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Implications of Running Shoe Degradation on Overuse Injury Incidence in NCAA Division 1 Female Distance Runners

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Abstract

Purpose: The purpose of this longitudinal study was to analyze the impact of the degradation in footwear, due to increased mileage, on the incidence of overuse injuries in the female distance runners on the Arkansas Cross-Country team over the course of four weeks. *Methods:* Eight female participants over the age of 18 from the University of Arkansas women's cross-country team that trained in a neutral-ride running shoe were recruited. Each week subjects recorded their mileage and completed a pain survey over the FOOT, LOWER-LEG, KNEE, UPPER-LEG, HIPS, and LOWER BACK while midsole thickness of their training shoes was measured at five locations: posterior heel, lateral heel, medial heel, lateral metatarsal arch, medial metatarsal arch. *Results:* There was a statistically significant main effect of WEEK for all shoe deformation locations except for the left lateral metatarsal arch with a *p*-value of 0.005. TOTAL, FOOT, and LOWER-LEG pain scores over the four weeks for each subject showed no consistent correlation with increased time across all subjects. The regression analysis showed no consistent pattern or relevance between shoe degradation and mileage or between shoe degradation and injury score. *Conclusion:* The midsole thickness of neutral-ride running shoes decreases as mileage is placed upon it over time. The limitations of this study inhibit our ability to determine if this change in midsole thickness has a detrimental effect on the athletes' overuse injury pain. Future studies should explore the changes in shoe characteristics throughout a season to determine if these changes play any role in an athlete's ability to perform their best and deal with an injury.

Introduction

According to data obtained by the National Collegiate Athletic Association (NCAA), as of the 2017-2018 academic year, there were 15,632 female cross-country student-athletes across all divisions (NCAA 2017). In 2015, the NCAA Injury Surveillance Program published a study claiming there were 5,723 annually reported injuries in women's cross-country (Kerr et al., 2015). Of these 5,723 injuries, recent studies have shown that female cross-country athletes experience the greatest number of overuse injuries, such as stress fractures, with a rate of 28.59 per 100,000 student-athlete exposures (Rizzone, Ackerman, Roos, Dompier, & Kerr, 2017) when compared to all other 25 NCAA sports. Athlete exposures were defined as, "1 student–athlete participating in 1 NCAA-sanctioned practice or competition in which he or she was exposed to the possibility of athletic injury," (Kerr et al., 2014). Stress fractures are overuse injuries characterized by repetitive and excessive stressors placed on the bone that increase the amount of bone remodeling and can lead to microfractures. When this is combined with a decreased recovery time, the resultant stress injury is considered a stress fracture (Niva, Mattila, Kiuru, & Pihlajamäki, 2009). These injuries can cause the student-athlete to miss a significant amount competition time and according to previous research, the average time before a cross-country runner can return to full participation after a stress fracture is 12-13 weeks (Miller, Jamieson, Everson, & Siegel, 2017).

The reason behind this high injury incidence rate in this demographic of athletes remains inconclusive. One contributing factor to injury occurrence in distance runners has been the type and cushioning properties of their footwear (Ryan, Elashi, Newsham-West, & Taunton, 2013). It should be noted that much research has been done to analyze the implications of footwear and ground-surface on injuries to military recruits, but there is less information on the implications that footwear could have on runners. One such example is Dr. Richard Greaney's 1983 study entitled "Distribution and Natural History of Stress Fractures in U.S. Marine Recruits," which found that when Marine recruits switched from combat boots to tennis shoes, there was a 13.5% decrease in calcaneal stress fractures (Greaney et al., 1983). In Dr. Michael Ryan's Nike-funded study, researchers analyzed the injury occurrence in a population of runners who trained for a 10km event in either a neutral, partial-minimalist, or a full-minimalist shoe. Results showed an overall injury rate of 23.2% with more injuries reported in both minimalist groups than the neutral group. Participants who wore the partial-minimalist shoe reported the greatest number of injuries while the reported pain of the calf/shin area was significantly greater in subjects running in the full-minimalist shoe. Analysis of this data proved that there is a higher likelihood of experiencing an injury with minimalist footwear (Ryan et al., 2013).

The largest difference between a minimalist running shoe and a neutral running shoe is cushioning characteristics, specifically midsole thickness. Neutral shoes provide an ample amount of support for the runner and were classified to have a midsole thickness of greater than 30mm; while minimalist shoes have very little cushioning and were determined to have a midsole thickness of less than 30 mm (Ryan et al., 2013). Because of these findings, it can be hypothesized that as the midsole thickness of neutral running shoes decreases due to mileage, the risk of injury will increase. Therefore, the purpose of this study was to analyze the impact of the degradation in neutral footwear, due to increased mileage, on the incidence of overuse injuries on the Arkansas Women's Cross-Country team.

Methods

This longitudinal study took place over four consecutive weeks and assessed the relationship between shoe deformation with increased running mileage and lower extremity pain symptoms. We recruited eight female participants over the age of 18 from the University of Arkansas women's cross-country team. Every participant was consistently training without restriction at the beginning of the study. Participants were only permitted to participate if they trained in a neutral-ride running shoe. Subjects were excluded from the study if they experienced an injury or training restriction in the two weeks before the beginning of the study. Subjects who normally trained in a minimal or stability shoe were also not allowed to participate. All protocols were approved by the University of Arkansas Institutional Review Board.

Each subject visited the University of Arkansas Women's Track & Field locker room and/or the Randal Tyson Indoor Track Center a total of five different visits, one week apart. Upon their first visit, the subject completed an informed consent. Next, their shoe size, brand, and model were recorded along with a self-reported weight. The subjects' shoes were brand new and without any mileage previously placed on them. Degradation was measured based on the midsole size of each shoe. The midsole thickness of both the left and right shoes was measured next with a digital caliper in five different locations:

1. Posterior Heel
2. Lateral Heel
3. Medial Heel
4. Lateral Metatarsal Arch
5. Medial Metatarsal Arch

The shoes were then marked with a line at each location using a permanent marker to ensure consistency in future measurements. For visits 2-5, the same measurements were taken using a digital caliper at the same five locations on both shoes. During visits 2-5, the participant's training log was also collected to record weekly mileage totals. While measurements were being taken, the participant was sent a survey link to the Nordic Pain Questionnaire (Clarsen, Myklebust, & Bahr, 2012) that asked various questions to determine pain levels and risk for overuse injury in the feet, lower leg, knee, upper leg, hips, and lower back. Once the measurements were complete, photographs of both shoes were taken from various angles to document visible wear patterns on the shoes. After the measurements and photographs were taken and the survey completed, the shoes were returned and could be used for training purposes. The participant was required to keep a weekly total of all mileage run in the shoes. This training log was then brought back for data collection in the following visit. The participant was asked to return one week later to repeat the same protocol until their measurements had been taken a total of five times.

Statistics

To answer hypothesis one, a t-test was performed on shoe degradation over the four-week period the shoes were in use. The measures at week 0 (the initial data collection) and week 4 (the final data collection) was used in the analysis. To account for the multiple comparisons, the p-value for significance was set at 0.005 (0.05/10). To answer hypothesis two, analysis of variance tests were run on the Nordic Pain Questionnaire (Clarsen et al., 2012) scores for foot, lower leg, and total pain were run over the four weeks. To answer hypothesis three, a linear regression analysis was conducted on each shoe deformation measure versus and mileage. To answer hypothesis four, a linear regression analysis was performed to test the correlation between shoe degradation by location and injury scores. For hypotheses 2-4, the statistical significance was set at $p<0.05$.

Results

Seven of the eight recruited subjects completed the four-week study. Total mileage over the study period ranged from 187-221 miles with a standard deviation of 10.0.

Hypothesis one claimed the running shoes would degrade over four weeks. The results of the t-test on hypothesis one, shoe deformation over time, is shown in Table 1. There was a statistically significant main effect of WEEK for all shoe deformation locations except for the left lateral metatarsal arch. Each location had a decrease in midsole size between 0.7-1.4 millimeters (mm).

Table 1. Mean (standard deviation) and *p*-values for week 0 and week 4 shoe deformation. *Denotes statistical significance

Location	**Week 0 (mm)**	**Week 4 (mm)**	***p*-value**
R: Posterior Heel	28.4 (2.2)	27.1 (2.3)	0.0013*
R: Medial Heel	32.4 (4.3)	31.1 (4.0)	0.0005*
R: Lateral Heel	30.1 (5.1)	28.7 (5.0)	0.0002*
R: Medial Metatarsal Arch	18.7 (0.7)	17.4 (0.6)	0.0002*
R: Lateral Metatarsal Arch	18.3 (0.7)	17.5 (0.5)	0.0016*
L: Posterior Heel	29.2 (2.2)	28.2 (1.8)	0.0024*
L: Medial Heel	32.7 (4.1)	31.4 (4.1)	0.0004*
L: Lateral Heel	30.0 (5.4)	29.0 (5.8)	0.0025*
L: Medial Metatarsal Arch	18.5 (0.6)	17.1 (0.4)	0.0002*
L: Lateral Metatarsal Arch	18.5 (0.6)	17.8 (0.6)	0.0062

Hypothesis two claimed pain scores would increase for all participants over four weeks. Figure 1 shows that TOTAL pain scores over the four-week period for each subject showed no significant correlation with increased time across all subjects. Pain scores were also included in Figure 2 and 3 for both the LOWER-LEG (Figure 2) and FOOT (Figure 3) because these areas were the most frequently recorded as having pain. FOOT and LOWER-LEG pain scores also showed no significant correlation with increased time across all subjects. It should be noted that subject two (S2) had to be terminated from the study after two weeks due to injury.

Figure 1

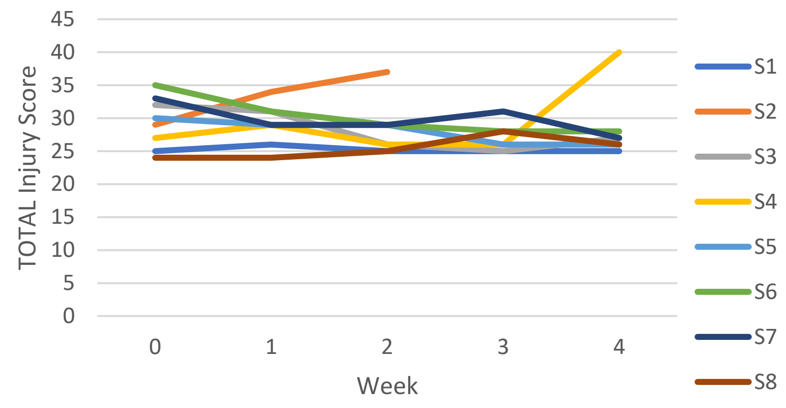


Figure 2

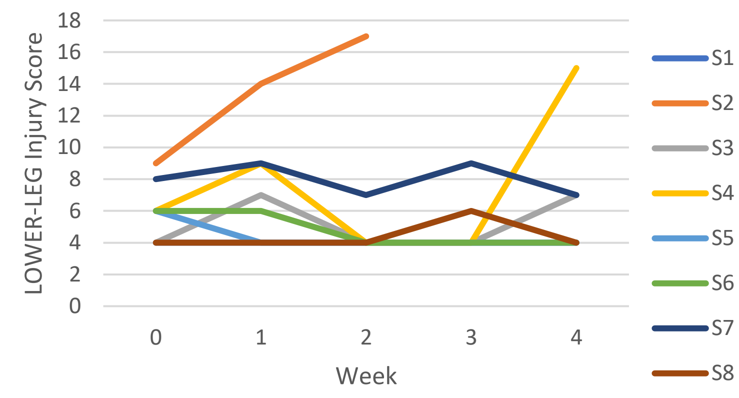
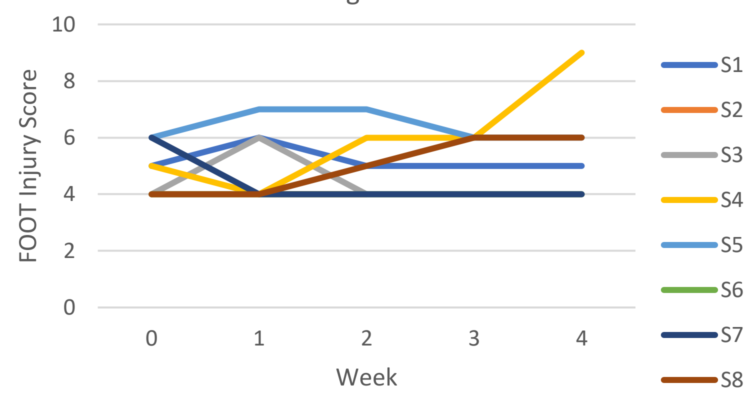


Figure 3



Hypothesis three claimed there would be a relationship between degradation and mileage over four-weeks. The regression analysis between shoe degradation and mileage over four weeks was not significant. The results showed no consistent pattern or relevance between the two variables. The R^2, R^2 adjusted, and *p*-values for all 10 measurement locations when compared with mileage can be seen in Table 2.

Table 2. Shoe measurement location, R^2, R^2 adjusted, and *p*-values for hypothesis three.

Location	**R^2**	**R^2 Adj.**	***p*-value**
R: Posterior Heel	6.071e-5	-0.19993	0.9868
R: Medial Heel	0.07374	-0.11151	0.5558
R: Lateral Heel	0.02706	-0.16753	0.7245
R: Medial Metatarsal Arch	0.091425	-0.09029	0.5098
R: Lateral Metatarsal Arch	0.10641	-0.07231	0.4752
L: Posterior Heel	0.208635	0.052669	0.3029
L: Medial Heel	0.098176	-0.08219	0.4938
L: Lateral Heel	0.030174	-0.16379	0.7095
L: Medial Metatarsal Arch	0.387245	0.264694	0.1356
L: Lateral Metatarsal Arch	0.003818	-0.19542	0.8953

Hypothesis four claimed there would be a relationship between shoe degradation and injury score. The regression analysis between shoe degradation and injury scores, both total and a specific body part, was not significant. The results showed no consistent pattern or relevance between the two variables. The R^2, R^2 adjusted, and *p*-values for all 10 measurement locations when compared with injury scores can be seen in Table 3.

Table 3. Shoe measurement location, R^2, R^2 adjusted, and *p*-values for hypothesis four.
*Denotes statistical significance

Location	**R^2**	**R^2 Adj.**	**P-value**
R: Posterior Heel	0.042327	-0.14921	0.6581
R: Medial Heel	0.113874	-0.06335	0.4592
R: Lateral Heel	0.054507	-0.13459	0.6144
R: Medial Metatarsal Arch	0.057935	-0.13048	0.6031
R: Lateral Metatarsal Arch	0.079428	-0.10469	0.5403
L: Posterior Heel	0.005819	-0.19302	0.8709
L: Medial Heel	0.628565	0.554278	0.0334*
L: Lateral Heel	0.02958	-0.1645	0.7123
L: Medial Metatarsal Arch	0.401456	0.281747	0.1266
L: Lateral Metatarsal Arch	0.017751	-0.1787	0.7758

Discussion

The purpose of the study was to analyze the impact of the degradation in footwear, due to increased mileage, on the prevalence of overuse injuries in the female distance runners on the Arkansas Cross-Country team.

Explanation of Results

Our first hypothesis claimed the midsoles of the participants' shoes would degrade over four weeks. The results from the t-test on hypothesis one, shown in Table 1, indicate that the *p*-values were statistically significant in 9 of 10 midsole locations; however, the change may not be relevant or externally valid. All ten midsole locations decreased between 0.7-1.4mm, but there is little research on if these changes in deformation will impact the athlete. It is unknown how much degradation would warrant a change in the cushioning capabilities of the shoe, or if the athletes switch out their shoes before any noticeable degradation occurs. Much of the research on this topic deals with the mileage count placed on the shoes rather than the degradation in midsole size. For example, Dr. P.W. Kong at the University of Texas at El Paso and his team, compared the effects of new versus worn running shoes with an intervention of 200 miles rather than midsole deformation (Kong, Kandelaria, & Smith, 2008). Therefore, for the average collegiate distance runner these changes in midsole size may not be relevant to their daily training and are not large enough to draw attention. Further research would need to be conducted to determine the effects of both large and small amounts of midsole degradation, in comparison with zero degradation, rather than just mileage.

Our second hypothesis claimed that bodily pain scores would increase for each subject over the four-week period. The graph in Figure 1 details the TOTAL, FOOT, and LOWER-LEG pain scores for each subject over the four-week period. Only FOOT and LOWER-LEG pain scores were included, in addition to the TOTAL, on the graph due to the higher frequency at which they were reported. Pain scores for the KNEE, UPPER-LEG, HIPS, and LOWER BACK areas were not highly reported in the studied population of athletes. Despite being the most frequently reported areas for pain, there was no consistent pattern or similarity across all subjects for the FOOT, LOWER-LEG, and TOTAL pain scores across all subjects. The lack of correlation between pain scores and overall time in the study can be attributed to study limitations such as the overall length of the study, the small subject pool, and the lack of a baseline pain levels for each athlete. Therefore, because of these study limitations and the lack of correlation in the data, our second hypothesis cannot be supported.

When looked at individually, the pain scores for subject four (S4) correlated best with our second hypothesis. Their TOTAL (Figure 1) and FOOT (Figure 3) pain scores increased or stayed the same every week over the four-week period. LOWER-LEG (Figure 2) pain scores also increased but did see a decrease in week two. One explanation for this overall increase in pain could be the mileage S4 ran. When compared to all other subjects, S4 ran the highest number of miles over the four-week period, 221, which was over 10 miles more than the next highest subject. While this is most likely not the only explanation for this increase in pain scores, it is beneficial for future studies to know that a longer study design, and therefore more mileage run, could have an impact on the consistency and increase in pain scores.

Limitations and guidelines for best practices

When researching within the field of athletics, there are many variables to consider. This issue is compounded further when performing research on athletes at the NCAA Division 1 level; due to the intense and strict nature of their environment. For this study, some limitations we encountered were:

- Length of Study
- Lack of athlete injury baseline
- Researcher Bias and measurement error
- Mileage Inaccuracies
- Number of Participants
- Differences in foot-strike
- Shoe brand differences

Length of Study

Data was collected for this study over a four-week period in which the athletes ran and recorded mileage in their shoes. This study length was chosen based on previous knowledge of the athletes' weekly mileage, as well as outside restrictions. It is evident in our results that much of our data was inconclusive for hypothesis 2 (Figure 1, 2, & 3), hypothesis 3 (Table 2), and hypothesis 4 (Table 3). One contributing factor to this is the lack of overall mileage run by each athlete, which was determined by the total length of the study. Of the seven subjects who completed the study, total mileage over the four-week period ranged from 187-221 miles. While this may seem like a substantial amount to the average runner, for these collegiate runners it is only a fraction of what they run throughout an entire season of competition. Competition seasons for NCAA Division 1 cross-country athletes could range anywhere from 3-4 months, which is at least triple the length of time our study analyzed. There is also a general rule of thumb in the running community that running shoes should be replaced after about 400 miles of running. A study performed by M. Fredericson in 1996 entitled, "Common Injuries to Runners. Diagnosis, Rehabilitation and Prevention," confirms this rule of thumb and claims running shoes should be replaced after 500 -700 kilometers (310-435 miles) of running (Fredericson, 1996). The seven athletes who completed this study ran approximately half of this suggested mileage. This information, in conjunction with the average length of competition season, implies that a four-week study was not long enough to accurately gauge the implications of mileage on midsole degradation and any subsequent injury occurrences. Future studies should make sure to balance these two factors and have a study length of at least 6-8 weeks. A longer study length will also help to account for any random fluctuations in weekly mileage as well as show mileage trends based on competition.

Lack of athlete injury baseline

One unique limitation that we did not foresee was the inconsistency of reported pain scores (Figure 1) which contributed to the lack of evidence to support hypothesis two and hypothesis four. After further review, we realized our lack of a baseline injury score for these athletes made it difficult to assess their changes in pain over the course of the study. We began collecting data for this study in January, which was a few weeks into the start of their Indoor Track & Field season. These athletes had been training consistently without proper rest since at least the month of June the previous year. Cross-country and Track & Field athletes are unique in that they compete in three separate seasons year-round, with heavy training that still occurs in the summer months. To properly gauge the changes in the athletes' injury scores, a baseline needs to be established when the athlete is healthiest and experiencing minimal stressors placed on the body due to running. Researchers at Wake Forest University collected various data using a baseline testing system during their two-year study, "To determine the risk factors that differentiate recreational runners who remain uninjured from those diagnosed with an overuse running injury," (Messier et al., 2018). The data and conclusions from this study were consequently significant and externally valid. Future studies should consider this factor and attempt to gather a baseline injury score for each subject during their 1-2 week break. This usually occurs at the end of their Outdoor Track season and before summer training begins but should be confirmed on an individual basis.

Researcher bias and measurement error

We found that when only one researcher collecting the data, it is easy for personal bias to influence the data collection. When the researcher knows the parameters, hypotheses, and overall goals of the study it is difficult to get an accurate measure of midsole thickness; especially when using a digital caliper that could give a multitude of measurements depending on how tightly it was squeezed. We found it difficult on many occasions to keep a consistent measuring technique for all the shoes, and as a result, the measures of midsole degradation could be inadvertently skewed. This limitation effected one of our main variables, shoe deformation, and therefore plays a role in the inability to confirm hypothesis three and four, as well as reduce credibility to hypothesis one. To remedy this bias, the study should operate as a double-blind study in which neither the subjects or those collecting the data are aware of why they measure midsole thickness. An average of three separate measurements should also be used to reduce measurement error or any remaining bias. Another option to reduce any human error would be to use a form of measurement other than the digital caliper, which still has to be operated by hand. Materials testing machines offer a suitable alternative to the digital caliper. These machines measure the tensile strength of a material, in this case, the midsole of a running shoe, by compressing it. While this does eliminate all human error, the format of the study would need to be altered due to the structural damage that may come to the shoes after they are compressed.

Mileage Inaccuracies:

When analyzing collegiate distance runners, it is important to understand how they train. For this study, the number of miles placed on the athletes' shoes was pivotal to understanding both midsole deformation and changes in pain scores. When designing this study, we did not account for the multiple different shoes the athletes wear during a given week of training, or even a single practice. While the shoes we analyzed were used in much of the mileage the athlete ran, they were not used during high-intensity track workouts or races. A separate racing flat and a racing spike were used for these different types of runs. As a result, the total mileage for the week was still correct, but the specific mileage count placed on the training shoes we analyzed was inaccurate. The inaccuracies that resulted from this oversight could have had implications on the lack of evidence and relevance for all four hypotheses, specifically hypothesis 1 and 3. Future studies should make sure to account for the use of multiple shoes by these athletes and possibly place an electronic or GPS tracking device on the shoes being analyzed. This technology would help to confirm the true mileage placed on the shoes in question, as well as eliminate any personal error or bias from the subjects when they verbally reported their mileage.

Number of Participants

For any subject research, the larger the participant pool, the more valid the results. This statement is also true in this study. Our study successfully recruited eight participants that met the criteria with one subject unable to finish. Our initial goal was to recruit around 20 participants from the Arkansas cross-country team. This proved to be more unrealistic than predicted. The data that was collected from the seven subjects is therefore not an accurate representation of the approximate 15,632 NCAA female cross-country athletes (NCAA 2017). Nor is this small pool of subjects able to produce enough data that could reveal any patterns between variables. To avoid this limitation in the future, this study should be conducted on a much larger scale that could analyze various NCAA female distance runners from schools across the country. Using athletes from a multitude of schools eliminates the number of participants limitation and can provide a more representative sample of the population in question. NCAA conferences like the PAC-12 are already executing research like this study on a large scale. Researchers at the Bowerman Sports Science Clinic, based at the University of Oregon, have developed a database at four different PAC-12 schools, University of Oregon, Stanford University, University of Southern California, and Colorado University Boulder to, "develop a system for integration of biomechanics-based data using an informatics approach to provide assessment of stress fracture risk in collegiate endurance running athletes," (Bowerman Sports Science Clinic). Already one year into their three-year study, these researchers are proving that data collection on a large scale is possible among NCAA student-athletes.

Differences in foot-strike patterns

Five different locations on the midsole of each running shoe were measured to calculate deformation. The posterior heel, lateral heel, medial heel, lateral metatarsal arch, and medial metatarsal arch locations were chosen based on the researcher's personal experience with wear patterns and to accurately measure the entire midsole. While these five locations are suitable in measuring deformation for this study, future studies may want to tailor the midsole measurement locations to the specific athlete based on their foot-strike. A biomechanical pre-test could be help determine if each athlete has a mid-strike, fore-strike, or heel-strike to then note which areas receive the greatest amount of force. It would be at these spots where the midsole should be measured to track any changes.

Differences in shoe brand

An excluding criterion for this study was for the participant to run in a neutral-ride running shoe. This was not exclusive of brand or shoe model, due to an already small subject pool. This broad criterion resulted in a study of three different shoes, the Nike Vomero 13, Brooks Ghost 10, and Brooks Ghost 11. With a larger study population, it would be wise to limit the study to a singular shoe brand which would provide a common thread in product creation and eliminate any slight differences in materials.

Conclusions

The high frequency of stress fractures in female collegiate distance runners can be attributed to many different factors. These factors are magnified further for athletes competing at the NCAA Division 1 level. The type, brand, and durability of the athletes' footwear can all play a role in how the athlete handles mileage and injuries. While previous research is not in agreement on the effects that footwear can have on these injuries, this study proves that midsole thickness of neutral-ride running shoes does decrease as mileage is placed upon it. The limitations of this study inhibit our ability to determine if this change in midsole thickness has a detrimental effect on the athletes' overuse injury pain. Future studies should explore the changes in shoe characteristics throughout a season to determine if these changes play any role in an athlete's ability to perform their best and deal with an injury. Special considerations should be taken to eliminate the limitations of this study.

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