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Does Wearing Multiple Pairs of Shoes Influence Injury Rates?

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DOES WEARING MULTIPLE PAIRS OF SHOES INFLUENCE INJURY RATES?

By

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ABSTRACT

DOES WEARING MULTIPLE PAIRS OF SHOES INFLUENCE INJURY RATES?

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Running research has attempted to better understand the causes of movement-related injuries and a large segment of this research revolves around footwear and training regimens. A survey has reported lower injury rates in runners who wore multiple shoes with in a 5-month period. Previous literature lacks the analysis of variables leading to training related decisions and whether wearing multiple pairs of shoes can have an extended influence on injury rates. **PURPOSE:** To determine whether wearing multiple pairs of shoes has an influence on injury rates. **METHODS:** A survey was developed to ask participant's injury related history along with their footwear, running surface, and reasons why they decided to make the decisions they made. A χ^2 goodness of fit test assuming equal distribution was used to determine whether wearing multiple pairs of shoes influenced injury rates. **RESULTS:** The χ^2 goodness of fit test assuming equal distribution demonstrated similar number of runners received an injury while running in the single and multiple shoe group (χ^2=4.172, p=0.41). **CONCLUSION:** Individuals who had a more extensive injury history wore multiple pairs of shoes and only individuals who switched within the last 5 years to multiple shoes saw improvement in acute injury rates.

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CHAPTER 1: Introduction

Running related injuries are multifactorial in their etiology, with varying theories as to the best method to lower injury risks. The most common type of running injuries are overuse injuries including iliotibial band syndrome, patellofemoral pain syndrome, plantar fasciitis, achilles tendonitis, and stress fractures (Fredericson & Misra 2012). Causes of overuse injuries can be separated by intrinsic and extrinsic factors. An example of an intrinsic factor includes anatomical structures while external factors include training habits, environmental conditions, and footwear (Renstrom & Johnson 1985, Jacobs & Berson 1986, Kaufman et al. 1999, Hootman et al. 2002, Zifchock et al. 2008).

A large branch of running biomechanics has analyzed the influence that footwear has on running gait. Midsole hardness, cushioning, motion control and other footwear properties along with footwear age and inserts have been studied to determine footwear's influences on gait and injury risk. (Cook et al. 1985, Kakihana et al. 2004, Butler et al. 2007, Erhart et al. 2008, Kong et al. 2009). All of these properties have shown varying effects leading to no consensus as to the best footwear design. The lack of hypothesized changes due to the introduction of new footwear properties and inserts have given rise to a paradigm stating human gait attempts to maintain a preferred movement pattern regardless of external perturbations (Nigg et al. 2015). Individuals utilize changes in kinematics to adapt to perturbations to maintain preferred movement patterns.

When rapid or vast changes in training regimen occur, running related injury risk increases. Changes introduced slowly cause progressive overload to occur increasing endurance related measures along with muscular adaptation (McNicol et al. 2008). As individuals may have reached a performance plateau and cannot increase their training regimen without injury risk, footwear may be of interest to introduce change to create increased adaptability. Increasing shoe count during training may add variation as footwear has demonstrated it has an ability to influence movement mechanics. Adding healthy variation causing adaptation to occur may increase variation in musculature used within the foot strengthening intrinsic muscles. This strengthening may be able to aid runners in lowering running related injuries.

1.1 Purpose of the Study

The purpose of this study was to determine whether individuals who wear multiple pairs of shoes have different rates of injuries than runners who were the same shoe throughout training. In order to accomplish this aim, runners were asked to complete a survey collecting training related variables and their running and injury history.

1.2 Significance of the Study

This study aims to fill a gap in the literature by analyzing differences in injury rates between shoe usage patterns and training history. Literature currently indicates that individuals who wear multiple pairs of shoes may be at a lower risk of injury, but there is a gap as to why and if there are any other factors that may be of influence to injury rates (Malisoux et al. 2015). This study looks at previous injury history and current training habits to see if there is a relationship between current and past injury history and their footwear usage patterns. This information would give a better understanding of if and why individuals wear multiple pairs of shoes and if that modification can lower injury risk.

1.3 Statistical Hypothesis

- Individuals who trained in a single pair of shoes will have a greater number of injuries than those who train in multiple pairs of shoes.

- Individuals who switch from single to multiple shoe usage will have had lesser incidence of injury reoccurrence.

CHAPTER 2: Literature Review

2.1 Introduction

In 2014 there were 20,000,000 reported race finishers in the United States (Running USA 2014). Although running has become increasingly popular, there appears to be no increases in the frequency of running related injuries (Nigg 2015). Running injury causes are not well understood and many theories have risen to try and explain this phenomenon. This literature review aims to present factors influencing injuries and various attempts made to lower injury rates in the general running population.

2.2 Running Related Injuries

Depending on injury definition and population studied, injury rates have been reported as 18-92.4% per 1,000 hours of running (van Gent 2007). A proposed cause of this large range is due to uncertainty as to the definition of an injury. Injury is difficult to define as pain sensitivity may change from person to person, but anatomical changes that lead to injury are fairly well understood. Anatomical structures have an individualize healthy threshold of stress they can withstand prior to permanent deformation. Wolff's and Davis's laws indicate bone and soft tissue respectively remodel in response to increased stress (Huiskes 1995). These biological adaptations are beneficial for injury prevention if given the proper time to heal and to accommodate to increased demands. Overuse injuries occur when the accumulation of the acute microtraumas inflicted through repetitive foot strikes of prolonged running surpass the tissue's healthy threshold and are not allowed time to remodel properly (Hreljac 2005).

Causes of overuse injuries can be categorized into intrinsic or extrinsic factors. Intrinsic factors include anatomical components such as foot arch, leg length discrepancy, muscular imbalance, structural deviations, and many others (Renstrom & Johnson 1985, Jacobs & Berson 1986, Kaufman et al. 1999, Hootman et al. 2002, Zifchock et al. 2008). Stress fracture risks were investigated regarding arch type height and it was determined that individuals with pes planus and cavus had increased injury risks (Kaufman et al. 1999). These findings contradict the previous findings of Cowan et al. 1993 and Giladi et al. 1985 indicating pes planus as a protective factor. Prolonged increased pronation has been demonstrated to influence kinematic patterns shown to increase injury risk (James et al. 1978, Viitasalo & Kvist 1983, Sommer & Vallentyne 1995, Becker et al. 2013). In a prospective study by Leetun et al. (2004) analyzing collegiate athletes, they identified athletes with lower preseason values in hip abductors and external rotator's strength had higher injury rates. (Leetun et al. 2004) The influence of muscular imbalance on injury risk is further emphasized by the findings of Knapik et al. stating a bilateral difference of 15% in knee flexor strength may result in an injury rate 2.6 times higher in those with lower strength (Knapik et al. 1991, Zifchock et al. 2008). The influence these intrinsic factors have on gait mechanics may be mitigated or eliminated by strength training or, in more severe cases, corrective surgery. While these factors are often due to chronic training errors leading to asymmetry, external factors are often adjustable.

External factors are often considered the highest risks of running related injuries. While mileage has been correlated to injury risk, it is unclear what volume of weekly mileage leads to the highest injury rates. Koplan et al. (1995) reported women running 40-49 miles and men running 30-39 miles were the only ranges that had a significantly higher rate of injury than those who run at a lower weekly volume, while Hootman et al. (2002) reported similar significance at 20 miles per week regardless of sex. In a study comparing miles run per week, hip and hamstring injuries were reported in individuals that had been increasing their miles per week compared to their counterparts (Wen et al. 1997). Although the distance ran per week can be an important influencer on injury risk, the pace at which one runs is also an injury risk factor.

Running intensity is the pace or average velocity at which one runs. A split in the literature exists as to the relevance of running intensity on injury risks. Jacobs et al. reports a pace faster than an 8 min/mile has significantly higher injury rates, but Hootman et al. (2002) found significance at a 15 min/mile (Jacobs 1986, Hootman et al. 2002). Individuals with iliotibial band syndrome and achilles tendinitis ran faster than controls by 3 seconds/mile and 13.8 seconds/mile respectively (Messier et al. 1995, McCrory et al. 1999). Although reports have demonstrated a difference in injury rates with varying weekly running intensities, many articles have reported no differences (Messier et al. 1988, Walter et al. 1989, Messier et al. 1991, van Mechelen et al. 1993, Jakobsen et al. 1994, Wen et al. 1998, Duffey et al. 2000). The previously mentioned external factors are running related, but factors also include the environment like running surfaces.

Lastly, running surface influences external forces potentially influencing gait mechanics and in turn injury rates. A study comparing running on asphalt, acrylic, and rubberized asphalt demonstrated a similar finding in many articles that although increased impact forces would be hypothesized, changes in loading rates and kinematics were discovered mitigating differences (Dixon et al. 2000). Decreases in loading rates were observed in the rubberized asphalt along with varying changes in joint angles and joint angular velocities observed across all groups. Similar changes in joint kinematics were measured by Hardin and colleagues. Greater extension at the hip and knee during foot contact, maximal hip flexion decreases, and increased peak angular velocity were all seen in more compliant surfaces (Hardin et al. 2004). Metabolic cost and leg stiffness changes due to surface stiffness was measured by Kerdok et al. indicating efficiency is also influenced by surface stiffness (Kerdok et al. 2002). Although running surface may influence gait mechanics, there isn't a choice as to what external surfaces you run on during races.

Elite runner's weekly mileage and pace averages far surpass novices, and road race surfaces are identical for all runners, but injury rates have been shown to be lower in elite runners (Macera et al. 1989, Buist et al. 2008, Videbaek 2015). Rapid and drastic changes in these variables may elicit increased injury rates. To minimize risk of injury due to external factors, slowly progress to increased distances and paces while allowing your body to adapt at each increase (Hickson et al. 1981, McNiol et al. 2008, Auersperger et al. 2014). Regarding running surface adaptation, if changing from road to trail or visa-versa, ease into the new running surface and start at low and slow paces and increase as you adapt. Lastly, this principle also applies to footwear where easing into a new pair or design may decrease injury risk.

2.3 Footwear

The footwear industry is an ever-changing field attempting to provide the newest design to increase sport performance and minimize injury rates. As a consequence of the inability to mass produce individualized footwear, contrasting opinions emerge as to the best design for minimizing injury rates. A proposal has been declared to shift toward a new paradigm of selecting footwear based on the runner's comfort as individuals have varying comfort preferences (Mündermann, Stefanyshyn, Nigg 2001). More comfortable shoe conditions have led to decreases in movement-related injuries and oxygen consumption (Nigg 2001, Luo et al. 2009). Due to individual foot anatomy and ideals of what is comfortable, footwear companies have developed a wide range of footwear designs including minimal and maximal footwear, different support qualities and insoles, and many other altering properties.

Research conducted in 1987 began a movement designing footwear to mimic ancestral barefoot running. Running with minimal constraints on the foot would allow for a more natural function believed to lower injury rates (Robbins & Hanna, 1987). Minimalistic footwear aims to imitate the shape, kinematics, or feel of barefoot running. Although closely simulating barefoot running, minimalistic footwear influences foot function and in turn manipulates kinetic and kinematic variables of running gait.

Changes in ankle angle at foot strike have been observed when individuals were introduced to minimalistic footwear. When trained rear foot and forefoot strikers with no barefoot running experience were introduced to minimalistic footwear, a tendency to shift to an ankle angle like a mid or forefoot strike was observed (Paquette, Zhang, Baumgartner 2012). Lieberman et al. had similar findings, but allowed participants a 6-week training intervention with the FiveFingers™ minimalist shoe. Rearfoot strike prevalence dropped from 72% to 36% and forefoot strikers increased from 14% to 57% (Lieberman et al. 2010). Along with foot contact angle, other kinematic and spatiotemporal variables have been measured when changing to minimalist footwear. Research discovered greater knee flexion at foot strike, shorter contact times, and increased step frequency in the minimalistic footwear (Schutte 2013, Sinclair et al. 2015, Hollander et al. 2015). Higher loading rates, peak plantarflexor moments, and eccentric ankle power were found in minimalistic footwear conditions compared to their shod counterparts but peak knee flexion and range of motion, peak extensor moment, peak early stance eccentric and late stance concentric power were reduced (Paquette, Zhang, Baumgartner 2012). Increased loading rates have been associated with tibial stress factors (Kadpoor and Nikooyan 2011) but altering to a forefoot strike has been shown to transfer the energy into rotational energy at the ankle (Lieberman et al. 2010). Research has not identified higher injury rates in any type of footwear condition compared to others, only that individuals changing to a midfoot strike without an assimilation process may be more susceptible to injury. The footwear with the most drastic design difference from minimalist footwear is maximalist footwear.

As minimal footwear attempts to mimic barefoot running, maximalist footwear attempts to increase cushion to absorb impact forces primarily at the heel. Maximal footwear is characterized by a highly cushioned midsole greater than 30 mm. Research is split regarding differences in kinematics between traditional footwear and maximal footwear. Decreased eversion range of motion, foot strike angle at contact, and inversion at foot contact along with an increased eversion at toe off have all been demonstrated in maximal footwear (Hannigan and Pollard 2019, Agresta et al. 2018). Peak and initial contact dorsiflexion has also been found to be lower in maximal footwear than traditional footwear (Becker, Borgia 2019). In 2016 Sinclair et al. examined runners with a rearfoot strike in minimalistic footwear, traditional, and maximal footwear with no significant differences between maximal and traditional footwear in kinetics or knee and ankle kinematics. Although not significant, higher loading rates were seen in maximal compared to traditional footwear indicating the increased cushion may not be enough to attenuate shock and may cause the runner to be susceptible to injury (Sinclair et al. 2016). Maximalist and minimalist footwear are variations in midsole thickness that allow for shock attenuation, but another important aspect to footwear is potentially controlling and supporting the foot if necessary.

To accommodate for anatomical variation of the foot, footwear companies have constructed several footwear designs with different levels of arch support. The three main categories in order of least to most support is: cushion trainer (neutral), stability, and motion control. Support level is often prescribed by foot arch height which leads to different requirements to most benefit the runner. A low arch height would value a motion control shoe due to the footwear's ability to limit the rearfoot motion caused by this arch type (Williams et al. 2001). High arches increase lower extremity loading, so a cushion trainer meant to attenuate these loads would be most suited for this population (Williams et al. 2001). As normal arch types have more average values, this group would benefit most from the stability category which offers a mix of control and cushion. In a collection of studies by Cheung and Ng, motion control footwear did not lead to a change in the rearfoot angle and plantar pressures on medial foot structures, even after a fatiguing protocol (Cheung & Ng 2006 & 2008). Both of these studies were compared to identical populations running in cushioned footwear and measured increases in both rearfoot motion and plantar forces in that group. Knee injuries are common in low arch runners and motion control footwear when worn by this population has been shown to lower peak tibial internal rotation which is a risk factor for knee injuries (Williams et al. 2001, Butler et al. 2006). As knee injuries are common in low arch runners, bony injuries are common in high arch runners (Williams et al. 2001). In the Butler et al. (2006) study, they measured lower peak positive tibial acceleration in high arched runners in cushioned trainers. Decreases in peak positive tibial acceleration may lead to decreased bony injuries and lower injury risk. These beneficial categories of footwear are accomplished through manipulating the midsole of the shoe.

The midsole stiffness of a shoe is the hardness of foam cushioning layer between the inner sole and outer sole of the shoe. Typically, the foam is composed of ethylene vinyl acetate (EVA), polyurethane (PU), or a combination of these with different hardness levels. It is with these combinations, footwear companies are able to create the above-mentioned motion control and other footwear designs. Each footwear manufacturer has a unique formula to manipulate foot motion within the shoe to most benefit the runner. For example, Brooks Shoe Company added a four-degree varus wedge in their midsole as a pronation control technique (Shorten, 2000).

The relationship between the ground surface and midsole hardness influences gait kinematics. As previously mentioned, since running surface can't be manipulated, midsole hardness coupled with training are a runner's opportunity to best accommodate for race day conditions. It is widely accepted that softer surfaces increase joint stiffness while harder surfaces create more shock absorbing kinematic changes. It is believed these kinematic changes are an attempt to minimize loading rate (Nigg 1987). There is a positive correlation between increases in midsole hardness and a greater load distribution on the medial ankle structures (Nigg 1987). Harder midsoles also cause increases in knee flexion velocity and ankle dorsiflexion velocity (Clarke, Frederick, Cooper 1983, Hardin, Bogert, Hamill 2004). A more recent article concluded a softer midsole may increase joint stiffness of the ankle and knee joint (Baltich, Maurer, Nigg 2015). An increase in joint stiffness is believed to be an attempt to offset surface compression and maintain a common center of mass trajectory throughout the run (Ferris et al. 1999). Footwear variations in midsole hardness allow runners the ability to increase or decrease hardness dependent on running surfaces. Although footwear may be a successful modification to accommodate for surface hardness, shoe inserts may also allow for an individualized increase or decrease in stiffness.

2.4 Footwear Inserts

Footwear inserts have been a valuable inclusion to footwear technology allowing for modifications to footwear minimizing pain or other negative symptoms that may lead to pain or other deleterious effects. Due to footwear companies developing footwear for the general population and individualistic foot anatomy variation, many individuals are utilizing less optimal footwear. The development of footwear inserts allows for increased accommodation to individualistic foot needs. Examples of footwear inserts include wedges and orthotics.

Wedge inserts are designed to shift the center of pressure under the foot and realign the limb axis. A lateral wedge shifts the axis to decrease the external knee adduction moment and redistribute the load toward the lateral aspect of the knee (Crenshaw et al. 2000, Shelburne et al. 2008). Lateral wedges have shown great success throughout literature at decreasing peak external knee adduction moment (Crenshaw et al. 2000, Kerrigan et al. 2002, Kakihana et al. 2004, Butler et al. 2007, Erhart et al. 2008). These changes in external knee adduction moment can be seen with as little as 1 mm differences in center of pressure shifts (Shelburne et al. 2008).

Wedges can be inserted on the medial or lateral aspect of the foot with various lengths and inclination angles. A study by Hinman et al. demonstrated full length lateral wedges lowered the external knee adduction moment to a greater degree and with more consistency than the rearfoot lateral wedge (Hinman et al. 2008). Although reported an angle of 5° or greater may lead to discomfort by Kakihana et al., many other studies have been conducted with greater angles and no reported discomfort (Nester et al. 2003, Schmalz et al. 2006, Russell et al. 2011, Weinhandl et al. 2015). A wide variety of results have been reported regarding wedge angles and their effectiveness on external knee adduction moment. With a full-length lateral wedge, Fischer et al. reported 15% and 19% reductions in external knee adductor moment in 4° and 8° wedges respectively (Fischer et al. 2007). A lower 5° wedge resulted in an 11.9% reduction in external knee adductor moment (Hinman et al. 2008) while 10° (Nester et al. 2003) and 14° (Schmalz et al. 2006) wedges displayed no reduction. These variations are believed to be caused by individuals reacting differently since most often studies are conducted on healthy runners who attempt to maintain their preferred movement pattern. This variation in effect is commonly seen in footwear inserts like wedges and orthotics.

Foot orthotics have shown on countless occasions to alleviate symptoms and pain in various populations (Leung et al. 1998, Gross et al 2002, Mejjad 2003, Powell et al. 2005, MacLean 2008). Decreases in pain are beneficial, but the mechanism in which orthotics produce these reductions is not fully understood. It has been observed that orthotics primarily influences the initial 50% of the stance phase (Nawoczenski et al. 1995, MacLean et al. 2006). Although not always significant, orthotics reduce rearfoot motion (Bates et al 1979, Hamill et al. 1992, Leung et al. 1998, Stackhouse et al. 2004, MacLean et al. 2006, MacLean et al. 2008). Similar results were measured regardless of foot strike (Stackhouse et al. 2004). In a study conducted by MacLean et al. They discovered a reduction in rearfoot eversion, rearfoot eversion velocity, and maximum ankle dorsiflexion and inversion moment (MacLean et al. 2006). In regards to knee kinematics, they saw no change in the orthotics group which contradicts Williams et al. who reported increases in maximum knee adduction angle (MacLean et al. 2006, Williams et al. 2003). MacLean et al. in a later study reported similar changes in rearfoot kinematics, but also reported decreases in maximum knee external rotation moment along with decreases in ankle impact peak and loading rate which have been linked to decreasing injury rates (Maclean et al. 2008). In that same study, they tested the orthotics group after a 6-week intervention and reported no differences in values over time. This indicates an immediate influence on gait from the orthotic and a lack of degradation in the orthotic within that period. Unfortunately, footwear ages and changes the midsole properties which may influence gait mechanics due to the shoe-orthotic relationship (MacLean et al. 2009).

2.5 Footwear Aging

Not unlike many other decisions made by runners, when to retire your current pair of shoes is dependent on the runner's preference. Runner's World and Fleetfeet both suggest 300-500 miles are an appropriate distance to begin to consider replacement for training shoes and lower for race day flats (Running Shoe FAQ 2008, Matsumoto 2018). Research conducted by Cook et al. determined at around 500 miles, a shoe has lost 40-55% of its shock absorbing qualities (Cook et al. 1985). In that article, they established shoe cushion absorption loss fits an exponential decay curve with roughly 10-25% loss at 10 miles, 27-39% at 100 miles, and a leveling off at around 53% after 500 miles. Recovery characteristics of the footwear was also analyzed with no difference in shock absorption ability regardless of time between testing at 0hr, 24hr, and 72hr (Cook et al. 1985). These trends were consistent across varying shoe types tested, initial absorption abilities were 33% different, indicating aging occurs at similar rates regardless of shoe construction.

A similar shoe aging study was conducted by Rao et al. looking at muscle activation, kinetic, and kinematic differences between running in shoes of different ages. The experimental design had three types of footwear characterized by elastic, viscous, or intermediate and aged one pair of each with a machine imitating a 2-month trail running protocol of 660 km and the other pair left aside for the participant. Participants stepped down a staircase 17cm with their right foot striking the force plate and stepping forward onto a platform with their left foot 17cm down. Material stiffness increased and shock absorption decreased across all groups. Vastus Lateralis pre-activation was higher in the fatigued elastic shoe conditions, but no other interactions were discovered for muscle pre-activation. Increased tibial accelerations and loading rates were revealed in the viscous fatigued shoe condition (Rao et al. 2014).

The aforementioned articles created the aging effect through mechanical means, but Kong et al. had participants utilize a specific pair of given shoes to pretest and post-test after running for 200 miles in that pair during their own training protocol. This design more accurately represents shoe aging in a practical sense. Thirty participants were split into three footwear groups by varying midsole designs: air, gel, and spring. Pre and post-test protocol included running down a runway at 4.5 m/s (6 min/mile). Results indicate no significant differences in vertical ground reaction force or instantaneous loading rate of the vertical forces. Significant differences were measured regarding kinematic variables. Stance time and plantar flexion at toe-off increased for all three groups in the worn shoes. Reduced values were observed for maximum forward torso lean, forward torso lean at toe-off, and maximum dorsiflexion at the ankle (Kong et al. 2009). Kong et al.'s findings coincide with the majority of literature indicating regardless of changes in footwear, external forces remain fairly constant while kinematic variables change to maintain a preferred movement path.

2.6 Conclusion

Adaptability regarding running, is the ability to maintain your current preferred movement path regardless of the external conditions. The preferred movement path was defined by Nigg et al. as "the skeleton of an individual athlete attempts, for a given task, to stay in the same movement path" (Nigg et al. 2015). Previous studies mentioned in this review analyzed movement through noninvasive techniques and have reported varying results. When analyzing these results with the preferred movement path paradigm, the varying results are the attempts of each participant's kinematics adjusting to external conditions to maintain their previous preferred movement path. Nigg et al. tested this paradigm by changing footwear and insert conditions while utilizing bone pins and measured minimal and nonsystematic changes in tibial and calcaneal movement (Nigg et al. 2010). This study along with a few other similar studies demonstrate external perturbations have minimal effects on the overall movement pattern due to kinematic adjustments throughout the stance phase (Eng & Pierrynowski 1994, Nawoczenski et al. 1995, Nigg et al. 2010). The inconsistency of the influence of footwear demonstrates a need to better understand footwear and footwear usage pattern's role on injury rates. Therefore, the purpose of this study is to determine whether training in multiple pairs of shoes has an influence on injury rates.

CHAPTER 3: Methods

3.1 Participants

Sixty-one runners were recruited in the local area by contacting various running groups. Thirty males (45.2 ± 12.6 years) and thirty-one females (41.5 ± 12.5 years) were recruited on the basis that they ran over 15 miles a week on average and were between the ages of 18 and 65. Runners were categorized into two groups, single shoe usage (n=30) and multiple shoe usage (n=31). Single shoe usage consisted of wearing a single model pair of shoes throughout training while the multiple group wore multiple models of footwear.

3.2 Procedure

This survey was developed to better understand injury history and its influence on current training regimens. To accomplish this aim, questions were developed to ask about footwear and injury history. Questions regarding footwear included the number of shoes worn during training, what models of shoes they own, when and why they rotated footwear, do they wear orthotics, and how long they have been running on multiple pairs of shoes. The injury section of the survey is a modified version of the Bartel et al. injury survey displaying a list of common running related injuries and allowed participants to select all the injuries they have had (Bartel et al. 2019). Each selected injury prompted a set of questions including whether the injury was a single occurrence, repeated occurrence, or chronic, when the first and most recent occurrence of the injury was, and a few questions asking how the injury affected their training. Along with these questions about footwear and injury history, the survey collected information regarding basic anthropometrics, average weekly training schedule, and what running surfaces they utilize and why they run on those surfaces. This survey was validated by a two-step process of getting initial edits from my committee members followed by a distribution to a small subset of runners that matched the desired survey population. Data from this pilot were analyzed and processed to determine whether the survey questions sufficiently produced interpretable results.

3.3 Limitations

A few limitations do exist with this study. The greatest limitation is, as with any retrospective survey, participants' recall bias as it relates to their injury history. To minimize error, a scale was used as to how recent the injury occurred and when they switched footwear usage patterns. Reporting as 5+ years leaves ambiguity but allows for consistency and minimizes error. This decision was deemed as minimally impactful due to the difficulty in inferring a single factor as potential injury preventing 5+ years ago. Another limitation of this study is the information regarding the influence of orthotics. Further research needs to analyze orthotic wear patterns and see if multiple shoe usage without orthotics may have a greater influence on injury rates.

3.4 Data Analysis

Survey questions were developed using Qualtrics software and results were then exported to Excel for interpretation and preparing for SPSS (Qualtrics, Provo, UT, Excel 2005). Processed data were then exported to SPSS, version 26, to perform normality testing and run a goodness of fit test (SPSS, Chicago, IL, USA). A χ^2 goodness of fit test assuming equal distribution was used to compare whether groups had differences in injury prevalence.

CHAPTER 4: Results

Within group normality testing indicated there was not an even distribution within both groups for numerous variables. A Mann-Whitney U test was used to compare differences between groups. Years participants ran was the only significantly different variable between groups with the multiple shoe group having a greater average (p=.033) than expected. The χ^2 goodness of fit test assuming equal distribution reported no differences in the number of individuals that received an injury while running between groups (χ^2=4.172, p=0.41).

Significantly Different Demographics Between Groups

Table 1

	Sex	Age (years)	Years Ran	Shoes worn
Single Shoe Group	Males: 13 Females: 18	40.55 ± 12.97	13.42 ± 10.74	1
Multiple Shoe Group	Males: 17 Females: 13	46.23 ± 11.75	20.77 ± 13.11	3.23

Means are displayed as Mean ± SD

Figure 1

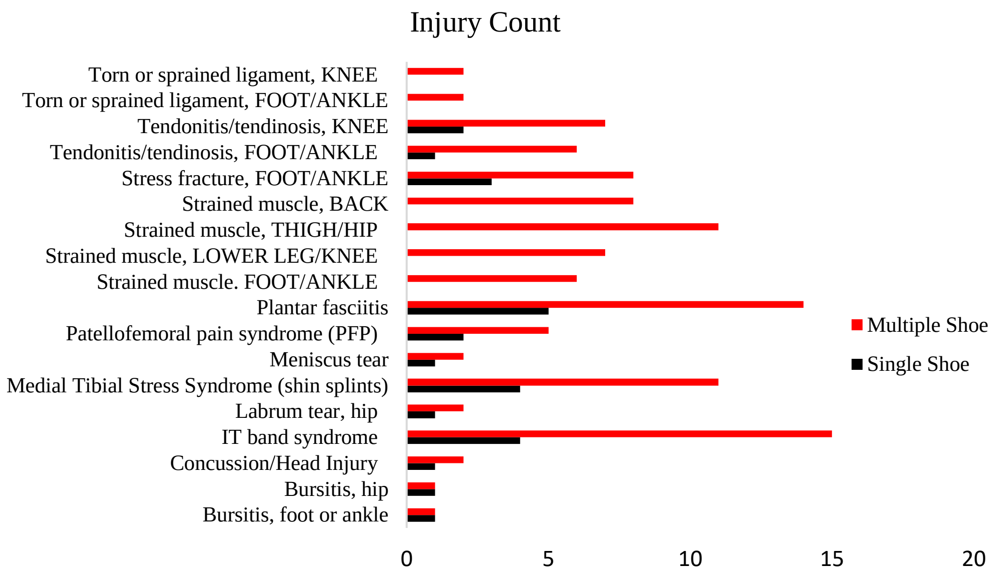


Figure 2

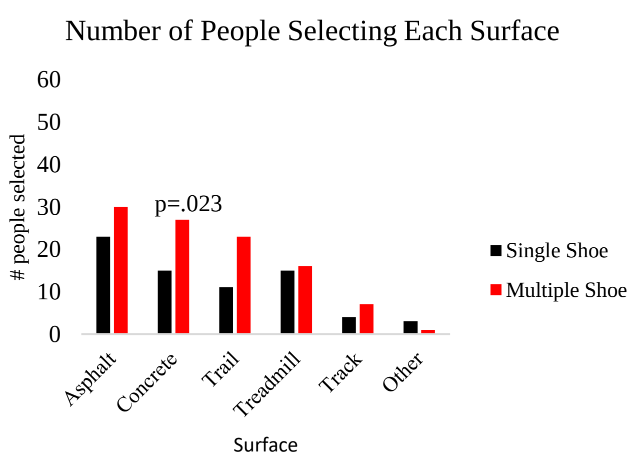
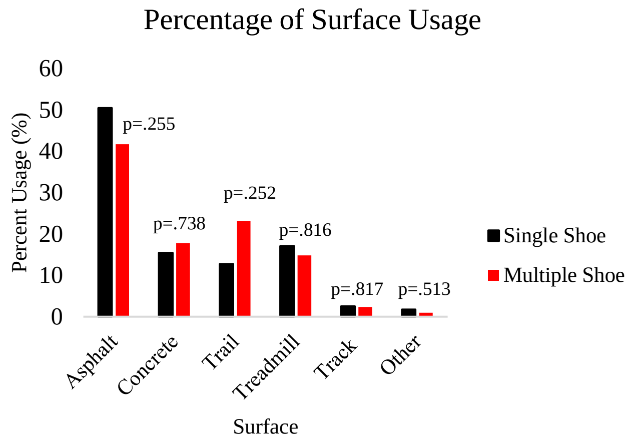


Figure 3



The multiple shoe group had 30 individuals report a total of 110 injuries during their entire running history, while the single shoe group had 22 individuals with 26 total injuries (Figure3). The multiple shoe group had 3.66 injuries per person compared to 1.72 injuries. There was a significantly greater number of injuries per runner in the multiple shoe group compared to the single shoe group ($p<.001$). Within the multiple shoe group, one runner experienced 12 injuries and the single shoe group had one runner report 7 injuries, these were outliers. The top five reported injuries were plantar fasciitis as the most common with at 19 cases, followed by iliotibial band syndrome (19), medial tibial stress syndrome (15), and a tie between a strained muscle in the thigh/hip and a stress fracture in the foot (11).

Figure 2 and Figure 3 illustrate the number of people that selected each type and the percentage of time runners spent on those surfaces prior to removing the treadmill outliers. Treadmill running was a highly selected option at 15 and 16 people in the single and multiple shoe group respectively, but within this subgroup, four runners comprised of the majority of time ran on that surface. These four runners ran over 80% of their time on the treadmill, but the next highest reported percentage was 50%. Treadmill percentage drops in the single shoe group from 17.1% to 12.5% and 14.81% to 6.87% in the multiple shoe group.

CHAPTER 5: Discussion

The purpose of this study was to determine whether wearing multiple pairs of shoes has an influence on injury rates. A longitudinal survey indicated individuals wearing multiple pairs of shoes had a lower injury rate compared to their single shoe counterparts by 39%, but a gap exists as to why individuals wear multiple shoes, and if other variables may be influencing injury rates (Malisoux et al. 2015). This survey aimed to identify why runners chose to wear multiple pairs of shoes and what other choices they make that may influence injury rates.

As previously mentioned, the hypothesis was that individuals who wore a single pair of shoes would have a higher total injury rate. This hypothesis is rejected as the multiple shoe group reported similar number of runners with a history of injury and had more injuries per person. Although they reported higher injury rates, the multiple shoe group had a significantly higher average number of years run than the single shoe group ($p=0.03$). Injury rates have been reported to be lower in runners with increased years of running, but the multiple shoe group had more years of running experience and higher injury rates (Macera et al. 1989, Buist et al. 2008, Videbaek 2015).

According to Fredericson & Misra, iliotibial band syndrome, patellofemoral pain syndrome, plantar fasciitis, achilles tendonitis, and stress fractures are the most common running related injuries (Fredericson & Misra 2012). Consistent with this literature, results from this study indicate over their total injury history, iliotibial band syndrome and plantar fasciitis were the most commonly reported injuries followed by patellofemoral pain syndrome, muscle strains, and stress fractures within the foot/ankle. Ratios of type of injury were consistent across groups besides the multiple shoe group having 20 total incidences of muscle strain while the single shoe group reported no cases of muscle strains. The occurrence of strains solely in the multiple shoe group may be indicative of individuals using a switch to multiple shoes as a preventative measure post injury.

When asked when they switched footwear and when their onset of an injury occurred, they were prompted with either <6 months, 6-12 months, 1-2 years, 2-5 years, and 5+ years. Although the exact time frames are unclear due to this categorization, it is possible to indicate which injuries have occurred post footwear switch and determine if footwear usage may have an influence on injury rates. Runners who have switched to multiple footwear 5+ years ago still have a high injury rate within the last 5 years, but individuals who switched within the last 5 years had a 50% decrease in injury occurrence. This group of runners had twenty total injuries prior to switching, but only reported 10 post switching. Prior to switching, half the injuries were chronic in nature and half were acute. Post switching, the number of acute injuries dropped to 3 while the chronic injuries only dropped to 7. Decreases observed in acute injury rates may be attributed to the possible increase in variability introduced by wearing multiple shoes. This variability may lead to increased adaptation benefiting the runner if introduced slowly (McNicol et al. 2008). The lack of change in repetitive or chronic injuries may indicate footwear is insufficient at alleviating more severe chronic conditions. These findings may indicate a short-term benefit of switching to multiple footwear usage as a preventative measure for decreasing injury rates but switching may have diminishing returns over time.

Runners have many decisions to make regarding their footwear decisions. This survey analyzes when and why runners changed their footwear, did they wear orthotics, and what type of footwear style they prefer. Overwhelming, the participants in this survey indicated mileage and comfort were their reasons for switching. Half the participants (50.8%) selected comfort while 19.7% selected mileage. Within the mileage group, half of those reported switching their footwear lower than the recommended mileage (under 200 miles). The next most selected answer was holes/wear and tear. When prompted how often did they replace their footwear, only four participants indicated greater than 500 miles while the majority indicated under 400 which aligns with the recommendation by major footwear companies to replace footwear between 300-500 miles (Running Shoe FAQ 2008, Matsumoto 2018). These findings support comfort being a top priority due to not allowing shoe degradation to create discomfort (Cook et al. 1985).

In addition to understanding when they replace their footwear, we wanted to know what their footwear style preferences were. Over half our participants (52.4%), regardless of footwear group, indicated neutral footwear was their favorite. Following neutral support, stability footwear was selected at 37.7%. No significant difference existed for footwear preference between groups. According to Subotnick, 60% of the general population has normal or close to normal arch height and neutral shoes are designed for normal arched individuals suggesting most of the participants are utilizing the theoretically best shoe design for their feet (Subotnik 1985).

Lastly, participants were asked whether they wear orthotics and if they were prescribed by a physician or self-prescribed. A total of 16 participants, 4 of which were in the single shoe group, reported wearing orthotics with 9 of them indicating it was self-prescribed. When asked to list all surfaces they run on, this subgroup had 11 individuals select asphalt, 9 concrete, 10 trail, 8 treadmill, and 2 selected track. Introducing orthotics may be effective in increasing comfort and consistency when changing shoes, but if individuals are using the same orthotic in all their shoes it will likely minimize the variability gained from training in multiple footwear.

In addition to varying footwear, some runners introduce training variability by choosing to run on different surfaces throughout their training regimen. Both groups reported asphalt and concrete (single shoe: 50.48% and 15.45%, multiple shoe: 41.75% and 17.75%) as their preferred running surface, but a higher percentage of multiple shoe users run on trails (single shoe: 12.76%, multiple shoe: 23.13%) in comparison to single shoe users. Runners in both groups ran in footwear designed for their surface selection and the multiple shoe group runners selected a minimum of two shoes in their preferred running surface and either one or two pairs of the other surface preference type. For example, trail runners had two trail shoes and either one or two road shoes. Multiple shoe runners' reason for selecting asphalt and concrete were ease of access, similar to race conditions, and running group runs on that surface. Runners selecting these options may indicate that runners find comfort in running with others and prefer to maintain consistency by training on surfaces similar to race day conditions. Interestingly, along with ease of access, the most common reason for trail running was injury prevention. Decreased surface hardness of trail running vs. asphalt may outweigh the risk of perturbations and uneven terrain to this subgroup.

All these decisions made by the runners in this survey indicate consistency and comfort are the top priorities. Individuals rotated their footwear prior to footwear degradation, they wore orthotics increase comfort, neutral footwear introduces cushioning while attempting to allow for natural movement of the foot with minimal obstruction, and the most common running surface is asphalt which is flat and relatively consistent. According to Nigg et al. increasing comfort can lead to decreases in movement-related injuries which coincides with this study when analyzing the group that switched within the last five years (Nigg 2001). Results from this study indicate a more extensive injury history leads individuals to wear multiple pairs of shoes to attempt to prevent future injuries. Further research analyzing the decisions made by runners and how injuries have influenced their decisions is necessary to better develop training strategies to lower injury rates.

APPENDIX A: Survey

What is your age in years?

What is your sex?

- Male
- Female
- Prefer not to say

What is your height in feet? (feet, inches)

What is your weight in pounds?

On average how many miles a week did you run in the last year?

- 0-14 miles
- 15+ miles

Answer the following questions based on the last 6 months: (Prior to COVID-19 quarantine)

Which surfaces did you run on? (Select all that apply)

- Asphalt
- Concrete
- Trail
- Treadmill
- Track
- Other ____

Explain why you chose to run on ${lm://Field/1}:

- [ ] Ease of access
- [ ] Similar surface to race conditions
- [ ] Running group runs on that surface
- [ ] Injury prevention
- [ ] Other ____

How long have you been running on ${lm://Field/1}?

- ○ < 6 months
- ○ 6-12 months
- ○ 1-2 years
- ○ 2-5 years
- ○ 5+ years

Explain why you chose to NOT run on ${lm://Field/1}:

- [ ] Lack of ease of access
- [ ] Not a similar surface to race conditions
- [ ] Running group doesn't run on that surface
- [ ] Injury prevention
- [ ] Other ____

What percent of time did you spend running on these different surfaces? (Out of 100%)

Asphalt :
Concrete :
Trail :
Treadmill :
Track :
Other :

Total :

Answer the following questions based on the last 6 months: (Prior to COVID-19 quarantine)

How many pairs of shoes did you have available to run in at a time?

- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ > 5

How many different pairs of shoes did you run in when training?

- ○ 1
- ○ 2
- ○ 3
- ○ 4
- ○ 5
- ○ > 5

How long ago did you first decide to wear multiple pairs of shoes when training?

- ◯ < 6 months ago
- ◯ 6-12 months ago
- ◯ 1-2 years ago
- ◯ 2-5 years ago
- ◯ 5+ years ago

Why did you decide to start wearing multiple pairs of shoes when training?

- ☐ Due to previous injury
- ☐ Prevent further injury
- ☐ Increase footwear longevity
- ☐ Experimenting with different footwear
- ☐ Other ____

What was your preference on footwear design? (Select all that apply)

- ☐ Motion Control
- ☐ Neutral
- ☐ Stability
- ☐ Minimalist
- ☐ Maximalist
- ☐ Other ____

List all the pairs of running shoes you have worn in the last 6 months in order of most worn to least worn: (Brand and Model)

How often did you cycle between different pairs of shoes?

- ◯ After each session
- ◯ Depending on purpose of training (i.e. short vs distance, trail vs road, etc.)
- ◯ Every so many miles
- ◯ Once a shoe is worn out
- ◯ Other ____

What factor influences you to replace your running shoes?

- ◯ Time
- ◯ Comfort
- ◯ Mileage
- ◯ No strategy
- ◯ Other ____

At what mileage did you replace your running shoes?

- ◯ < 100 miles
- ◯ 100-200 miles
- ◯ 201-300 miles
- ◯ 301-400 miles
- ◯ 401-500 miles
- ◯ > 500 miles

What was your reasoning for replacing your running shoes at that mileage?

- ◯ Comfort
- ◯ Cost/value
- ◯ Other ____

How often did you replace your running shoes?

- ◯ < 2 months
- ◯ 2-4 months
- ◯ 5-6 months
- ◯ > 6 months

Did you wear any orthotics?

- ◯ Yes
- ◯ No

Were the orthotics prescribed/recommended by a physician or self-prescribed?

- ◯ Physician prescribed
- ◯ Self-prescribed

How many years have you been running for?

____

Please describe your weekly running schedule in the last six months: (Prior to COVID-19 quarantine)

	Monday	Tuesday	Wednesday	Thursday	Friday	Saturday	Sunday
Miles							
Pace (min/mile)							
Intensity (low, medium, high)							
Additional physical activity							

Have you ever experienced an injury while running? In this case, an "injury" is pain that has kept you from running for more than one week at a time.

- ○ Yes, only once
- ○ Yes, more than once
- ○ No, I have never been injured while running

Have you ever felt pain or discomfort that was not serious enough to stop running or seek medical care, but caused you to alter your training or mileage?

- ○ Yes
- ○ No

What part of your body have you felt pain in while running? (select all that apply)

- ☐ Foot or ankle
- ☐ Lower leg
- ☐ Knee
- ☐ Thigh, hip, or pelvis
- ☐ Back or neck
- ☐ Upper body (shoulder, elbow, hand)

What part of your body have you felt pain in while running? (select all that apply)

- ☐ Foot or ankle
- ☐ Lower leg
- ☐ Knee

- ☐ Thigh, hip, or pelvis
- ☐ Back or neck
- ☐ Upper body (shoulder, elbow, hand)

How long ago was your first injury?

- ○ < 6 months ago
- ○ 6-12 months ago
- ○ 1-2 years ago
- ○ 2-5 years ago
- ○ 5+ years ago

How long ago was your most recent injury?

- ○ < 6 months ago
- ○ 6-12 years ago
- ○ 1-2 years ago
- ○ 2-5 years ago
- ○ 5+ years ago

From the list below, please select any injuries that you have experienced.

- ☐ Bursitis, foot or ankle
- ☐ Bursitis, knee
- ☐ Bursitis, hip
- ☐ Concussion/Head Injury
- ☐ IT band syndrome
- ☐ Labrum tear, hip
- ☐ Medial Tibial Stress Syndrome (shin splints)
- ☐ Meniscus tear
- ☐ Patellofemoral pain syndrome (PFP)
- ☐ Plantar fasciitis
- ☐ Strained muscle. FOOT/ANKLE
- ☐ Strained muscle, LOWER LEG/KNEE
- ☐ Strained muscle, THIGH/HIP
- ☐ Strained muscle, BACK
- ☐ Stress fracture, FOOT/ANKLE
- ☐ Stress fracture, LOWER LEG/KNEE
- ☐ Stress fracture, THIGH/HIP
- ☐ Stress fracture, BACK

- [ ] Tendonitis/tendinosis, FOOT/ANKLE
- [ ] Tendonitis/tendinosis, KNEE
- [ ] Tendonitis/tendinosis, HIP
- [ ] Torn or sprained ligament, FOOT/ANKLE
- [ ] Torn or sprained ligament, KNEE
- [ ] Torn or sprained ligament, HIP
- [ ] Other, please specify body part and type of injury ____________________

Please describe the occurrence of your ${lm://Field/1}:

- ○ Single injury (happened only once)
- ○ Repetitive injury (happened more than once, but healed in between)
- ○ Chronic (consistently hurts unless I stop running)

Did your ${lm://Field/1} cause you to stop running?

- ○ No, I continued to run
- ○ Yes, for less than one week
- ○ Yes, for more than one week and less than one month
- ○ Yes, for more than one month and less than three months
- ○ Yes, for more than three months

Did you seek medical care for your ${lm://Field/1}?

- ◯ Yes
- ◯ No

How was your ${lm://Field/1} treated? (Please select all that apply)

- ☐ Rest
- ☐ Pain medication or steroids
- ☐ Cast or brace
- ☐ Treatments such as ice, heat, ultrasound, electrical stimulation, massage
- ☐ Exercise, either take-home or in a clinic
- ☐ Surgery
- ☐ Other ____

How long ago was your first occurrence of ${lm://Field/1}?

- ◯ < 6 months ago
- ◯ 6-12 months ago
- ◯ 1-2 years ago
- ◯ 2-5 years ago
- ◯ 5+ years ago

How long ago was your most recent occurrence of ${lm://Field/1}?

- ◯ < 6 months
- ◯ 6-12 months ago
- ◯ 1-2 years ago
- ◯ 2-5 years ago
- ◯ 5+ years ago

Did your occurrence of ${lm://Field/1} cause you to alter your training?

- ◯ Yes, but only until recovered
- ◯ Yes, permanent change
- ◯ No

In what ways did you alter your training?

- ☐ Mileage per week
- ☐ Runs per week
- ☐ Pace
- ☐ Surfaces ran on
- ☐ Footwear modification
- ☐ Other ____

What footwear modifications did you implement?

- ☐ Change brand/model
- ☐ Change footwear design (neutral, motion control, etc.)
- ☐ Increase amount of shoes worn
- ☐ Other ____

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