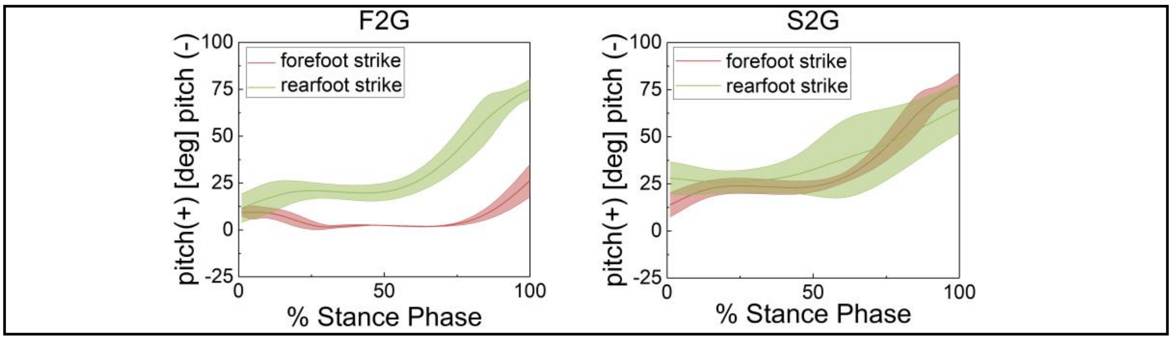

Figure 1 Temporal patterns of toes angles during stance phase of treadmill running. F2G is the sagittal plane angle of the 1st metatarsal to the ground. S2G is the sagittal plane angle of the 2nd metatarsal to the ground. Mean (solid line), plus and minus a standard deviation (band) were calculated.