Impact of the Shock Absorption Properties of Basketball Shoe Cushioning Systems on the Likelihood of Lower Extremity Overuse Injuries

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Abstract

Performance basketball shoe cushioning systems are designed to balance two key characteristics: shock absorption and energy return. A greater amount of shock absorption is intended for injury prevention while increased energy return allows for better performance. The purpose of this study was to determine the relationship between shock absorption properties of basketball shoe cushions and the likelihood of lower extremity overuse injuries. The methodology included two phases. In Phase One, the shock absorption capabilities of four basketball shoe cushioning systems were tested in a "Drop Test." A metal weight was dropped onto an apparatus which put force onto the heel of deconstructed cushions, which rested on a force plate. The force plate measured the intensity of the force that passed through the cushion, which established the relative shock absorption capabilities of the cushioning systems. The results of the test demonstrated, with statistical significance, that the shock absorption capability of the Nike Zoom Shift cushioning system is inferior to that of the AND1 Tai Chi, AND1 Attack and Nike Lebron 16. The second phase of the study determined the force applied to the foot using advanced insole technology during jump landings for participants wearing each of the four basketball shoes. It was demonstrated, with statistical significance, that there was more force on the foot in the Zoom Shift and the AND1 Attack cushioning systems compared to the Lebron, which implies better protection for the athlete wearing the Lebrons. Since increased force on the foot over time is a key driver of overuse injuries, the results from the two phases in the study were compared to demonstrate that the greater shock absorption capabilities of the Lebron cushioning system leads to less force on the foot, and therefore, a lower likelihood of overuse injuries.

Introduction

In recent decades, Americans are participating in increased amounts of sports and recreational activities. Recent estimates show that in 2015, 213 million Americans took part in sports and fitness activities (Sheu, Chen & Hedegaard, 2016). As a result of the increased number of participants, injury numbers grew as well. It was found that there was an average of 8.6 million injuries per year between 2011-2014, which equates to 34.1 injuries per 1000 persons (Sheu, Chen & Hedegaard, 2016). Basketball, with 26.9 million participants in 2010 (iii.org - National Safety Council, 2010) has the most injury incidences, with an average of 851,000 annual injuries, which accounts for 9.9% of all sports-related injuries. Within basketball, and all sports, injuries are mainly categorized into two types: acute injuries, which occur due to a sudden force or impact resulting in direct damage to ligaments or bones (Edwards, 2015), and overuse injuries, which result from repetitive microtrauma that leads to local tissue damage (Wilder & Sethi, 2004). Overall, approximately 50% of injuries are classified as overuse (Wilder & Sethi, 2004). This study focuses on overuse injuries in basketball. Common overuse injuries include stress fractures, tendonitis and shin splints (Wilder & Sethi, 2004), and the majority of basketball overuse injuries involve the lower extremities, with the most common injury site being the knee (Leppänen, Pasanen, Kujala & Parkkari, 2015).

Footwear today is engineered and designed for athletic efficiency and to enhance sports performance, while minimizing the risk of injury. Because basketball shoes have many different characteristics and features, there are debates and varying views about what actually constitutes an effective shoe. One of the many characteristics is shock absorption, which was emphasized in shoe designs beginning in the 1970s and 1980s. Shock absorption, the property of athletic shoe cushioning systems that this study is focused on, is defined as a reduction of the potentially harmful impact forces that occur in running, jumping and other activities. The impact force during running can be two to three times the athlete’s body weight, while the forces at the joints can be up to ten times the body weight. Injuries such as stress fractures, tendonitis and damage to joint cartilage are linked to these repeated impact forces (Wilson, 2018). While it might be expected that increased amounts of shock absorption in a cushion better protects from injuries, it is possible that increased shock absorption may sacrifice other important performance features.

Shoe designers focus on footwear construction that balances shock absorption and energy return, two properties that are often in conflict (Huzzard, 2018). The midsole component, typically comprised of polymer foam and located between the upper and outer sole, is the key to addressing this balance of shock absorption and energy return. Shoe manufacturers look for the ideal material to reduce the transmission of force to the foot, while providing adequate energy return to enhance performance. The shock absorption material is most critical at the heel where the calcaneus (heel bone) absorbs the most pressure of any part of the foot during running (Huzzard, 2018).

While research on the relationship of overuse injuries and shoe cushioning systems is scarce, some studies have examined related questions. Lam, Ng & Kong (2016) examined the influence of hard vs. soft midsoles on plantar pressure distribution in male university basketball players. The results indicated that softer midsoles can reduce plantar loading during basketball movements. Bergstra, Kluitenberg, et al. (2015) studied the differences in plantar pressure in runners wearing minimalist shoes (with very little cushion) compared to standard shoes. The authors found that running with the minimalist shoe did not affect comfort, but did increase plantar pressure, which may increase the incidence of metatarsal stress fractures. Finally, Milgrom, Finestone, et al. (1992) performed a randomized study on 390 military recruits to compare the incidence of overuse injuries while wearing standard military boots, as compared to basketball shoes. Overall, the incidence of overuse injuries (90%) did not change, but specific injuries related to vertical impact loads did show statistically significant improvement in basketball shoes.

Although the prior studies summarized above do indicate that certain types of shoes can reduce plantar pressure and overuse injuries, none of the research specifically measures the shock absorption property of the midsole materials in the shoe types compared in each study. The study described in this paper attempts to address that gap by measuring the shock absorption capability of various basketball shoe cushioning systems to determine if there is a correlation between shock absorption and the likelihood of overuse injuries. Phase 1 of this study measured differences in the shock absorption properties of four different basketball shoe cushioning systems. Phase 2 measured the total force on the foot using Loadsol in-shoe insole technology to determine if the shock absorption measurements from Phase 1 are correlated to the likelihood of overuse lower extremity injuries. It was hypothesized that the shock absorption measurements for the cushioning systems would be a reliable predictor of the force on the foot measured during Phase 2.

Research Question

Based on in-depth literature review, it was determined that there is a gap in the available research regarding specific characteristics of sneaker cushioning systems and the impact on overuse injuries. This led to the formation of the research question: “What is the relationship between the shock absorption properties of basketball shoe cushioning systems and the likelihood of lower extremity overuse injuries?”

Methods and Materials

Phase 1

Cushioning Systems Studied

The study included four deconstructed basketball shoes, each with a different cushioning system: (1) AND1 Tai Chi EVA midsole ("Tai Chi"), (2) AND1 Attack Harmonix/EVA system ("Attack"), (3) Nike Zoom Shift Phylon midsole ("Zoom Shift"), and (4) Lebron 16 Max Air system ("Lebron"). All four cushioning systems were extracted from size 9 shoes in order to maintain consistency. Kevin Matthews, Technical Director at ESO Footwear, assisted in sourcing and deconstructing the midsole and outsole for each of the sneakers.

Figure 1: Four deconstructed cushioning systems - Tai Chi (top left), Attack (top right), Lebron (bottom left) and Zoom Shift (bottom right).

Experimental Setup

The experimental setup was designed to test for the shock absorption properties of the four deconstructed cushioning systems. The shock absorption data was obtained by performing a Drop Test that measured the maximum force (in Newtons, "N") applied to a force platform by a metal weight that was dropped from five feet high onto a shoe cushion placed on top of the force platform. The maximum force reading on the force platform indicated the shock absorption capabilities of the cushioning system; the better the shock absorption, the lower the maximum force on the platform.

The setup consisted of the deconstructed midsoles, a force platform, a five foot PVC pipe with 2"diameter, a cylindrical 176.2g metal weight with 1.75" diameter, and the SparkVue data collection application. Each cushion was placed on the center of the force platform such that the center of the heel was directly over the center of the force platform. After securing the cushion with heavy duty Gorilla tape, the PVC piping was placed on the heel of the cushions perpendicular to the platform. The PVC piping was utilized to provide a pathway for the metal weight to be dropped onto the cushions that were secured to the force plate, ensuring a consistent contact point between the weight and the cushion. The SparkVue application was connected to the force platform to retrieve the force data measured during the procedure.

Figure 2a: Experimental setup with the cushioning system on the force platform and the PVC pipe resting on the heel of the cushion.

Figure 2b: Experimental setup just before the cylindrical metal weight was dropped.

<u>Experimental Protocol</u>

Twenty-five Drop Test trials were performed on each of the four cushioning systems. The initial test was performed on the Tai Chi. For each trial, the Sparkvue application was activated prior to the metal weight being dropped. The metal weight was dropped through the PVC piping onto a precise location in the middle of the heel of the Tai Chi cushioning system that was secured to the center of the force platform. After 25 trials, the Tai Chi cushion was replaced with each of the other three cushioning systems, and the identical protocol was repeated.

Data Collection and Statistical Analysis

The SparkVue application recorded the maximum force applied by the metal weight for each trial. SparkVue captured the raw data and the graph of the force applied during the time period of each Drop Test (*Figure* 3).

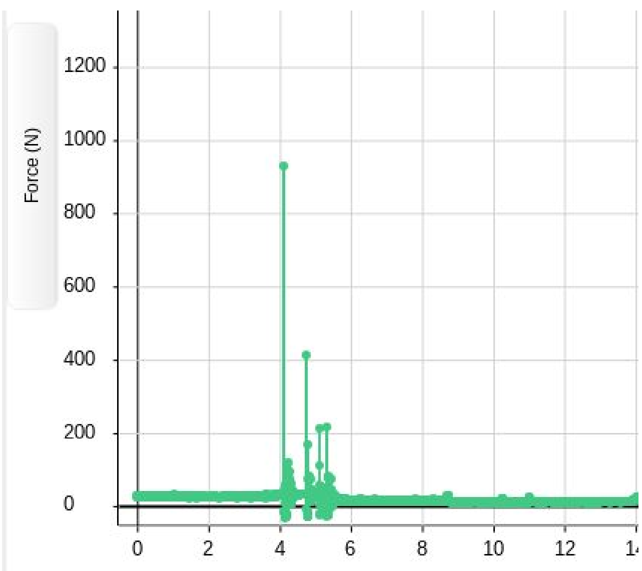

Figure 3: Example of a Force (N) vs Time (s) graph created by the SparkVue application during the Drop Test

After the testing was completed, the maximum force data for each trial from the SparkVue application was manually transferred to a Microsoft Excel spreadsheet, and the mean maximum force and standard deviation were calculated for each of the data sets. A One-Way ANOVA test was used to determine if the differences in the mean maximum force for each of the data sets for each cushioning system were statistically significant. Once a significant difference was identified, a post-ANOVA analysis was performed to determine which data sets contained a significant difference in relation to the other data sets. The post-ANOVA analysis method applied was the Tukey Method because it allows for simultaneous comparison of multiple pairs of data sets.

Phase 2

Cushioning Systems Studied

Phase 2 of the study included the same four basketball shoes used in phase 1; however, in Phase 2, the whole shoe was used as opposed to only the deconstructed cushion. Each shoe possesses a different cushioning system: (1) AND1 Tai Chi EVA midsole ("Tai Chi"), (2) AND1 Attack Harmonix/EVA system ("Attack"), (3) Nike Zoom Shift Phylon midsole ("Zoom Shift"), and (4) Lebron 16 Max Air system ("Lebron"). All four cushioning systems shoes in the protocol were size 9 in order to maintain consistency.

Experimental Setup

The experimental setup was designed to test for the reaction force back up on the foot while performing athletic movements in each of the four basketball shoes tested. The force measurements were obtained by performing jump landings off a bench while wearing Loadsol insole technology ,"a valid and reliable tool (Burns & Deneweth, 2019)" which measured the normal force (F_N) of the ground onto the foot/body. The maximum force measurements for each jump landing was recorded via the Loadsol app.

The setup consisted of the four basketball shoes, the Loadsol insole technology, a 0.43 meter high bench, the loadsol application, and three human participants, all with the same shoe size (men's size 9). The bench was marked with tape, directing the participants where to place their feet, so that the jumping position was consistent for each trial and across all three participants. Additionally, the participants were instructed to keep their hands in front of their bodies during the entirety of the jump (from take off to landing) and to land on the spot marked with tape in order to ensure consistency of the mechanics of each jump. The Loadsol insoles were connected via bluetooth to the Loadsol application, which enabled the data collection.

Experimental Protocol

Five jump landings were performed by each participant in each of the four shoes. A total of twenty jump landings were performed by each participant, resulting in a total of 60 jump landings. For each trial, the Loadsol application was activated prior to each participant's jump. Each participant was given ample rest time between each jump to ensure fatigue did not affect the data.

Data Collection and Statistical Analysis

The Loadsol application recorded the maximum force on the foot for each jump landing, capturing the raw data and providing the graph of the force applied during the time period of each jump landing (*Figure* 4). After the testing was completed, the maximum force data for each trial from the Loadsol app was uploaded to icloud drive and then manually transferred to a Microsoft Excel spreadsheet. The mean maximum force and standard deviation were calculated for each of the data sets and then a One-Way ANOVA test was used to determine if the differences in the mean maximum force for each of the data sets for each cushioning system were statistically significant. Once a significant difference was determined, the Tukey Method, a post-ANOVA analysis that allows for simultaneous comparison of multiple pairs of data sets, was performed to determine which of the data sets contained a significant difference in relation to the other data sets.

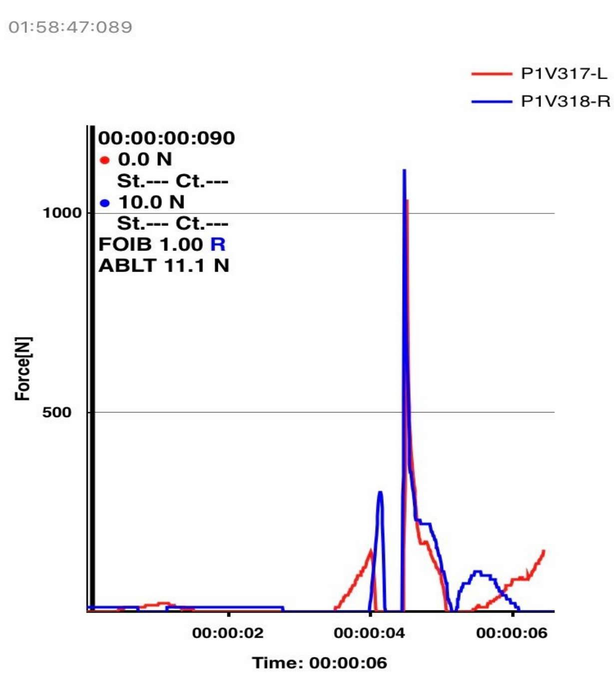

Figure 4: Example of a Force on Foot (N) vs Time (s) graph created by the Loadsol application during the jump landings

Results

<u>Phase 1</u>

The results of the testing indicate a raw difference in the mean maximum force for each of the four cushioning systems (*Figure* 5). The mean maximum force measurements for each cushioning system were as follows: Tai Chi - 899.93N, Attack - 924.29N, Lebron - 915.72N, and Zoom Shift - 1094.96N.

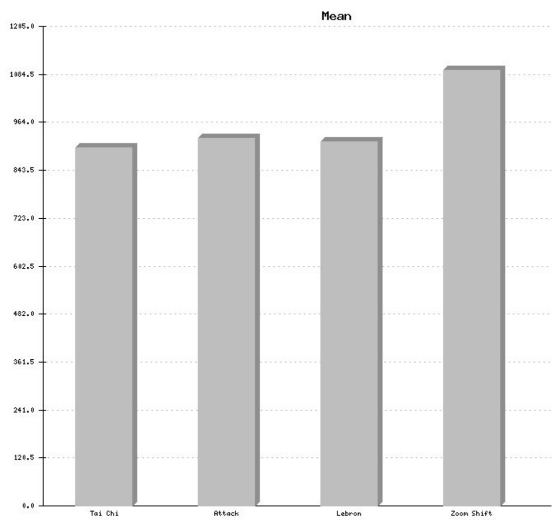

Figure 5: Bar graph of the mean maximum force measurements for the four cushioning systems

For each of the four groups, a standard deviation and 95% confidence interval was calculated. As shown in *Figure* 6a and 6b, the standard deviation and confidence interval for the Zoom Shift were meaningfully greater than the other test groups.

Means table						
	Label	*Mean*	*Stddev*	*95% z-C.I.*		*Freq*
r1:	*Tai Chi*	*899.93*	*162.24*	*836.33*	*963.52*	*25*
r2:	*Attack*	*924.29*	*186.09*	*851.34*	*997.24*	*25*
r3:	*Lebron*	*915.72*	*192.69*	*840.18*	*991.25*	*25*
r4:	*Zoom Shift*	*1095*	*226.13*	*1006.3*	*1183.6*	*25*
All		*958.72*	*206.16*	*918.32*	*999.13*	*100*

Figure 6a: Summary table of mean, standard deviation, and 95%

confidence interval for each data set.

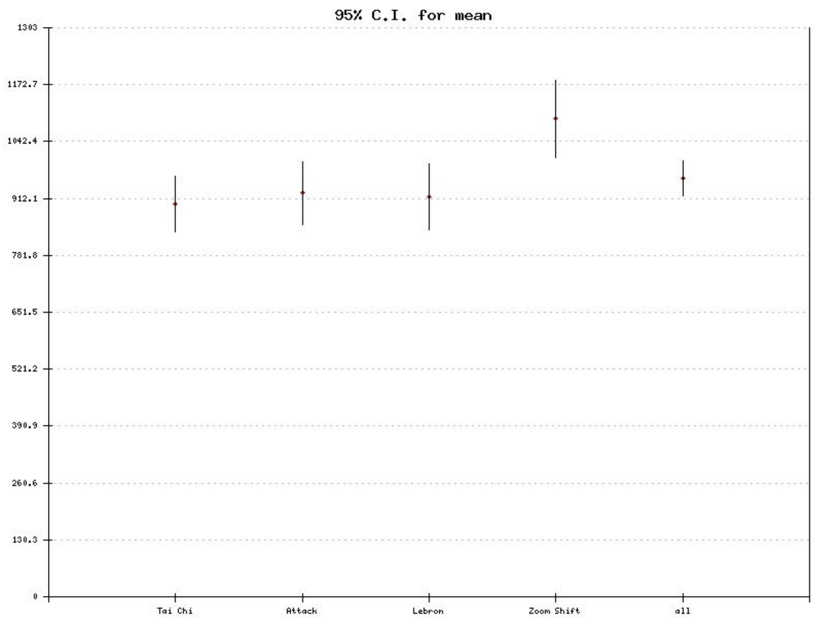

Figure 6b: Graph of the 95% confidence interval for the four cushioning systems

A One-Way ANOVA test was performed to determine if any of the observed differences in means were statistically significant. The ANOVA test null hypothesis was that there were no variances between the means for each of the test groups. Based on a p-value = 0.0014 (< 0.05), the null hypothesis was rejected (see *Figure* 7). This indicated that the data includes a significant difference within certain data sets, but further analysis was required to determine which pairs of means were statistically different from each other.

Anova table				
Source	Σ of Sq.	%	Mean Σ-sq	df
Explained	626327	14.89	208776	3
Unexplained	3581205	85.11	37304	96
Total	4207532	100%		99
F-value: 5.5966; p-value: 0.0014				
Residual standard error: 193.14				

Figure 7: ANOVA table with p-value = 0.0014 (< 0.05)

The Tukey method, utilized to compare all possible pairs of means, was selected as the post-ANOVA analysis tool. Using the results from an ANOVA test, a Tukey value (T) is calculated and compared to the absolute value of the difference of the means of each pair of data sets. If the difference in means is greater than the value of T, then the difference is statistically significant. The calculation resulted in a T = 142.62; as shown in *Figure* 8 below, only three pairs indicated a statistically significant difference in the means with a value of T higher than 142.62. The Tai Chi, Attack, and Lebron cushioning systems did not show a statistically significant difference in their means, when compared to each other. However, each of these cushioning systems did show a statistically significant difference in the mean maximum force when compared to the mean of the Zoom Shift (*Figure* 8).

Pairwise Comparison		Diff of Means	Tukey Value (T)	T vs. Diff Means
Tai Chi	Attack	24.36	142.62	-118.26
Tai Chi	Lebron	15.79	142.62	-126.83
Tai Chi	Zoom Shift	195.03	142.62	52.41
Attack	Lebron	8.57	142.62	-134.05
Attack	Zoom shift	170.67	142.62	28.05
Lebron	Zoom Shift	179.24	142.62	36.62

Figure 8: Pairwise comparison of all four data sets utilizing the Tukey method

Phase 2

The results of Phase 2 indicate a raw difference in the mean maximum force (N) on the foot in the four different basketball shoe cushioning systems. The standard deviation was also calculated. The mean maximum forces and standard deviations are shown in the diagram below (*Figure* 9).

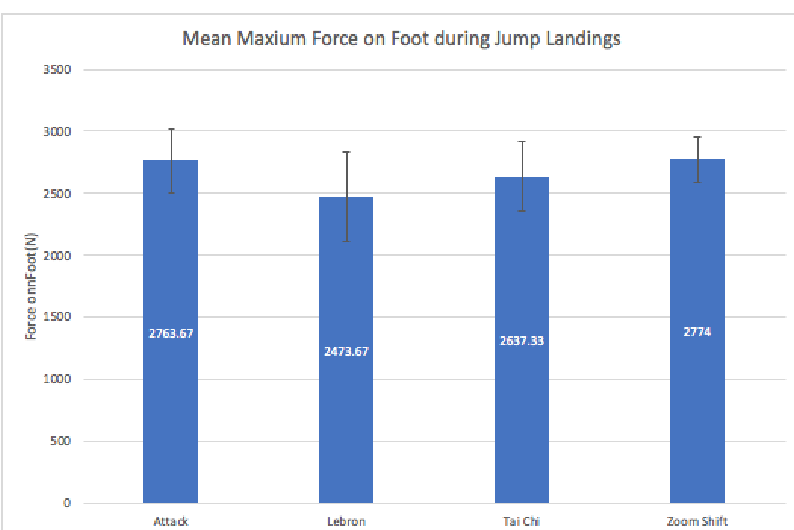

Figure 9: Bar graph of the mean maximum force on the foot measurements for the four cushioning systems

The results show a considerable difference between the Lebron (2473.67 N) and the Tai Chi, Attack, and Zoom Shift (2637.33 N, 2763.67 N, and 2774 N, respectively). A One-Way ANOVA test was performed to determine if any of the observed differences in means were statistically significant. The null hypothesis, that there were no variances between the means for each of the test groups, was rejected based on a p-value = 0.0139 (< 0.05) (see *Figure* 10) This indicated that the data includes a significant difference within certain data sets, but further analysis was required to determine which pairs of means were statistically different from each other.

Summary of Data						
	Treatments					
	1	2	3	4	5	Total
N	15	15	15	15		60
∑X	41455	37105	39560	41610		159730
Mean	2763.6667	2473.6667	2637.3333	2774		2662.167
∑X2	115476625	93576425	105409800	115919600		430382450
Std.Dev.	254.7861	357.6734	277.3463	187.7422		295.5767

Figure 10: Summary of Anova test with p-value = .013899

The *f*-ratio value is 3.86591. The *p*-value is .013889. The result is significant at $p < .05$.

The Tukey method was selected as the post-ANOVA analysis tool because of its ability to compare all possible pairs of means. Using the results from an ANOVA test, a Tukey value (T) is calculated and compared to the absolute value of the difference of the means of each pair of data sets. If the difference in means is greater than the value of T, then the difference is statistically significant. The calculation resulted in a T = 266.45; as shown in *Figure* 11 below, only two pairs indicated a statistically significant difference in the means with a value higher than 266.45. The Tai Chi cushioning system did not show a statistically significant difference in its mean when compared to the other shoes. However, the Attack and Zoom Shift did show a statistically significant difference in the mean maximum force when compared to the mean of the Lebron (*Figure* 11).

Pairwise Comparison		Diff of Means	Tukey Value (T)	Diff Means - T
Tai Chi	**Attack**	126.3334	266.45	-140.12
Tai Chi	**Lebron**	163.6666	266.45	-102.79
Tai Chi	**Zoom Shift**	136.6667	266.45	-129.79
Attack	**Lebron**	290	266.45	23.55
Attack	**Zoom shift**	10.3333	266.45	-256.12
Lebron	**Zoom Shift**	300.3333	266.45	33.88

Figure 11: Pairwise comparison of all four data sets utilizing the Tukey method.

Discussion and Conclusion

The overall objective of this study is to determine if the shock absorption capability of cushioning systems in basketball shoes can reduce the likelihood of overuse injuries. The first phase of the data collection was designed to measure the shock absorption properties of cushioning systems for four different sneakers - the Tai Chi, Attack, Lebron and Zoom Shift. A higher force generated by the Drop Test indicates less shock absorption from the cushioning system. The results from the study showed no statistically significant difference in the shock absorption capability amongst the Tai Chi, Attack and Lebron. However, the Zoom Shift cushioning system demonstrated a clear difference with a significantly higher mean force measurement, indicating a lower shock absorption capability compared to each of the other three cushions.

The results of phase 1 support the conclusion that the use of different materials in basketball shoe cushioning systems does lead to variances in the shock absorption measurements. It is particularly interesting that the Lebron shoe is marketed and priced as a premium comfort and performance shoe, yet it demonstrated the same shock absorption capability as the two less expensive and less known AND1 shoes (the Tai Chi and Attack). One explanation for the Lebron's lack of shock absorption advantage is that shoe designers prioritize comfort, a characteristic that can be easily perceived and felt during use, over measureable shock absorption. Additionally, many basketball shoes are designed for increased energy return, a performance characteristic of shoes that provides players with extra bounce back. It can be difficult to balance energy return performance and shock absorption, which are often in conflict. Of course, the Lebrons are built especially for sports performance (high energy return), which could explain their lack of advantage regarding shock absorption. Given that the Zoom Shift was the worst performer in this study of shock absorption, further research would be interesting to better understand the property of the specific materials in the Zoom Shift that may have led to the poor performance.

In Phase 1 of the study, the total downward force on the force platform (a proxy for the floor during recreational use), was measured, which established the relative shock absorption capabilities for the Tai Chi, Attack, Lebron and Zoom Shift. To determine if the shock absorption levels correlated to the likelihood of overuse lower extremity injuries, Phase 2 was performed, where the total force on the foot, which is more correlated to overuse lower extremity injuries, was evaluated. The force on the foot was measured using Loadsol in-shoe insole technology from the motion laboratory at the Hospital for Special Surgery. The hypothesis of Phase Two was that insole force measurements would be highest for the Zoom Shift, which would demonstrate a correlation between shock absorption (as measured in Phase 1) and the force exerted on the foot, which would lead to overuse lower extremity injuries, as research has suggested that relatively large and rapid impact forces while running increase the risk of developing an overuse injury of the lower extremity (Hreljac, 2003).

The results of Phase 2 showed a statistically significant difference in the force on the foot measurements between the Lebron and the Zoom Shift, and between the Lebron and the Attack, indicating a lower likelihood for overuse injuries in the Lebron shoe and a higher likelihood for overuse injuries in the Zoom Shift and Attack. And, although no significant difference in the mean maximum force on the foot between the Lebron and Tai Chi was detected, the raw data displays a noticeable difference in the force measurements. Phase 2 of the study supported the results from Phase 1, as the Zoom Shift, which measured (in Phase 1) as the cushioning system with the worst shock absorption, tested as the shoe with the most force on the foot in Phase 2. The results from Phase 2 do help resolve one of the most intriguing questions that arose from Phase 1: is the Lebron shoe, the most expensive of the four shoes by a wide margin, actually better at protecting from overuse injuries than the other three shoes? Looking at the results, the relatively large increase in price for the Lebron shoe is justifiable as it reduces the amount of force on the foot, therefore decreasing the likelihood of overuse lower extremity injuries. The air cushioning system of the Lebron “simply offers a different experience than a cushioned foam[s]” of the Zoom Shift, Attack, and Tai Chi.

The results of this study are useful to basketball footwear companies, such as Nike, Adidas, and others, as they will better understand the impact of the shock absorption property in basketball shoes on overuse injuries. This could result in the production of more basketball shoes with increased shock absorption. Additionally, this study is valuable to all basketball players, from players in youth leagues to professional players, as they will be able to make informed decisions when choosing their footwear.

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