ABSTRACT

The Effects of Carbon Insoles on Reactive Strength and Vertical Leg Stiffness as an Indicator to Sprint Performance

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Sprinting is the peak expression of performance. Different strength and physical characteristics play roles in the expression speed. Leg stiffness is a major factor on rate of force development, and performance. The pairing of eccentric and concentric contractions is termed the stretch shortening cycle and is assessed by the reactive strength index (RSI). The purpose of this study was: (1) to investigate the effects of the carbon insole on the expression of vertical leg stiffness (k_{vert}) and RSI; (2) examine the effects of the carbon insoles on sprint kinematics. Fifteen participants were recruited and were asked to perform a drop jump and a 20-yard sprint in two conditions (carbon, traditional insoles). The only significant differences between conditions for the performance variables were in the drop jump ($p > 0.05$). Further research is needed looking at sprint kinetics and kinematics and varying insole stiffness at maximal velocity.

The Effects of Carbon Insoles on Reactive Strength and Vertical Leg Stiffness as an Indicator to Sprint Performance

by

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

COM – Center of Mass

DJ – Drop Jump

GCT – Ground Contact Time

GRF – Ground Reaction Force

hGRF – Horizontal Ground Reaction Force

K_{vert} – Vertical Stiffness

LANK – Left Ankle

LASI – Left Anterior Sacroiliac Joint

LHEE – Left Heel

LKNE – Left Knee

LPSI – Left Posterior Sacroiliac Joint

LTHI – Left Thigh

LTIB – Left Tibia

LTOE – Left Toe

MBS – Midsole Bending Stiffness

MTP – Metatarsal Phalangeal

MTU – Musculotendinous Unit

RANK – Right Ankle

RASI –Right Anterior Sacroiliac Joint

RHEE – Right Heel

RKNE – Right Knee

RPE – Rating of Perceived Effort

RPSI –Right Posterior Sacroiliac Joint

RSI – Reactive Strength Index

RTHI – Right Thigh

RTIB – Right Tibia

RTOE – Right Toe

SSC – Stretch Shortening Cycle

vGRF – Vertical Ground Reaction Force

VO_2 Max – Maximal Oxygen Consumption

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DEDICATION

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CHAPTER ONE

Introduction

Sprinting is an intricate undertaking that places a high demand on the performer. Sprinting involves a high-level synchronization of movements and the proper sequencing of muscle actions to perform at a top level. Speed is a function of stride length and stride frequency; thus, implying that higher speeds can be reached when either or both variables are improved. Elite sprinters have stride lengths and stride frequencies as great as 2.6 meters long and up to five steps per second (Clark et al 2017). In previous research there were indications that the force employed at ground contact is more crucial to determine speed (Brughelli et al 2011). The larger the forces employed at ground contact, the greater the displacement of the athlete's body and shorter ground contact times can be produced, thus equaling greater speeds (Healy et al 2019).

An increase in running speeds is the result of increased forces. The magnitude and direction of the forces need to be considered. Athletes have to lessen horizontal braking force and exploit the vertical forces. These vertical forces are important because after the momentum has been developed during the initial acceleration phase (first 20m), the body will typically keep going forward at the same speed as long as the internal and external forces acting on the body are in equilibrium (Haugen et al 2018). A braking force refers to forces that act in the opposing direction of movement. These oppositional forces whilst sprinting typically cause slowing down (negative acceleration) and the chief cause of unwarranted braking is making ground contact too far in front of the athlete’s center of mass (COM). Increases in vertical displacement will cause more efficient ground contact position and increase the probability of negative foot-speeds on subsequent contacts. Increasing leg stiffness will improve vertical ground reaction forces (vGRF) which will allow the competitor to better offset the impacts of gravity (Haugen et al 2018).

It is recognized that stiffness in the human leg has a major influence on various variables including the rate of force development, elastic energy storage and utilization, and sprint kinematics (Brughelli and Cronin 2008). Leg stiffness is defined as the ratio of ground reaction forces to maximum leg compression at the middle of the stance phase (Brughelli and Cronin 2008). Vertical stiffness is measured by mass and the natural frequency of oscillation (Serpell et al 2012).

Various strength abilities play large roles throughout the performance of a sprint. During the ground contact phase of sprinting, there is a pairing of an eccentric contraction with a concentric contraction and is termed the stretch shortening cycle (SSC) and is repeatedly utilized in many sport movements (Healy et al 2019). A fast SSC performance has been evaluated by the measurement of the reactive strength and is typically measured using drop jumps (Healy et al 2019). Reactive strength is measured by the reactive strength index (RSI) = Flight Time / Ground Contact Time (Pedley et al 2017). Elite sprinters are better suited to contact the ground with a stiffer leg spring which thereby increases vertical ground reaction forces and increases the utilization of the muscle-tendon unit's (MTU) elastic elements, consequently achieving higher running speeds (Douglas et al 2018).

Speed and performance can be trained to a certain extent. Much of what separates an elite from an amateur lies in his/her genetic profiles. The amazing world of science and technology can offer potential performance gains using new technological advances such as carbon fiber insoles that are added into running shoes. When athletes run barefoot, they must employ extra muscular effort to lessen the impact of their foot when it crashes into the ground, while runners that run in well cushioned shoes (midsole material performs the task of cushioning) employ less muscular effort. One downside to wearing well cushioned shoes is that they add to the overall mass which increases the metabolic cost (Tung et al 2014). According to the cushioning hypothesis, for every 100 grams of mass added to a shoe, VO_2 increases by approximately 1%.

Currently most of the literature that analyzes the use of carbon insoles comes from endurance running due to the popularity of Nike's Breaking 2-hour. These studies look at running economy and the energetic cost of running (Hoogkamer et al 2018; Barnes and Kilding, 2019), while few studies have been performed on jumping and sprinting tasks using a carbon insole. These few studies have examined the use of the carbon insoles to increase midsole bending stiffness specifically targeting the metatarsophalangeal (MTP) joint. A stiffer midsole may help effective force transmission onto the ground during the support phase of sprinting and having a stiffer midsole reduces the energy lost at the MTP joint from the touchdown to take off phase of running (Nagahara et al 2018; Willwacher et al 2013). A stiff soled shoe restores the lost forces during the support phase, enhancing the plantarflexion at the MTP joint towards the toe-off (Nagahara et al 2018).

Every year athletes continue to break records and set a new status quo. The improvements come from a myriad of sources, such as improved footwear, clothing, and training devices. For example, the Nike Explore Team Sport Research Lab created a new fabric which they call the AeroReact and it is "uniquely engineered to adapt to changes in a runner's temperature. Supporting the body's existing thermoregulation capabilities"

(Innovated for Adaptive Breathability, 2018). By being able to better thermoregulate, the body can focus on other areas that are critical to performance. Another example is the Diamondback Andean. This bike is so fast and groundbreaking that the UCI (Union Cycliste International) does not allow it in races. Diamondback created an Aero Core that aims at reducing drag between the wheels and the frame by shielding the drivetrain and smoothing airflow over the structure. At present, speed is the name of the game and faster is always better. Nike has also started incorporating carbon into their running shoes which has already been proven effective in the marathon. One company that markets and sells carbon insoles boasts an impressive return of energy due to increasing stiffness which relates to increased athletic explosiveness by 9.3% (https://vktrygear.com/pages/the-insole).

VKTRY carbon insoles, have five stiffness levels. These correlate to different sports and the demands of said sport. In addition to the claims by VKTRY of a 9.3% increase in explosiveness, they also claim a 1.6-inch increase in vertical jump height (https://vktrygear.com/pages/the-insole). By the addition of the VKTRY insoles, if the results show increased reactive strength indexes (RSI) and increase the vertical stiffness then it is safe to assume that the speeds will increase which will lead to new records being set. Carbon insoles have not received a large amount of attention in the literature regarding reactive strength and vertical stiffness; however, the existing body of evidence points to the possibility of improvements to performance.

Research Question

The purpose of this study was to determine if adding a carbon insole into a sneaker can increase the vertical stiffness and reactive strength index during sprinting and jumping.

Hypotheses

Ho: There will be no significant difference in reactive strength between the carbon and standard insoles.

Ho: There will be no significant difference in Vertical Ground Forces between the carbon and standard insoles in sprinting.

Ho: There will be no significant difference in Vertical Ground Forces between the carbon and standard insoles in the drop jumps.

Variables

The primary variables looked at in this study were to determine if the use of VKTRY insoles improved the reactive strength index (RSI) and to determine if the use of VKTRY insoles improved the vertical stiffness (K_{vert}). Secondary variables include changes in ground contact times (GCT), and differences in vertical ground reaction forces (vGRF).

Delimitations

1. Participants must be between 18-35 years old.
2. Participants must have participated in at least 4 weeks of moderate to vigorous activity prior to testing.
3. 15 Males and/or Females will be selected as participants in the study.
4. Participants must fit a US men's shoe size 8,10,12, or a US women's shoe sizes 6,8,10.
5. Participants cannot have recently experienced any lower extremity injuries.
6. Participants will be recruited from Baylor University via advertisement flyers.

7. Participants will attend all study-related visits in the Baylor Laboratories for Biomotion at the Baylor Research and Innovation Center (BRIC), Waco, TX.
8. Participants will be recruited from local gyms, fitness clubs and organizations in Waco, Texas.

Limitations

1. Participants' differing sleep, dietary, and exercise habits may influence outcomes of the study.
2. Measurement variability and participant stress levels ("White coat syndrome") may influence results, such as targeting.
3. Study outcomes may only be relevant for the chosen population.

Assumptions

1. All research team members will be adequately trained in all necessary study protocols.
2. All necessary equipment will function properly and produce valid results.
3. Participants will comply with study protocol in taking their respective supplementation for the proper intake duration.

Definition of Terms

Reactive Strength: The ability to absorb force in one direction and then apply more force in the opposite direction.

VKTRY: Brand of insoles.

Stiffness: The resistance of an object or body to a change in length.

Drop Jump: Designed to examine athlete reactivity. The Drop Jump (DJ) test consists of an athlete standing on a platform behind force plates, stepping off and dropping onto the plates, absorbing the drop, and immediately propelling back up into a vertical jump.

CHAPTER TWO

Literature Review

Introduction

Sprinting ability is a vital element in performance for a range of athletic activities and depending upon the distances, sprinting may include acceleration, maximum velocity, and a deceleration phase (Douglas et al 2020). While acceleration ability is paramount to sprint performance (Morin et al 2011), maximum velocity capabilities are of significant interest to team sport and sprint athletes. There is a strong correlation between an athlete's top velocity and performance in field sports. One study showed that the relative rate of acceleration remained the same regardless of sprint performance, thus indicating that a higher top end velocity enables a superior performance (Douglas et al 2020). Additional evidence indicates that faster sprinters attain higher top end speeds (velocities) by the application of larger relative vertical ground reaction forces (da Rosa et al 2019). The larger relative vertical ground reaction forces (vGRF) come from elite sprinters maximizing the utilization of the elastic structures in the musculotendinous unit within the stretch shortening cycle (SSC). This gives the sprinters a greater reactive strength and greater vertical leg stiffness, which produces superior performance (Douglas et al 2020). Much of these traits, such as the SSC are genetic and specifically trained. With science constantly improving, elite and amateur athletes are performing faster, stronger, and quicker than before with improved sneaker design.

One such improvement comes from carbon fiber insoles in athletic sneakers. Named 2020s top choice for runners by Runner's World, VKTRY Performance Insoles have a full-length carbon fiber base with 5 levels of flexibility that can be customized to provide optimum performance and protection. VKTRY Insoles were originally created for the US Olympic Bobsled Team to improve athletic explosiveness. In 2018, the Korey Stringer Institute at the University of Connecticut produced results from their research indicating that VKTRY Insoles improve lower body biomechanics during running and shock absorption during landings (Casa, 2020).

Sprinting

Since runners tend to develop an innate running style from a young age, it can be painstakingly difficult to change their running mechanics. In general, people think running is something that is done instinctively. It is a skill that can and should be trained due to its extreme complexity. Running is the result of a unique combination of movement variables including, knee joint angle, ground contact time, leg stiffness, stride length and step frequency (Lockie et al 2015). Running, and specifically sprinting are described by footstep kinematics. Stride length is the distance between the separate contacts of each foot and stride frequency is the rate at which steps can be produced, typically stated at steps per minute. Contact time is the duration the leg is on the ground and flight time is the interval of time when the athlete is in the air. Preceding research has exemplified the significance of a large stride length (da Rosa et al 2019). Shorter ground contact times have also been linked to greater velocities (Hunter et al 2005).

Three key goals need to be met in effective maximal sprinting: the conservation of stability, the reduction of braking forces, and the optimization of vertical forces. Stability is vital to any athletic endeavor because it ensures the body can move with maximum efficiency. Running with one's core stabilized and properly aligned often leads to the ideal movement of the appendages (Haugen et al 2018). When one's body is out of alignment and experiencing instability, runners often try to reclaim stability by the early grounding of their swing leg. Early grounding of the swing leg means that the foot will still be moving forward when ground contact is made. This is referred to as positive foot speed and is problematic to economical sprinting due to increased braking forces (Haugen et al 2018). Once a sprinter is generating the necessary vertical forces, the athlete's center of mass (COM) will travel in a sinusoidal trajectory, with the highpoint of the curve occurring at the midpoint of the flight phase and the low point of the curve occurring just after contact is made (Haugen et al 2018). The maintenance of these three goals is what separates the elite from the amateur.

Sprinting comprises different phases including: the initial acceleration, the attainment of maximal velocity, and maintenance of maximal velocity, each with specific mechanical demands (Yetter and Moir 2008). A fast sprint start relies strongly on the total amount of muscle mass that can be activated to increase the energy of the body's center of mass (COM). Initially in the first push off the initial acceleration phase requires a specific muscle activation pattern that optimizes the interaction between horizontal and vertical forces during the stance phase. It should also be noted that during the maximal velocity phase, large vertical forces need to be generated during each stance phase to allow sufficient time to reposition the swinging leg once maximum velocity is reached (Yetter and Moir 2008); to maintain said velocity requires a reduction in braking forces. Max speed is reached after 30 meters and will be maintained if the horizontal and vertical forces exceed braking forces (Cigoja et al 2019).

Sprint Mechanics

Fast and slow runners take largely the same amount of time to relocate their limbs when sprinting at their individual top end speeds, which is contradictory to what the general population believes (Clark et al 2017). Rather than speeding up the repositioning of the legs, the predominant mechanism for attaining faster speeds is the application of greater forces and shorter ground contact times. The average runner has a preferred step count of 168 steps/minute (Quinn et al 2019). If properly trained, a step count of 180 steps/minute can produce a more efficient running economy, lower oxygen use, and lower heart rates (Quinn et al 2019). With stride frequency being the same across both elite and novice runners, the biggest determining factor for performance is the GRFs, which is what athletes have the biggest control over (Hunter et al 2005). Applying greater mass-specific ground forces maximizes velocity and acceleration (Haugen et al 2018). Data indicates that faster sprinters attain higher max velocities by the utilization of primarily larger vertical forces (Brughelli et al 2011). Sprinters enhance force production and general execution by using their legs in a spring like fashion during each contact with the ground, and due to higher vertical forces, shorter ground contact times are possible when compared to amateur athletes (Clark et al 2017). During the initial part of the stance phase, the leg is compressed as the body is pulled down due to gravity (Clark et al 2014). At the onset of contact, the leg stores strain energy in the elastic tissues (ligaments, tendons fascia, etc.), which is then utilized in the later portions of the stance phase (Clark et al 2014). The strain energy is freed via the elastic recoil that propels and accelerates the body into the flight phase. A recent study showed that the fastest sprinters produced 26% greater vertical ground reaction forces than the slowest sprinters (Brughelli et al 2011).

During bipedal locomotion, two main sources for the development of GRFs are the passive skeletal resistance to gravity and the moments generated at the lower extremity joints (Luo 2020). The majority of the GRF development can be attributed to the extension of the knee. While the ankle is an essential element in successful running mechanics, the knee joint angle influences peak vGRF (Kubo et al 2016). By increasing the knee flexion angle at initial contact, it was found that there was a reduction in peak vGRF in the later part of the stance phase (Derrick 2004). One study looking at barefoot and shod running kinematics, observed knee and ankle angles at toe-off while running at 4.5m/s. The average knee angle at toe-off was 142 degrees with shoes and 141 degrees for barefoot (Francis et al 2016). Another study that looked at sprinting observed a knee angle of 155.4 degrees at toe-off (Haugen et al 2018).

When looking solely at ground reaction forces (GRF), those forces can be broken down into horizontal GRF and vertical GRF components. Recently, researchers have shown that the horizontal (hGRF) component of the resultant GRF is a key feature of sprint acceleration performance, regardless of skill level (Hunter et al 2005; Morin et al 2015). Morin et al (2015) looked at running kinetics over a maximal sprint and the results showed that the average horizontal force in terms of body weight was 0.350 and vertical force was 1.62 greater than body weight.

While hGRF is indicative of superior performance in the early stages of sprinting, it is also a potential source of braking which diminishes performance (Hunter et al 2005). A braking force acts posteriorly and often in the onset of the stance phase and is the result of where the foot makes contact about the body's COM. The ability to create a negative foot speed is the key characteristic that most often separates the elites from the amateurs. This negative foot speed occurs when a runner pulls the ground surface backward while propelling their body forwards. If the foot is not moving backwards as fast as the COM is moving forward, a braking action will occur during every stance phase (Udofa et al 2019). The braking GRF is diminished by using an extremely dynamic touchdown guaranteeing a high extension velocity of the hip and flexion velocity of the knee at the moment of touchdown (da Rosa et al 2019).

Leg Stiffness

As stated previously, leg stiffness is an important factor to increasing vertical ground reaction forces. In the realm of sprint and jump biomechanics, stiffness and conformity refer to the amount of deformation of an object in relation to the forces acting on the object. Stiff objects are hard to deform while compliant materials are easy to deform just like an athlete can be both flexible and stiff. Elite athletes display greater stiffness than their amateur counterparts as their joints move less when they encounter the ground while sprinting or jumping. Leg stiffness (K_{vert}) is considered a quintessential attribute to the enhancement of the stretch shortening cycle (Kurt et al 2018). Komi (1992) suggested that a higher stiffness in the leg muscles during a stretch shortening cycle (SSC) exercise led to a greater storage and reused elastic energy. Stiffness in the human body portrays the capacity to withstand displacement once GRFs are applied and can be characterized as the ratio between peak vGRF and the displacement of the center of mass (Kurt et al 2018).

Models such as the spring-mass model have been created to look at spring-like limbs to explain gait mechanics. When modeling the stiffness of a compliant leg, the system qualities include the gait cycle, and the amplitude and oscillations around the COM (Kim and Park 2011). When the foot makes contact with the ground, joint motion at the ankle, knee, and the hips lower the body's COM, representing absorption of energy and spring-like compression. During the energy production phase of a stride, the limb is extending, characterizing recoil of a spring (Bishop et al 2006).

Further research analyzes how runners compete on a variety of terrains with different stiffness properties. The elastic and viscoelastic properties of varying surfaces can affect the stiffness of the joints in the lower extremity, producing faster or slower competition times. For example, Lejeune et al (1981) discovered the fact that running on sand was 1.6 times more taxing in terms of energy expenditure due to a significantly lower leg stiffness when comparing to the leg stiffness levels of running on a firm surface. If the human leg stiffness was unwavering, then efficiency would significantly drop on compliant surfaces. The stiffness of the leg fluctuates depending on the nature of the terrain that the limb encounters (Bishop et al 2006).

Leg stiffness has major influences on rate of force development and elastic energy storage, and usage. The running kinematics affected by changes in leg stiffness are ground contact times, flight times, stride lengths, stride frequency, and force production (Brughelli and Cronin 2008). Force sensors are commonly used to assess stiffness, since GRF can be measured directly by the force plates. Vertical stiffness can then be calculated as k_{vert} = Mass* Natural frequency of oscillation squared, also written as $k_{vert} = m\omega^2$ (Cavagna et al 1988; Cavagna et al 2005; Cavagna, 2006).

Ground Contact Time

Stefanyshyn and Nigg, hypothesize that restricting the amount of metatarsal phalangeal joint dorsiflexion would potentially reduce the amount of energy loss at the joint (2000). Cigoja et al (2019), found that running at submaximal speeds in a sneaker that had an increased midsole bending stiffness was characterized as having significantly longer ground contact times (Control = 239.6ms; Stiff = 252.0ms). Longer contact times typically result in smaller peak vGRF, due to decreased leg stiffness. Additionally, this study also found increased peak vertical ground reaction forces were elevated and it was thought to be due to the carbon plate acting as a torsional spring that allowed the absorption of more energy that was then relayed to the body at toe-off (Cigoja et la 2019). In the initial acceleration phase of a sprint the ground contact times are longer (.195s) due to the need to increase the forces needed to get the body up to speed and shorter in the later phases of acceleration (.136s). At maximum velocity, the contact time is half (.096s) of what the initial contact times were (Morin et al 2015; Haugen et al 2018)

Sneaker Design

When athletes run barefoot, they must apply an additional muscular effort to cushion the impact of the foot when it crashes into the ground. Whilst athletes run in well cushioned sneakers, the midsole material does the task of cushioning presumably. One downside to wearing well cushioned sneakers is that they add additional mass which increases the metabolic cost, according to the cost of cushioning hypothesis (Tung et al 2014). This hypothesis states that for every 100 grams of mass added to a shoe, VO2 increases by approximately 1% (Tung et al 2014). Nike's research lab wanted to combine the benefits of well cushioned sneakers and the benefits of running barefoot, to maximize running potential. The addition of the carbon insole allowed Nike to create a shoe that was stiff like barefoot running but did not allow the loss of significant energy and was cushioned enough to reduce the metabolic demand required to soften landings.

Running sneakers have been shown to elicit different effects on running. While running, the leg muscles create forces to cushion the impact of the ground and the cushion in the sneakers contribute to absorbing impact forces to prevent chronic overuse injuries such as shin splint and tibial stress fractures among long distance runners (Hoogkamer et al 2018). One study found that wearing sneakers produced a 2.5% slower stride frequency and a ground contact that was 5.9% longer versus running barefoot (Tung et al 2014). While these studies are performed on endurance races, such as marathons, there are implications that trickle down to sprinting.

Science is constantly evolving at a rapid pace; new research continues to emerge and the new technology on carbon insoles getting much attention from the running community. Much like the pursuit of running the first sub four-minute mile, the first sub two-hour marathon has been of much interest as of late. So much in fact that Nike created a whole research team and design team to help a group of elite marathoners break that two-hour barrier. Recent research since the debut of Nike's new carbon midsole sneakers focuses on where the improvements come from. For the most part, the improvements have come from an increase in running economy (Hoogkamer et al 2018; Barnes and Kilding 2019). Researchers predicted that a sub two-hour marathon is "unlikely to happen before the year 2100" (Weiss et al 2015). Nike set out on a quest to design a shoe to help speed along the process of running a sub two-hour marathon. Running, 26.2 miles (marathon) in two hours translates to an average of 1 mile every 4 minutes and 32 seconds. The previous world record marathon averaged 4 minutes and 39 seconds, so to break two hours, the pace per mile would need to increase by 2.5% (Hoogkamer et al 2018). In the end the 2-hour barrier was broken by Eliud Kipchoge in 2019, while wearing Nike's Alphafly Next%, which featured 3 carbon plates and a 40mm stack height.

In general, there are three physiological factors that determine and predict running velocity. The factors are VO_2 Max, lactate threshold, and running economy (Hoogkamer et al 2018). At the uppermost levels of competition, most athletes have a similar VO_2 Max, but the running economy varies by 30% (Hoogkamer et al 2018). These variances are what separate the top 1% from the top 5% in competition. Three main properties of sneakers that can influence running economy are outsole traction, shoe mass, and midfoot bending stiffness. The Nike Alphafly Next%, was 264% stiffer in the midsole than a traditional running sneaker (Worobets et al 2015; Beck, 2020).

Midsole Bending Stiffness

Midfoot bending stiffness is where the most mechanical energy is gained or lost. There are three major areas of focus in terms of mechanical energy production for sprint performance. The enhancement of the musculoskeletal system, boosting energy return, and diminishing energy lost (Roy et al 2006). When the foot contacts the ground, the joint motion of the foot, ankle, knee, and hip lower the body's COM. At ground contact, the foot dorsiflexes and plantar flexes during the toe-off at the end of the stance phase (Stefanyshyn et al 1997). Researchers commonly analyze the metatarsal phalangeal (MTP) joint where the energy is lost at touchdown, little energy is generated during take-off (Stefanyshyn et al 2000; Stefanyshyn et al 1997; Nagahara et al 2018; Roy et al 2006). A stiff midsole in a running sneaker generates restorative force during the stance phase, enhancing plantarflexion at the MTP joint at toe-off (Nagahara et al 2018). With no energy being created at the MTP joint during the stance phase, the energy needs to either dissipate or be returned. Stiffening the sneakers midsole would lessen the energy wasted at the MTP joint and result in improving performance (Stefanyshyn et al 2000). In the Stefanyshyn's (2000) study, he found that stiffening the midsole resulted in no significant difference in the amount of energy absorbed by any of the joints besides the MTP joint. This reduction in energy absorption at the MTP joint produced an increase of 1.7cm in vertical jump height with the stiffer midsoles (Stefanyshyn et al 2000). This study also found that increased midsole bending stiffness led to sizeable decreases in MTP joint dorsiflexion, which resulted in a drop in the amount of energy absorbed at the MTP joint.

Stiffening the MTP joint with carbon is more effective at producing energy return due to its enhanced stiffness properties rather than the typical polyethylene that comprises traditional sneaker midsoles (Cigoja et al 2019). A good example of the energy return of carbon was demonstrated by a double-sided amputee that was able to perform close to world-class athletes in the 400m dash while wearing sprint-specific lightweight carbon prostheses (Weyand et al 2010). This athlete returned more than 90% of the energy at toe-off that was initially present at touch down (Weyand et al 2010). The energy storage potential in conventional running shoe midsole materials is small compared with the human Achilles tendons, feet and stiff carbon insoles (Willwacher et al 2013). Energy return from the MTP joint would necessitate the flexible midsole and the toes to perform a noticeable plantar flexion at the end of the stance phase (Stefanyshyn et al 1997).

There are few studies that have examined the influence of shoe sole bending stiffness using carbon fiber insoles (Stefanyshyn, and Fusco 2004; Nagahara et al 2018;

Stefanyshyn and Nigg 2000). It is hypothesized that increasing MTP joint stiffness shifts the point of force application of the GRF to the front of the foot (Willwacher et al 2013). Stefanyshyn, and Fusco (2004) reported on bending stiffness in the later phases of sprinting (20-40m). Nagahara proposes that looking at midsole bending stiffness in the later parts of a sprint to be disadvantageous due to the limb motion and force productions being very different between the early and later stages of acceleration. In addition, support time in the early phase of acceleration is longer which could be suggestive that the impact of midsole bending stiffness on sprint performance is clearer during the early phase of acceleration rather during the later phase (2018). In Stefanyshyn and Nigg's (2000) study, participants jumped higher in a stiff soled shoe compared to a traditional soled shoe when performing maximal effort vertical jumps. The results were due to the increased midsole bending stiffness which led to a reduction of the energy being lost at the MTP joint.

VKTRY Performance Insoles

The claim to the VKTRY insoles is "Unmatched Energy Return and Shock Absorption to Improve Athletic Performance and Increase Injury Protection" (VKTRYgear.com). Willwacher (2013) hypothesized that increasing MTP joint stiffness shifts the point of force application of the GRF to the front of the foot, and this is reflected through the design of VKTRY's carbon insoles. VKTRY's insoles have a flexible forefoot, a stiff midfoot, and flexible rearfoot (VKTRYgear.com). A flexible forefoot allows adequate toe flexion and propels the athlete forward; the flexible heel helps absorb some of the shock that occurs at landing, and the stiff midsole is designed to limit the bending and reduce the loss of energy at that MTP joint (Nagahara et al 2018). Crafted from 100% aerospace carbon fiber, the company claims that athletes using their insoles get on average

0.12 seconds faster in a 40yrd dash, an increase of 9.3% in explosiveness, and a 1.6-inch increase on one's vertical jump. The company's third-party testers claim that, test subjects experienced significantly less GRF with VKTRY insoles when running (10%) (Casa, 2020).

Reactive Strength

Reactive strength is the capacity of the muscle tendon complex to produce a powerful concentric contraction following a rapid eccentric contraction (Schuster and Jones 2016). Reactive-strength training is generally referred to as plyometrics. The word plyometric is derived from the Greek word plethyein which means to increase (Verkhoshansky, 2012). Verkhoshansky initially termed plyometrics as the "shock" method. Plyometrics (depth jumps, drop jumps, etc.) is a method of jump training that incorporates an overloaded eccentric stimulation to the muscle unit (Verkhoshansky, 2012). In general, all athletic movements in sport have plyometric features (sprinting, jumping, changes of direction, etc.). The muscle function that is required in movements seldom calls for the use of only eccentric or concentric contractions (Cormie et al 2010). Rather, the sequential combination of eccentric and concentric contractions forms the most frequent type of muscle action necessary in athletic movements, the stretch-shorten cycle (Newton et al 2008). When a muscle is stretched out and then instantaneously shortened, the muscular force generated during the concentric contraction is greater than those achievable by concentric only contractions (Cormie et al 2010). Movements and activities are categorized by the characteristics of their stretch shortening cycle (SSC), fast (sprinting, drop jumps, bounding), is referred to as less than 250ms or slow (depth jumps, change of directions), which refers to greater than 250ms in duration (Beattie et al 2017). The SSC is an integral part to the plyometric exercise because it enhances the ability of the musculotendon unit to elicit the greatest forces in the shortest amount of time (Saez de Villarreal et al 2012). Plyometrics have been shown to effectively improve sprint performance and agility (Verkhoshansky, 2012). Over several decades, various studies have established that eccentric contractions can maximize the force applied and the work performed by the muscle (Schuster and Jones 2016; Newton et al 2008; Saez de Villarreal et al 2012,). The eccentric contractions are linked to greater mechanical efficiency and can minimize the mechanical effects of impact forces (Verkhoshansky, 2012).

Reactive strength is usually assessed via the reactive strength index (RSI), specifically through the drop-jump (Ball and Zanetti 2012). Initially developed at the Australian Institute of Sport in the 1990s (Young, 1995), RSI is depicted as a person's ability to shift quickly from an eccentric to concentric contraction and is a gauge of explosiveness (Kurt et al 2018). The RSI can also be used as a feedback tool as it not only offers a measure of the ability of an athlete to utilize the SSC, but it also helps assist athletes in understanding power development (Schuster and Jones 2016).

Drop Jumps

The Drop Jump (DJ) test is designed to examine reactive strength. The DJ RSI is calculated by either jump height or flight time and divided by ground contact time (Douglas et al 2017). The Drop Jump (DJ) is performed when an individual drops off a box one footed on to a force plate and then jumps for maximal vertical displacement before landing on both feet (Schuster and Jones 2016; Flannigan and Comyns 2008). This test is considered a fast stretch-shortening movement used to assess reactive strength. When an athlete lands on the platform his/her eccentric loading phase is heightened by means of the added force of the drop and the primary measure of the test is to see how quickly the athlete can move from absorption to propulsion (Flannigan and Comyns 2008). The aim of a drop jump exercise is to enhance the ability of tendons and muscles to store and release elastic energy when subjected to excessive stretching forces such as those within jump landings and the stance phase of sprinting (Ball and Zanetti 2012).

According to Pedley et al (2017), there are five phases to a drop jump: step-off, descent, contact phase, take-off, and the second landing. At step-off, athletes should stand upright on a box with their hands placed on their hips, the movement should be started by stepping off the box with a single leg, rather than jumping off. During the descent phase, athletes descend to the floor with the limbs and trunk stiffened but with the ankle in a neutral position to encourage ankle stiffness. To some extent of flexion in the knees and hips should be present during the descent as well. Once contact is made, feet should be shoulder width apart and heels should remain off the floor. The center of mass is likely to fall a small distance during the ground contact due to a small amount of hip and knee and ankle flexion, but it should be rapidly reversed. At the point of take-off, the toes should be the final part of the foot to leave the floor and the hips, knees and ankles should be fully extended because of an explosive triple extension in the vertical direction. Lastly, in the second contact, the athlete comes back to the ground landing in a soft manner in order to absorb the forces from the landing (Pedley et al 2017). In the technical model of the drop jump, there is no arm swing and hands should remain on hips the entire jump duration (Pedley et al 2017; Schuster and Jones 2016). In addition, Khuu, et al (2015) present evidence that suggests that various verbal instructions could affect DJ performance outcomes. An example is when subjects are given specific instructions to jump as high as possible while having the shortest ground contact time, subjects do decrease said contact times, but at the cost of having lower max jump heights (Khuu et al 2015; Etnoyer et al 2013; Young et al 1995).

Conclusion

The body has an incredible ability to resist deformation, which allows the body to translate energy from one movement to another, for instance sprinting and drop jumps. A stiffer musculotendinous unit enhances the rate of force development which aids in events that require maximum force production over very short periods of time; for instance, the stance phase of sprinting or the landing phase of a drop jump (Brughelli, and Cronin, 2008). The primary variables for the identification of performance are the reactive strength index and vertical leg stiffness. Vertical and joint stiffness increases with running velocity and jump height. Stiffness in the human body portrays the capacity to withstand displacement once ground reaction forces (GRFs) are applied. Vertical stiffness (K_{vert}) is measured as mass (kg) multiplied by the natural frequency of oscillation squared (Brughelli, and Cronin, 2008). The reactive strength index (RSI) is the capacity of the muscle tendon complex to produce a powerful concentric contraction after a rapid eccentric contraction, also termed the stretch-shortening cycle and can be measured by flight time divided by ground contact time (Schuster, and Jones. 2016). Other variables that can separate the elite from novice athletes include horizontal ground reaction forces (hGRF), peak vertical ground reaction forces (vGRF), ground contact times (GCT), speed (m/s), and knee joint angles at contact and at toe-off.

CHAPTER THREE

Methods

Participants

There were 15 total participants in the study (7 males and 8 females). All participants performed all tasks with both conditions (Carbon insoles, Traditional insoles). Participants were required to do the following: fill out a COVID-19 questionnaire, read, comprehend, and sign a university-approved informed consent before engaging in any part of the study. All participants met the following criteria:

- Must not have a history of lower extremity injury.
- Must have participated in at least four weeks of moderate to vigorous exercise leading up to the study.
- Must be between 18-35 years old.
- US men's shoe size 8,10,12
- US women's shoe size 6,8,10

Study Site

All meetings and data collection sessions took place in the Baylor Research and Innovation Center (BRIC) and in the in the Biomotion Lab on the campus of Baylor University, Waco, TX.

Independent and Dependent Variables

The independent variable for this study was the insole material. The dependent variables included: the reactive strength index (RSI), vertical leg stiffness (K_{vert}), peak vertical ground reaction force (vGRF), and ground contact times (GCT), speed, and knee angles.

Study Design

Participants were asked to perform two separate tasks over the course of one session: a drop jump (DJ) and a 20-yard sprint. Participants completed both tasks in both insole conditions after being randomly assigned to either the carbon insole or the traditional insole. Participants were asked to pick a number 1-10. Those that picked odd numbers started with the traditional insoles and all the even numbers started with the carbon insoles. The participants were not told which insole they would be receiving. The tasks were performed as follows; Sprint, DJ (condition 1), rest 5:00 minutes, Sprint, DJ (condition 2). The study had each participant perform three trials of the drop jump and five trials of the sprint task in both conditions. All participants were supplied with the same shoe for testing to ensure accurate results across all subjects. The shoe used was the Nike Zoom Structure 22.

Consent Form Process

The consent form were emailed to the potential participant for them to read over and vocalize any questions or concerns they may have had before signing the consent form. Upon completion of reading the consent form, participants visited the lab to undergo a screening questionnaire to confirm eligibility for participation. If successful, participants were familiarized to the study protocol via a verbal and written explanation outlining the study design and then reread and officially signed the approved informed consent form. Upon signing the consent form, participants completed a medical history questionnaire and went through a general physical examination to determine whether they met eligibility criteria.

Participant Withdrawals

The participants were free not to take part or to withdraw at any time for any reason. No matter what they decided, there were no penalty or loss of benefit to which they were entitled. If they decided to withdraw from this study, the information that they have already provided were kept confidential. Participants could not withdraw information collected prior to his/her withdrawal. The researcher had the right to take the participant out of this study without his/her permission. This would happen because: 1) the researcher thinks it is in his/her best interest; 2) if the researcher found physical problems that, in due judgment, make completing the experimental procedures risky.

Warmup

After the informed consent and COVID-19 questionnaire were filled out, the participants performed a warmup to optimize performance and mitigate injury. Participants warmed up with a five-minute jog on the treadmill at a self-selected speed. Participants were instructed to keep the RPE between an 8-12 on the Borg scale then followed by a series of six dynamic stretches that covered a 10yrd span. The dynamic stretches included: high knees, butt kicks, A-skips, B-skips, punter kicks, and flexed-foot hops.

Data Collection

Vicon Nexus 2.5 was used to collect all the kinetic and kinematic data associated with the body. A 14-camera set up was utilized collecting data at 300Hz. The cameras in the lab were aimed at the three ATMI force plates. The ATMI force plates were collecting data at 1200Hz. This study's sole focus was directly aimed at the lower body. The plug-in gait lower body marker set was used. In all 16 markers were utilized: RASI, LASI, RPSI, LPSI, RTHI, LTHI, RKNE, LKNE, RTIB, LTIB, RANK, LANK, RTOE, LTOE, RHEE, LHEE

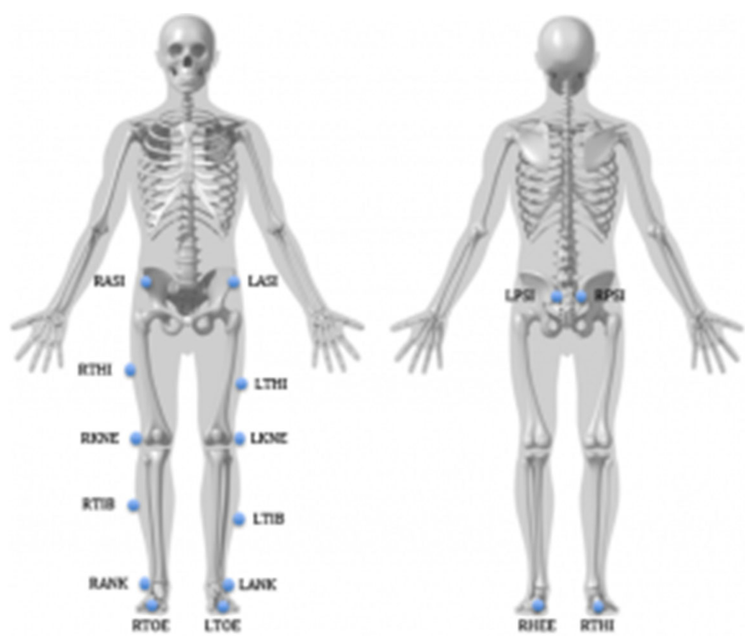

Figure 1: Plug-in gait lower body marker locations

Drop Jump Protocol

The Drop Jump (DJ) measured the reactive strength (RSI). This assessment consists of an athlete stepping off a box, landing with minimum ground contact time and jumping for maximum height. The drop jump RSI is calculated by flight time divided by ground contact time (Douglas et al 2017).

The drop jump test had three successful trials associated with each condition. A successful trial was both feet land entirely on one force plate. The same height box was used for all participants, the box height was 68-cm tall. Participants were verbally instructed to step off the box with one foot and not jump. Participants were instructed to land with two feet inside of one of the ATMI force plates. Then immediately jump off the ground and then re-land on the ATMI force plate. The ATMI force plates were used to establish ground contact time and flight time. The primary cue for participants was to minimize ground contact time. The minimization of contact time is a better cue, than maximizing vertical jump height due to the secondary variable being vertical stiffness. Participants were also instructed to keep hands on their hips throughout the entire drop jump to minimize the use of the arms. (The use of arms increases the flight time)

The vertical stiffness withing the drop jump is calculated as a whole body, as opposed to individual leg stiffness due to the participants dropping onto one force plate. Vertical stiffness is calculated as $\mathbf{k_{vert} = m\omega^2}$.

Sprint Protocol

The 20-yard sprint test measured the vertical leg stiffness (K_{vert}). This test started participants in the 3-point start on one side of the lab and had them get up to top speed as fast as participants could. Participants were instructed to stay within a set number of floor tiles in hopes participants land one foot completely in one of three force plates along their path. Participants were not instructed to hit a specific ATMI force plate so that the participants could not target the force plates and change their sprinting stride.

Five successful trials were conducted and in between each trail was a one-minute rest period. This rest period met the work to rest ratio required to fully recovered from a bout of intense maximal exercise. A successful trial was deemed as the participant having an entire stance phase within one of the force plates with the same leg each time.

Participants were verbally instructed to start in a three-point stance and get up to max speed as quickly as possible. Participants had a three command start: Ready, Set, Go.

To assess vertical stiffness, a force plate is mandatory so that the F/t (F=vertical force, t=contact time) curve is generated. This curve is used to determine the half-period of oscillation and is measured at the time when external forces are exceeding body weight during ground contact. The half-period of oscillation is stated as (P/2) where P equals the period of oscillation (Figure 1). The natural frequency of oscillation (ω) can be calculated from (P/2) with $\omega = 2\pi/P$. Vertical stiffness can then be calculated as $\mathbf{k_{vert} = m\omega^2}$ (Cavagna et al 1988; Cavagna et al 2005; Cavagna, 2006).

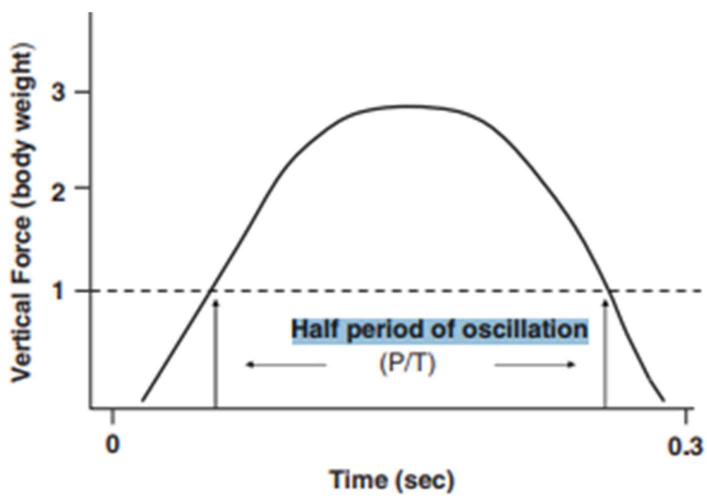

Figure 2. Force/Time Curve (Brughelli and Cronin 2008).

Ground Reaction Force (GRF) and Ground Contact Times (GCT)

Three ATMI force plates were used to measure the vertical ground reaction force (vGRF), horizontal ground reaction forces (hGRF) and the ground contact times (GCT). The vGRF and GCT were assessed for both the drop jump task and the sprinting task. The GCT is measured in milliseconds and the GRF is measured in newtons. These additional variables are secondary and are measured indirectly and are a part of the two principal tasks.

Speed

The speed at which the participants sprinted at was measured via the Vicon Nexus 2.5 cameras. These cameras were set to capture at 300Hz. To determine velocity, the center of mass (COM) was established as the center point between the ASI and PSI markers of the plug-in gait lower body model (Figure 2). The exported data included the XYZ coordinates of all markers, the position of all markers in relation to the L-frame and wand calibration, the acceleration and velocity of each marker throughout the data capture. Velocity (m/s) was established by dividing the distance the COM traveled by the time. These additional variables are secondary, measured indirectly and are a part of the two principal tasks.

Knee Angles

The majority of the GRF development can be attributed to the extension of the knee. By increasing the knee flexion angle at contact there is a reduction in peak vGRF (Derrick 2004). Data was subsequently exported into Microsoft Excel. The exported data included the XYZ coordinates of all markers, the position of all markers in relation to the L-frame and wand calibration, and the knee angles throughout the data capture. Going into Nexus 2.5, then selecting subject, a drop-down menu appears and provides model outputs. These model outputs specifically look at joint angles and moments. The knee joint angle was displayed in graphical form for the entire time the participant was within the field of view for the cameras. The graph showed when ground contact occurred on the force plate via a black diamond, the toe-off was marked by an upwards arrow. The X-axis of the graph displayed the knee flexion. The knee angles at contact and toe-off variables are secondary, measured indirectly and are a part of the two principal tasks.

Statistical Analysis

All statistical analysis was be performed in SPSS 27. In SPSS 27, the variables were separated by insole conditions. The analysis was done as a general linear model, with repeated measures. The within-subject factors were the insoles (carbon, traditional), the between -subject factor was gender (male, female). This method of analysis was utilized for the RSI and the K_{vert}. It was also used on the vertical GRF and GCT, speed, horizontal GRF, and knee angles at initial contact and at toe-off. The two-way ANOVA compares the mean differences between groups that have been split on two independent variables (insoles). The primary purpose of a two-way ANOVA was to understand if there was an interaction between the two independent variables on the dependent variable. The level of significance was set at $P < .05$.

CHAPTER FOUR

Results

Participant Characteristics

The participants recruited for this study were amateur athletes with a minimum of four weeks of prior vigorous-intensity physical activity as defined by the CDC. All participants were recruited from the local fitness facility of Train Waco. In total, the study included 15 participants. Participant 7 was removed from the data due to being a statistical outlier, as defined by being outside the third quartile. Of these 15 participants, 7 of the participants were male and 8 were female, but after removing the outlier, 6 men remained. The baseline anthropometric data describing the 14 participants who completed the study are expressed in Table 1, 2.

Table 1.

Group Specific Participant Baseline Characteristics.

Participant Baseline Characteristics	Men	Women
Sample Size (n)	6	8
Age (years)	24.57 ± 3.64	23 ± 3.11
Height (cm)	182.71 ± 8.19	171.75 ± 7.49
Body Weight (kg)	79.1 ± 5.90	65.07 ± 6.50

Note: SD = standard deviation; cm = centimeters; kg = kilograms; Significant differences were investigated by an independent groups t-test.

Drop Jump Data

The drop jump (DJ) was used as an assessment tool to establish the RSI, K_{vert}, and vGRF. The DJ data was gathered through ATMI force plates and Vicon Nexus 2.5 motion capture cameras. The data was processed through Microsoft Excel and graphical representation came from JMP 15. Table 2 represents the means for these variables along with the p-value that dictates significance.

Table 2.

Drop Jump Data

Variables	Carbon	Traditional	p-value (≤.05)
RSI	1.195 ± .335	1.131 ± 0.328	0.242
K_{vert}	7300.317 ± 3348.579	5349.623 ± 1982.827	0.023
vGRF (N)	4436.725 ± 885.348	4002.743 ± 794.697	0.001

Note: All data are presented as mean ± standard deviation (SD). RSI = Reactive Strength Index, K_{vert} = vertical stiffness, vGRF = vertical ground reaction force, N = Newton.

Reactive Strength Index

Analyses revealed no statistically significant interaction between insole group and gender in the expression of RSI, ($F_{1, 10}$ =0.992, P =.343, ηp^2 = 0.09). Additionally, there was no main effect for insole group ($F_{1, 10}$ =1.545, P =.242, ηp^2 =.134). However, the RSI in the treatment group was greater than that of the control group, although the variables did not reach statistical significance. The RSI is visually represented in Figure 3. RSI is increased from 1.09 ± 0.333 $mm \cdot ms^{-1}$ in the traditional insoles to a score of 1.163 ± .373 $mm \cdot ms^{-1}$ in the carbon insoles.

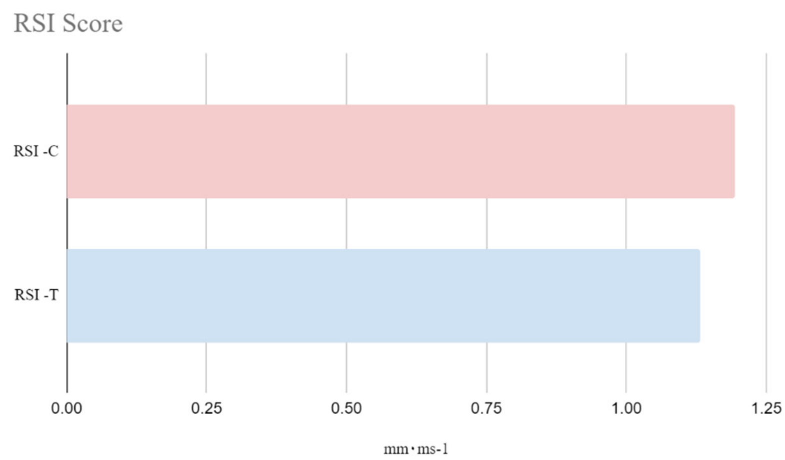

Figure 3. RSI Scores. *Note*: C = Carbon Insole, T = Traditional Insole

Vertical Stiffness

The analyses revealed statistically significant interaction between the main effect for insole group ($F_{1, 10}$ =7.014, *P* =0.023, ηp^2 =0.389). However, between insole groups and gender in the expression of K_{vert}, there was no significant interaction ($F_{1, 10}$ =1.061, *P* =0.379, ηp^2 = 0.162). Additionally, the mean for the K_{vert} in the treatment group was larger than that of the control group. The K_{vert} increased from 5349.623 ± 1982.827 in the traditional insole to 7300.317 ± 3348.579 in the carbon insole as seen in Figure 4.

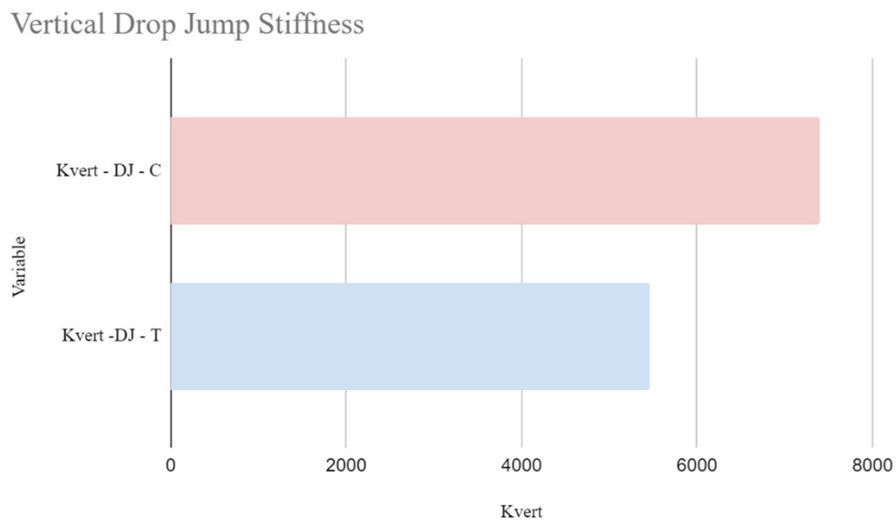

Figure 4. Vertical Drop Jump Stiffness. *Note*: C = Carbon Insole, T = Traditional Insole

Peak Vertical Ground Reaction Force

The final variable analyzed in the drop jump was peak vertical ground reaction force (vGRF). The analyses revealed a statistically significant effect on insole group ($F_{1, 10}$ =18.673, P =0.001, ηp^2 =0.609). However, there was no statistically significant interaction between the insole groups and gender in the expression of vGRF in the DJ ($F_{1, 10}$ = 1.54, P =0.238, ηp^2 = 0.114). Again, the mean vGRF was statistically larger in the treatment group (4436.725 ± 885.348 N) than that of the control group (4002.743 ± 794.697 N).

Sprint Data

The sprint data was gathered through ATMI force plates and Vicon Nexus 2.5 motion capture cameras. The variables that were analyzed for the sprint were, vertical stiffness (Kvert), peak vertical ground reaction forces (vGRF), horizontal ground reaction forces (hGRF), ground contact time (GCT), speed, and the knee flexion angle at ground contact and at toe-off. Table 3 represents the means for these variables along with the p-value that dictates significance.

Table 3.

Sprint Data

Variables	Carbon	Traditional	p-value (≤.05)
K_{vert}	40293.88 ± 15105.16	38514.95 ± 9053.52	0.490
vGRF (N)	1780.08 ± 268.72	1815.91 ± 276.76	0.124
Speed (m/s)	5.11 ± 0.539	5.09 ± 0.53	0.839
GCT (ms)	0.19 ± .028	0.181 ± .03	0.689
hGRF (N)	302.45 ± 57.10	307.79 ± 63.60	0.611
Knee Flexion Angle at Contact (deg)	20.51 ± 10.22	17.08 ± 10.27	0.051
Knee Flexion Angle at Toe-Off (deg)	13.62 ± 6.55	12.47 ± 6.91	0.248

Note: All data are presented as mean ± standard deviation (SD). K_{vert} = vertical stiffness, vGRF = vertical ground reaction force, N = Newton, m/s = meter per second, ms = millisecond, hGRF = horizontal ground reaction force, deg = degrees.

Vertical Stiffness

After performing the analysis on the vertical stiffness (K_{vert}), the analyses revealed no statistically significant interaction between insole groups and gender in the expression of K_{vert} in the sprint ($F_{1, 10}$ =0.144, P =0.711, ηp^2 =0.012). Additionally, there was no main effect for insole group ($F_{1, 10}$ =0.506, P = 0.490, ηp^2 =0.040). However, mean for the K_{vert} in the treatment group was larger than that of the control group, although the variables did not reach statistical significance. The K_{vert} increased from to a score of 40293.88 ± 15105.16 with carbon insoles, from 38514.95 ± 9053.52 with the traditional insoles.

Peak Sprint Vertical Ground Reaction Forces

Analyses revealed no statistically significant interaction between insole groups and gender in the expression of vGRF ($F_{1, 10}$ =.005, *P* =0.945, ηp^2 =0.000). Additionally, there was no main effect for insole group ($F_{1, 10}$ =2.740, *P* =0.124 ηp^2 =0.186). The mean for the vGRF in the control group was larger than that of the treatment group. vGRF is decreased from 1815.91 ± 276.76 N in the traditional insoles to 1780.08 ± 268.72 N in the carbon insoles. Vertical GRFs can also be represented as a ration of body weight as seen in Figure 5.

Horizontal Ground Reaction Forces

Analyses revealed no statistically significant interaction between insole groups and gender in the expression of hGRF ($F_{1, 10}$ =.490, *P* =0.497, ηp^2 =0.039). Additionally, there was no main effect for insole group ($F_{1, 10}$ =.273, *P* =0.611, ηp^2 =0.022). T. The mean for the hGRF which is represented as a ratio of body weight is Figure 5, can also be see in table 3 as whole numbers (Traditional = 307.79 ± 63.60, Carbon = 302.45 ± 57.10).

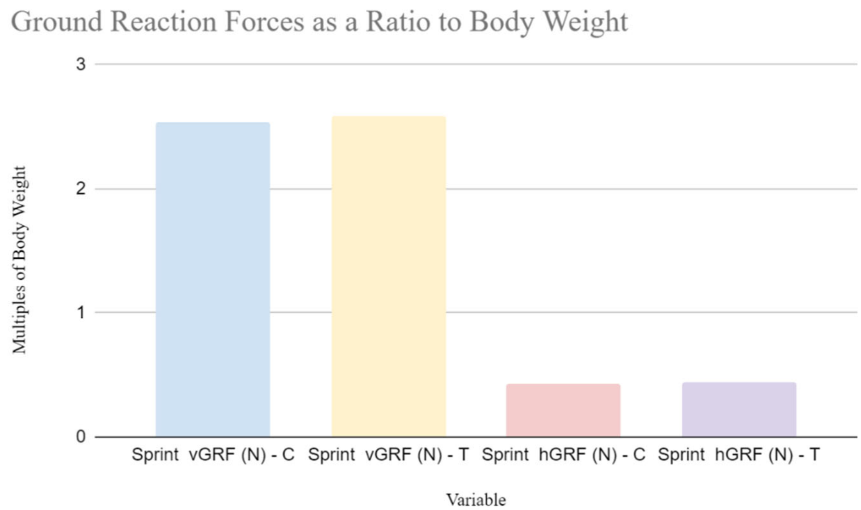

Figure 5. Ground Reaction Forces as a Ratio to Body Weight. *Note*: C = Carbon Insole, T = Traditional Insole, vGRF = Vertical Ground Reaction Force, hGRF = Horizontal Ground Reaction Force.

Ground Contact Time

Ground contact time (GCT) was analyzed in the sprint task, analyses revealed no statistically significant interaction between insole groups and gender in the expression of GCT ($F_{1, 10}$ =.398, P =0.680, ηp^2 =0.062). In addition, just like the previous variables, there was no main effect for insole groups that showed a statistically significant change ($F_{1, 10}$ = 0.168, P =0.689, ηp^2 =0.014). Furthermore, while all of the factors within the GCT variable did not show a statistical significance, the mean ground contact times in the treatment group were longer than that of the control group. The GCT decreased from 0.19 ± .028sec (carbon) to 0.181 ± .03sec (traditional).

Speed

After performing the analysis on the speed of both insole groups, the analyses revealed no statistically significant interaction between insole groups and gender in the expression of speeds in the sprint ($F_{1,10}$ =0.177, *P* =0.738, ηp^2 =0.01). Additionally, there was no main effect for insole group ($F_{1,10}$ =0.043, *P* =0.893, ηp^2 =0.004). However, mean for the speed in the carbon insole group was larger than that of the traditional insole group. The speed decreased from 5.11 ± 0.539 m/s in the carbon insole to 5.09 ± 0.530 m/s in the traditional insole.

Knee Flexion Angle

The knee flexion angle was measured at point of ground contact and at toe-off. At point of contact, the analyses revealed no statistically significant interaction between insole groups and gender in the expression of speeds in the sprint ($F_{1,10}$ =.112, *P* =0.743, ηp^2 = 0.009). Additionally, there was no main effect shown for insole groups, even though the p-value was close to reaching significance ($F_{1,10}$ =4.676, *P* =0.051, ηp^2 =0.28). The carbon insole had a greater knee flexion angle at initial ground contact (20.51 ± 10.22deg) than the traditional insole (17.08 ± 10.27deg).

Similarly, the knee flexion angle at toe-off showed similar results. The carbon insole had a greater knee flexion angle at toe-off (13.62 ± 6.55deg) than the traditional insole had (12.47 ± 6.91deg). As seen previously, at toe-off the analyses revealed no statistically significant interaction between insole groups and gender in the expression of speeds in the sprint ($F_{1,10}$ =1.199, *P* =0.295, ηp^2 = 0.091). Lastly, there was no main effect shown for insole groups which was different than the knee flexion angles at ground contact ($F_{1,10}$ =1.472, *P* =0.248, ηp^2 =0.109

CHAPTER FIVE

Discussion

Introduction

It was proposed that the addition of carbon insoles into sneakers should allow for an increase reactive strength and for the ability to apply greater vertical forces through increases in leg stiffness. The first two hypotheses were rejected, in that the addition of carbon insoles had no effect of the RSI or the vGRF in the sprint task. Contrarily, there was a significant change in vGRF in the drop jump.

- Ho: There will be no significant difference in reactive strength between the carbon and standard insoles.
- Ho: There will be no significant difference in Vertical Ground Forces between the carbon and standard insoles in sprinting.
- Ho: There will be no significant difference in Vertical Ground Forces between the carbon and standard insoles in the drop jumps.

When looking at other kinematics, many of the carbon insole variables were heightened over that of the traditional insoles; only the K_{vert} and vGRF in the DJ was shown to be statistically significant.

Drop Jump

The aim of this study was to examine the effects that carbon insoles might have on an athlete's reactive strength as measured in the drop jump. Reactive strength is measured via the reactive strength index (RSI) that is strongly associated with sprint performance

(Healy et al 2019). Reactive strength assessments are also a common indicator of an athlete's ability to use their stretch-shortening cycle (SSC) to increase force production. Drop jumps are regularly used as an assessment of reactive strength. The aim of the drop jump exercises is to improve the tendons and muscles ability to store and release elastic energy when exposed to high stretching forces such as those found within jump landings and stance phases in sprinting (Ball and Zanetti, 2012).

The results of this study found no significant difference between the insole conditions (carbon, traditional) on the participants RSI score as shown in Table 2 and in Figure 3. The mean for the RSI in the carbon group (1.195 mm·ms^{-1}) was larger than that of the traditional group (1.131 mm·ms^{-1}), although the variables did not reach statistical significance ($p<.05$).

By increasing lower limb stiffness with the carbon insoles, reactive strength seemed to be larger due to the prevention of excessive lengthening of muscles under high stretch loads and indirectly by increasing force production during subsequent muscle activation and utilization of the elastic structures within the SSC (Pedley et al 2107). For the study, participants stepped off a 68-cm box, landed and spent as little time on the ground as possible and then jumped as high as possible. The vertical stiffness is essential in drop jumps because it limits knee flexion and contact time, allowing for larger RSI (Pedley et al 2017). In this study, the K_{vert} increased from 5349.623 ± 1982.827 in traditional insoles to 7300.317 ± 3348.579 in the carbon insoles which was deemed statistically significant (*P* = 0.023). The greater the vertical stiffness the larger the peak vGRF should hypothetically be (Derrick, 2004). The DJ test confirmed this in that the vGRF was significant (*P* = .001).

The carbon insoles produced and average vGRF of 4436.725 ± 885.348 N, and the traditional insoles produced an average of 4002.743 ± 794.697 N.

Sprinting

One of the other aims of this study was to examine the effects of carbon insoles on the vertical leg stiffness while sprinting. Due to laboratory setup, the vertical stiffness was assessed during the initial acceleration phase (0-10m), as opposed to the maximal velocity phase. This is an important distinction to make due to the running mechanics being very different between these two phases. One of the largest distinctions between acceleration phase and max velocity phase is the ground contact time which typically falls between .196 and .152 seconds in initial acceleration and between .119 and .094 seconds at max velocity (Wild et al 2011). The data for this study did not produce a statistically significant finding for ground contact times between insole conditions. The GCT decreased from .19sec in the carbon insoles to 0.181sec in the traditional insoles. This is consistent with what Cigoja et al (2019) found (Control = 239.6 ms; Stiff = 252.0 ms) although they were much higher due to the paces in that study being submaximal. Another significant difference between these two phases is the flight time (~0.06s = acceleration, ~0.126s = max). These are important distinctions to make due to each phase's characteristics containing different properties that would change the vertical stiffness.

Stiffness is often defined as the resistance of an object or body to a change in length. The mechanical stiffness in the human leg has a major influence on various athletic abilities including rate of force development, elastic energy storage and the utilization, and sprint kinematics (Brughelli and Cronin, 2008). According to Douglas et al (2019), a stiffer leg will allow the attainment of higher vertical ground reaction forces and decrease ground contact time. Gender effect was found only a factor when comparing men and women's ground reaction forces, due primarily to weight discrepincies (males = 79.1 kg, females = 65.07 kg). Once the participants bodyweights are taken into account, the difference became nonsignificant (Figure 5). Additionally, it stands to reason that the stiffer the leg, larger the vGRFs and faster the speeds that the participants can achieve.

Research studies demonstrate that the horizontal forces (hGRF) become a less identifying factor of performance as the distance increases. The importance of a large hGRF decreases throughout the acceleration phase towards maximum velocity phase, which is when the peak vertical forces become the largest identifier for performance (Wild et al 2011). This present study only looked at the hGRF at the 10-meter mark (halfway) through the participants 20-meter sprint, which is still very early in the acceleration phase.

GRF development can be attributed to the extension of the knee (Derrick, 2004). The knee joint flexion angle influences peak vGRF (Kubo et al 2016). By increasing the knee flexion angle at initial contact, it was found in the present study and in Derrick's 2004 study, that there was a reduction in peak vGRF. The carbon insole had a greater knee flexion angle at touchdown (20.51 deg) than the traditional insole had (17.088 deg) albeit insignificant ($P = .051$). With the carbon insole having larger knee flexion angles, the data gathered from this study in terms of vGRF is in line with other findings (Derrick, 2004; Kubo et al 2016). Vertical ground reaction forces changed from 2.58 times greater in traditional insoles to 2.53 times greater in the carbon insole when looking at relative vGRF (Figure 6). The larger the knee flexion angle at contact results in s lower peak relative vGRF.

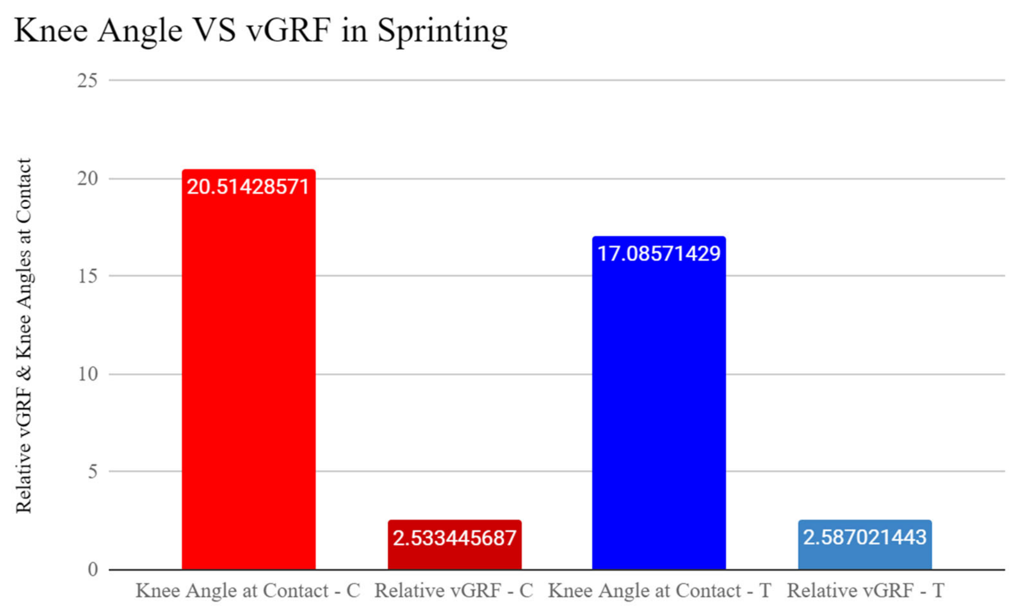

Figure 6. Comparison between Knee Flexion Angles at Contact and vGRFs.

Conclusion

Results from this study show that the use of carbon insoles does not cause a significant increase in reactive strength, or vertical stiffness to enhance sprint performance in amateur athletes. However, there were some interesting trends in the data that does boast some merit for their use, although it is not significant.

Due to the novelty of carbon insoles, this study it is on the forefront of research into the effects that carbon insoles have on sprint performance. In a sprint the winner can be determined by .01 seconds or it could be the difference between a defender chasing down the ball carrier and making the tackle or letting them score a touchdown. Athletes are always looking for marginal gains to give them the potential edge. Carbon insoles may provide that edge to push an athlete to that next level. More research needs to be done on this topic, especially looking at varying stiffness levels.

Due to uncovering significant findings only in the drop jump task, where the relative vertical force exceeds 4-6 times their body weight. Would a less stiff insole find significant findings in the sprint task were the relatives forces were 1.5-3 times participants body weight?

One possible explanation for the lack of significant results may be the number of participants in the study. A total of 15 participants were included in the study, with results from 14 being used in the statistical analysis. A greater number of participants could in fact lead to a more significant result from the statistical analysis. One possible explanation for the lack of significant findings in the sprint, is that the acceleration phase has longer ground contact times, greater joint flexion angles, and a greater emphasis on horizontal ground reaction forces (Wild et al 2011). Trying to achieve max velocity in a short amount of time leaves smaller room for improvements that may not seem significant. Another possible explanation for the lack of significant findings in the DJ, could be the fact that carbon insoles used in the treatment group were significantly stiffer and it was noted by some athletes that they found it uncomfortable. This discomfort could produce skewed results due to athletes not being comfortable or familiar with such a stiff insole. A third potential for lack of significance could come from the standardized box height of 68-cm. This height could be too tall or too short depending on the participant. In the future the Bosco drop jump test might produce better results in that, this has the participant drop from varying heights (20 cm, 40 cm, 60 cm, 80 cm, and 100 cm), and this would allow researchers to see where subjects are the most reactive (Bryne et al 2020). Future studies may benefit from also having participants engage in a break in period to allow them to get use to the stiffer insole, so that the participants are less conscientious of the difference in feel between insole conditions. Additionally, future studies may benefit from looking at the GCT, K_{vert}, speed, knee angles, vertical ground reaction forces once the athlete has reached their top speed.

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