2017

The Effect on Postural Balance as a Result of Different Types of Golf-Specific Footwear Over an Extended Duration

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THE EFFECT ON POSTURAL BALANCE AS A RESULT OF DIFFERENT TYPES OF GOLF-SPECIFIC FOOTWEAR OVER AN EXTENDED DURATION

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A thesis submitted to the faculty of The University of Mississippi in partial fulfillment of the requirements of the Sally McDonnell Barksdale Honors College.

Oxford
May 2017

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ACKNOWLEDGEMENTS

I would like to thank Dr. John Garner for his help as my advisor throughout the research and writing process; Sam Wilson for allowing me to be a part of this dissertation study as well as advising and critiquing me throughout the entire process; Dr. Dwight Waddell for serving as an advisor and reader; and Dr. Scott Owens and Dr. Mark Loftin for serving as the second and third readers of my thesis paper.

I would also like to thank the Sally McDonnell Barksdale Honors College for always supporting me through my academic endeavors and pushing me to participate in my community outside of the classroom. Lastly, I would like to thank the Department of Exercise Science for providing me with resources and opportunities I have needed to be academically successful.

ABSTRACT

The sport of golf is increasingly popular within the United States, with an estimated 35 million participants worldwide. To be successful, the golf swing, regarded as a difficult biomechanical motion to accomplish, needs to be accurate and powerful. A proper swing incorporates a weight shift from the rear foot to the leading foot, which indicates that balance is crucial to maintain. The purpose of this study was to examine the effect of golf-specific footwear on static balance over an extended duration in order to relate it to golf performance. Twelve recreationally trained males (age: 23.4±2.2 years; height: 181.5±9.0cm; mass 95.8±18.6 kg) with no history of injuries or disorders participated in the study. The study lasted about four days, which included a familiarization day, and experimental days lasting around four hours each. Static balance was assessed by equilibrium scores using the NeuroCom Equitest Sensory Organizational Test (EO, EC, EOSRV, EOSRP). The conditions were counterbalanced prior to the start of the experimental days, which included a dress shoe style (DS), a minimalist shoe style (MIN), and a tennis shoe style (TS), with a barefoot condition (BF) as the control variable. A predetermined alpha level of 0.05 was used, and results were analyzed using a 4x5 repeated measures ANOVA [4 footwear conditions (BF, DS, MIN, TS) x 5 measurement times (pre, 60, 120, 180, 240)]. There was a significant interaction, within the EC condition, detected at the three-hour mark, where the DS condition indicated an impairment in balance control compared to the BF condition. However, there was no indication of significance among the golf-specific footwear. This expresses the fact that

may have the ability to choose golf-specific footwear according to preference without worrying about static balance detriments.

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CHAPTER 1

INTRODUCTION

Golf is an increasingly popular sport throughout the world. In the United States alone, there are about 26.5 million golfers (Hume et al., 2005). Even with the biomechanical difficulty of being successful in this sport, it doesn't stop the estimated 35 million participants worldwide (Hume et al., 2005). The Professional Golf Association is one of the largest sports organizations in the world, with more than 28,000 adults working toward the promotion of the sport of golf (Professional Golf Association, 2016). Golf attributes about $176.8 billion to the US economy annually, with $5.6 billion of that just toward supplies and apparel (Golf Economy Report 2011). The aim of golf is to hit the golf ball into a small hole in the ground with as few shots as possible (Hume et al., 2005). With the popularity of the sport rising, the number of scientific literature associated has increased to better understand the technique in order to be successful. To achieve this, professionals aim to better their driving performance (Chu et al., 2010). The golf swing has been regarded to be one of the most difficult motions to accurately execute, when attempting to swing a relatively long club at a relatively small ball in the desired direction with efficiency (Lindsay, Mantrop, Vandervoot 2008).

Past research indicates that a straight back and stable pelvis that is perpendicular to the ground is needed to transfer the most amount of energy into the ball (Chu et al., 2010). The swing used among golfers consists of a backswing at the start, followed by a a downswing and a follow through. At the beginning of the backswing, the weight of the golfer is shifted to the trail, or rear, foot (Lindsay, Mantrop, Vandervoot 2008). A strong downswing can increase the power generated, and causes the body weight to shift forward to the leading foot (Chu et al., 2010). Skilled golfers have been shown to have a greater weight shift during the downswing toward the leading foot (Lindsay, Mantrop, Vandervoot 2008).

In general, balance training can be effective for athletic performance. It allows muscles to contribute to the force needed for the action by decreasing muscle proportions for body stabilization (Hrysomallis 2011). Throughout a game of golf, the golfer will play, on average, anywhere between 9 and 18 holes, while having to maintain the efforts of several efficient swings at each hole. It is imperative that a stable posture and balance should be sustained. A weight shift is used for an accurate and skilled swing, but a transfer that is too large makes it hard for the body to control (Hume et al., 2005). Even with their surroundings, the hilly green and uneven surfaces may require proficient balance abilities (Hrysomallis 2011). Hrysomallis (2011) also found that elite golfers have better static balance ability. Although static balance is not automatically associated with the game of golf, it is suggested that it can assist in the weight shift of the swing.

Balance is the ability to maintain the body's center of mass (COM) within its base of support (BOS) (Winter 1995). The human body coordinates input from three systems in order to maintain and execute balance and postural stability (Winter, Patla, Frank 1990). They include the visual, vestibular, and proprioceptive systems. These systems allow the body to know its position in space, and correct the impairments (Guskiewicz, Perrin 1996). Vision is considered the first line of defense and aids the body by making obstacles and the environment apparent (Winter, Patla, Frank 1990). The vestibular system is housed within the inner ear and provides information on the body's orientation (Winter, 1995). The vestibular apparatus sends afferent sensory information from the head's orientation to the muscles as efferent feedback (Mittal, Narkeesh 2012). Control of posture is maintained by the ability of proprioceptors, which include sensory receptors on the feet, Golgi tendon organs, and muscle spindles (Sturnieks, Lord, St George 2009). Muscle spindles lie in parallel with muscle fibers and are responsible for detecting the fibers' length, as well as the velocity and rates of the stretch (Taylor 2009). From the information received, a muscle contraction occurs in response to the stretch (Guskiewicz, Perrin 1996). Golgi tendon organs are located within the musculo-tendinous junction and respond to the rate of tension within the muscle, and inhibits the contracting muscle (Guskiewicz, Perrin 1996). The continuous feedback on the status of each muscle to the nervous system plays a role in executing and correcting balance.

Footwear worn takes a key role in balance as it acts as a medium in between the surface of support and the foot (H. Chander et al., 2013). However, it also serves as a hindrance to the somatosensory feedback mechanisms that control and improve balance (H. Chander et al., 2013). The sole of the foot is regarded as an important region to maintain balance and posture, due to the high density of mechanoreceptors (Rogers et al., 2013). Characteristics of footwear such as heel height, shaft height, midsole hardness, and mass have been investigated to improve the quality of balance while impairing receptive input (H. Chander et al., 2015; Chander, Garner, Wade, 2013; Menant et al., 2009). It has been shown that balance is preserved with footwear that has a slightly elevated heel, less mass, and medium to hard sole (H. Chander et al., 2015). The COM can be shifted anteriorly when wearing a higher heel, making it harder to control within the BOS, and increase risk of falling (Menant et al., 2009). A shoe with heavier mass has been found to require a higher energy expenditure than compared to one with a lighter mass (H. Chander et al, 2015). Balance maintenance is also improved by a harder sole compared to a softer sole, which can inhibit proprioceptive feedback by a cushioning effect (H. Chander et al., 2013).

Although past literature has shown these ideal shoe characteristics for occupational footwear, these can be expanded to golfers and their footwear. For golf specifically, the forces during the golf swing that the body generates comes from the soles of the feet to the ground, known as ground reaction forces (GRF) (Lindsay, Mantrop, Vandervoot, 2008). It has been found that footwear modifies the interaction between the foot and the ground (Hennig, 1998). Shoes with less cushioning can facilitate a more optimal running and walking performance, as they decrease GRFs through shock absorption (Logan et al., 2007). Further, in the past, metal spikes ranging from 6 mm to 8 mm were foundational to the traditional golf shoe (Worsfold, Smith, Dyson 2007). Although the spikes were helpful to maintain grip and traction, it began to damage the green on which golfers play. The evolution of the shoe has included an outer sole with raised moldings, known as alternative spikes, to provide additional traction instead of the metal spike (Worsfold, Smith, Dyson 2007). The alternative spikes allow for multiple points of contact with the ground, and covers a larger surface area than metal spikes (Worsfold 2011). Traditional golf shoes are also constructed with stiff, leather designs similar to a “dress shoe,” and research questions whether a more flexible and lighter shoe might be more advantageous (Worsfold 2011). With the changes occurring throughout the history of the golf shoe, a need for the correct form of golf-specific footwear is imperative to achieve the desired performance of the sport.

Similar to those that work in occupational settings, golfers are exposed to prolonged standing and walking. Extensive past literature has explored footwear over extended durations and their effects on balance. With a duration ranging from 3 to 4 hours, past literature has shown that weight shifts increase in effect from a decrease in balance ability (Cham, Redfern 2001). However, research is lacking in the area that explores how golf shoe types affect balance and therefore, golf performance. There have been previous studies on occupational footwear and its effects on balance over a four-hour duration, where a high boot shaft was shown to be optimal for prolonged standing and walking (Chander, Garner, Wade 2013). The four-hour duration can equate to about half an occupational work day, which matches an average round of a game of golf. An investigative approach to the most efficient golf-specific footwear to endure it is necessary. The main focus of this paper is the effect of balance ability while wearing golf specific footwear over an extended duration.

Purpose:

The purpose of this study is to analyze posture and balance through equilibrium scores while wearing the different types of golf-specific footwear throughout an extended duration.

Hypotheses:

H_{01}: There will be no significant difference among the golf-specific footwear and its effect on balance control.

H_{A1}: There will be a significant difference among the golf-specific footwear and its effect on balance control.

It has been shown in previous studies that shoe characteristics such as shaft height, shoe mass, midsole thickness, and heel height can significantly affect balance and postural control (H. Chander et al.; 2013, H. Chander et al., 2014; Menant et al., 2008). However, it is uncertain whether those characteristics that can impair balance will apply to golf specific footwear and therefore, golf performance. Considering that past literature indicates a higher mass shoe will cause a balance detriment, we expect the heaviest footwear condition to be significantly worse than the others.

H_{02}: There will be no significant differences affecting balance over time.

H_{A2}: There will be a significant difference affecting balance over time.

There has also been evidence that balance can be significantly impaired over an extended duration (H. Chander et al., 2015). It is unclear whether or not the four-hour duration of the study will cause a significant main effect in time among the different conditions. However, we expect that balance ability will decrease as the duration is prolonged throughout the study. The barefoot condition is expected to withstand the extended duration better, due to the continuous proprioceptive information from the environment.

Definitions

Balance: a generic term describing the dynamics of body posture to prevent falling; the ability to maintain the body's center of mass within its base of support (Winter, 1995).

Base of Support (BOS): for a human, the area bound by the tips of the toes in the anterior portion and the tips of the heels posteriorly (Levangie, Norkin 2006).

Center of Gravity (COM): the point at which a single force of magnitude should be applied to a rigid body or system to balance exactly translational and rotational effects of gravitational forces acting on the components of the body or system (Rodgers, Cavanaugh, 1984).

Center of Mass (COM): describes the point on a body that moves in the same way that a particle subject to the same external forces would move (Rodgers, Cavanaugh, 1984).

Center of Pressure (COP): a quantity available from a force platform describing the centroid of the pressure distribution (Rodgers, Cavanaugh, 1984).

Equilibrium: that condition when the resultant force and moment acting on a body are zero (Rodgers, Cavanaugh, 1984).

Fatigue: when a muscle is not able to produce as much force, and sensations of muscle force and effort are dissociated (Taylor, 2009).

Golgi Tendon Organ (GTO): responsible for sending information about tension in the muscle or rate of change of tension; located in the tendons near their junction (Guskiewicz, Perrin 1996).

Ground Reaction Force (GRF): the forces that act on the body as a result of interaction with the ground (Rodgers, Cavanaugh, 1984).

Muscle Spindle: send information to the nervous system about either the muscle length or its rate of length (Guskiewicz, Perrin 1996).

Postural Control: the task of controlling the body's position in space for the dual purposes of stability and orientation (Palmieri et al., 2002).

Sensory Organizational Test (NeuroCom): evaluates the integrity of the three sensory modalities of balance by selectively disrupting somatosensory and/or visual information regarding the body's center of gravity (Guskiewicz, Perrin 1996).

Somatosensory System: functions via mechanoreceptive senses of touch pressure, vibration, and the sense of position, which determines the relative positions and rates of movement of parts of the body (Guskiewicz, Perrin 1996).

Vestibular System: senses linear and angular head accelerations to interpret the body's orientation in space through structures found in the inner ear (Winter 1995).
Visual System: provides information about the environment, as well as the orientation and movement of the body (Winter, Patla, Frank 1990).

CHAPTER II

REVIEW OF LITERATURE

Balance is essential for all animals in order to achieve most of our daily movements safely (Winter, Patla, Frank 1990). With falls being a prevalent injury, the balance control system is constantly at work to correct the unstable human body (Winter 1995). It is known that, anatomically, two-thirds of the body mass is located about two-thirds of the body height above ground, causing a challenge in maintaining a stable posture (Palmieri, Ingersoll, Stone, Krause 2002). Specifically, with humans being bipeds, they only have two feet touching the ground while standing. The body faces the problem of trying to control a relatively high center of gravity over a small base of support (Guskiewicz, Perrin 1996).

Human balance is maintained by coordinating three subsystems: the sensory system, the central nervous system, and the musculoskeletal system (Winter, Patla, Frank 1990). Even more specifically, postural control needs to be executed in order for the body to understand its position and orientation in relation to space and gravity (Guskiewicz, Perrin 1996). This equilibrium can be successfully managed by combining the visual, vestibular, and somatosensory inputs from the sensory system. An impairment to any one, or combination, of the subsystems can and will lead to a postural instability (Horak 2006).

Vision is a necessary component of balance as it primarily aids the body's movement by avoiding the environment's obstacles (Winter 1995). It can accurately provide information on orientation and spatial relationships to safely navigate the body (Winter, Patla, Frank 1990). The visual system further excels in balance control as it shifts the visual field in relation to natural body sway (Sturnieks, Lord, St George 2009). For example, a body sway to the right causes a visual field shift to the left. The shift results in the central nervous system of the human body to interpret itself as an egocentric movement (Sturnieks, Lord, St George 2009). Past research clarifies that poor vision in at least one eye can increases the postural sway area by approximately 30% and the risk of loss of balance itself (Sturnieks, Lord, St George 2009). However, vision only accounts for a percentage of the sensory information upon which balance relies. Although, it has been shown that a dependence on vision can increase when inputs from either the vestibular or somatosensory systems is altered (Horak 2006). The ability of the body to re-weight sensory information is an important and crucial tool for maintaining stability when moving from one sensory context to another.

The vestibular system consists of structures in the inner ear that serve to sense the body's orientation in space by interpreting linear and angular head accelerations (Winter 1995). These structures include semicircular canals, the utricle and the saccule, which account for the equilibrium mechanism (Mittal, Narkeesh 2012). The semicircular canals transduce angular acceleration information, while the utricle and saccule are responsible for monitoring linear accelerations of the head (Sturnieks, Lord, St George 2009). Although the vestibular system can work independently, it can be integrated with the visual system through the vestibulo-ocular reflex (Sturnieks, Lord, St George 2009). This reflex retains visual fixation during head movement by causing the eyes to rotate in an equal and opposite direction (Guskiewicz, Perrin 1996). Research explains that when visual and surroundings and surface under the base of support are tilted, the vestibular system takes precedence (Guskiewicz, Perrin 1996). People with malfunctioning vestibular systems have apparent impairments in balance, and are at increased risk of recurrent falls (Sturnieks, Lord, St George 2009).

The somatosensory system presents the body with the relative position of the joints, as well as the length and force of the muscles (Winter, Patla, Frank 1990). Receptors that lie in muscles, joints, and skin contribute to these by detecting mechanoreceptive senses such as touch, pressure, and vibration (Rogers, Page, Takeshima 2013). Meissner's corpuscles, Pacinian corpuscles, Merkel discs, and Ruffini endings are cutaneous and subcutaneous receptors that deliver information on stroking, vibration, pressure and skin stretch, respectively (Sturnieks, Lord, St George 2009). Presented as afferent tactile information, the receptors located on the soles of the feet aid in standing balance (Sturnieks, Lord, St George 2009). Research suggests that the preferred sense for balance control comes from the somatosensory information of the feet touching the support surface (Guskiewicz, Perrin 1996). The feet contain a dense amount of mechanoreceptors to influence movement and postural stability (Rogers, Page, Takeshima 2013). However, it is muscle spindles and Golgi tendon organs that play a primary role in postural control through the central nervous system. Muscle spindles consist of sensory receptors that lie in parallel with muscle fibers (Taylor 2009). At the beginning of a stretch, the spindles signal velocity and rate of the stretch, as well as length of the muscle. Muscle spindles complete the myotatic reflex, which creates a contraction in response to the muscle being stretched (Guskiewicz, Perrin 1996). Golgi tendon organs serve as a second type of proprioceptor for the assessment of joint position, and are located in the musculo-tendinous junction (Sturnieks, Lord, St George 2009). They sense passive and active muscle tension and the rate of that tension. By sending continuous information, the GTO is able to detect changes in tension by either passive stretch or active contraction (Sturnieks, Lord, St George 2009). The muscle is able to prevent overstretching by GTOs initiating the polysynaptic reflex and inhibiting contraction (Guskiewicz, Perrin 1996). Through the use of muscle spindles and Golgi tendon organs, the body is able to prepare appropriate contractions to maintain postural stability (Guskiewicz, Perrin 1996). Even at rest, the somatosensory system remains at work to evaluate and correct upright posture by muscle contraction.

In order to understand balance, it is imperative to know definitions and differences between terms such as the body's center of mass, gravity, pressure, base of support, and postural sway. The center of mass (COM) is the weighted average of the center of masses of each body segment using a total body model (Milton, Cabrera, Ohira, Tajima, Tonosaki, Eurich, Campell 2009). The body's center of gravity (COG) can be defined as the point at which the body weight can be considered to act (Rogers, Cavanagh 1984). Used interchangeably with COM, the COG is the vertical projection of the COM into the ground (Winter 1995). The total area in which the body makes contact with the ground constitutes the base of support (BOS) (Rogers, Cavanagh 1984). Balance is the ability to maintain COG within its BOS. Once the COG reaches the edge or outside the parameters of the BOS, the body is no longer within the limits of stability, which is the maximum angle the body can deviate from the vertical in the anterior and posterior directions. (Palmieri, Ingersoll, Stone, Krause 2002). The body's center of pressure (COP) is often mistaken as synonymous with the COG. COP is the center of distribution of the total force applied to the supporting surface (Palmieri, Ingersoll, Stone, Krause 2002). Most of the research on postural control records the COP in a bipedal stance, when both feet make contact with a single force platform, known as the net COP (Palmieri, Ingersoll, Stone, Krause 2002). These recordings show the limits of the BOS in the anterio-posterior and medio-lateral directions. Lastly, postural sway is the constant, small deviations in the position of COG (Sturnieks, Lord, St George 2009).

The human body faces challenges to maintain good balance and posture. Humans have a smaller base of support to keep the body's center of gravity within, compared to quadrupeds with a larger base of support. Another prominent problem is that the 'limits of stability' is shaped like a cone or inverted pendulum pivoting about the ankle (Winter 1995). Depending on the direction of the sway, the net ankle movement is controlled through ankle musculature to correct the imbalance of the COG (Winter, Patla, Frank 1990). For example, in a forward sway, the plantarflexors activate in order to move the COP anterior to the COG. This action causes the angular acceleration to reverse, and angular velocity to decrease until it results in a reversed state, which eventually induces the body into a backward sway (Winter 1995). In effect, during the backward sway, the plantarflexors decrease activation until COP lies posterior to COG. This continues as the COP must continuously move in the anterior and posterior directions with respect to COG in order to bring the body back to a quiet stance (Winter 1995). However, The COP's dynamic range needs to be greater than that of the COG, or the corrective response cannot be adequate (Winter 1995). In this situation, the body may have to prevent a fall by moving a limb forward or backward to uphold balance (Winter, Patla, Frank 1990). The body's sway in the anterior and posterior directions can be used to determine a computer generated equilibrium score. The equilibrium score, which compares the subject's limits of stability with the theoretical limits, can range from 0% to 100%. (Wrisley et al., 2007). A 0% indicates a fall and 100% indicates perfect static balance (Wrisley et al., 2007).

Reactions to balance deficits become more complex when larger perturbations are involved. There are strategies that the body uses in order to overcome these disturbances: the ankle strategy, the hip strategy, and the stepping strategy (Rogers, Page, Takeshima 2013). The ankle strategy is used when facing small amounts of sway, and is the most common form of control when the feet are stationed on a firm surface (Horak 2006). The ankle musculature takes precedence in controlling the inverted pendulum by activating ankle plantarflexors and dorsiflexors (Winter 1995). This is most effective when in quiet stance. With a larger perturbation, the hip joint is active (Horak 2006). To maintain balance, the hip strategy flexes the hip to move COG posteriorly and extends the hip to move COG anteriorly (Winter 1995). In a situation where the body could no longer maintain the COG over the BOS from an external perturbation, the stepping strategy would be used to recover equilibrium (Horak 2006). The step moves the BOS under the COG and reestablishes balance in the direction of the sway experienced. (Rogers, Page, Takeshima 2013).

As the control systems work together to maintain balance and posture, one must also consider the external factors. The floor typing, footwear, duration of balance maintained, and fatigue could all contribute to postural stability.

Flooring characteristics have been found to influence balance ability. When analyzing dynamic balance, different walking surfaces have been shown to decrease walking velocity, and step length, while increasing step width (Menant at al., 2009). When the surface condition is wet or slippery, it has been shown that compensatory gait changes are employed to preserve balance and prevent falls. This is accomplished by reducing the required coefficient of friction between the foot and walking surface (Menant et al., 2009). When flooring isn't wet, it might be ideal to have a soft flooring condition to attenuate forces during a fall. However, it is apparent that surfaces with a low stiffness have the capability to impair balance and its recovery (Wright, Laing 2010). Further, soft flooring such as foam surfaces challenge balance, as it has been postulated to decrease somatosensory receptors in the ankle and foot (Wright, Laing 2010). From this, it has been seen that subjects, pre-perturbation, increase co-contraction of ankle musculature to increase the ankle stiffness on lower-stiffness surfaces (Wright, Laing 2010). The best type of flooring has characteristics that increase stiffness and elasticity, as well as a decrease work lost and load decay (Cham, Redfern 2001). Research suggests that it can reduce number of weight shifts, leg skin temperature, and leg volume. Subjective testing on floors also correlated with this type of surface, as subjects stated the least amount of discomfort and fatigue (Cham, Redfern 2001). In one study, the floor with the highest thickness, least load required for deflection, and highest work lost was continuously ranked the worst for the number of COP shifts and fatigue (Cham, Redfern 2001). However, it is known that optimal material for flooring needs more research. While there are flooring surfaces that are better for balance and posture than others, their good rankings are not as clear as the negative performances (Cham, Redfern 2001).

Another characteristic that needs to be taken into account is the type of footwear worn. Footwear in general affects balance by inhibiting the information from the mechanoreceptors on the soles of the feet and around the ankle joints, as well as the muscle spindles acting on the ankle joint musculature (Hosoda et al., 1997). Research has found that footwear also increases postural response latencies, which suggests a slower balance response compared to a barefoot condition (H. Chander et al., 2015). However, the barefoot condition causes a greater required muscle activity to maintain balance than when wearing footwear (H. Chander et al., 2015). Even with a faster response, walking barefoot or in socks increases the risk of falling, making footwear an important balance factor (Menant et al, 2008).

The height of heels can significantly affect balance. A higher heel has been shown to reduce walking velocity, which could be a result of the height being a perceived threat to stability (Menant et al., 2009). However, one study indicated that walking velocity wasn't affected when the height of the heel ranged from 1 cm to 2 cm (Menant et al., 2009). The height also alters the COM. With a higher heel, the COM is shifted to the anterior portion of the body, making it harder to control (Menant et al., 2008). Further, with an elevated heel, the shoe is tipped at an angle. Research suggests the angle allows more time to control the medio-lateral stability required in correct balance (Menant et al., 2008). The higher heels have been observed to slow down reactions to perturbations (Hosoda et al., 1997). This contributes to a lack of balance control, and an increased risk of injury from falling.

In relation to sole thickness, research suggests that although soft soles can decrease pain by a cushioning effect, it can have a negative effect on balance by inhibiting pressure change detections (H. Chander et al., 2013). Information from the sole region of the foot is the area where pressure increases are first sensed (Hosoda et al., 1997). The medio-lateral range of COM displacement was reduced in a soft sole shoe compared to a hard midsole shoe. According to past literature, during ambulation, people show a greater lateral BOS-COM margin in soft-sole shoes, indicating a detrimental effect on balance (Menant et al., 2009). The firm and hard midsoles are also assumed to contribute to improved balance maintenance by increasing feedback from proprioceptive and cutaneous receptors (H. Chander et al., 2013). Compared to shoes with a softer sole, a work boot has a greater sole surface area, which could increase the BOS and balance ability (H. Chander et al., 2015). Past literature also suggests that the midsole can affect dynamic balance by stating an increase in sole softness creates a more conservative gait pattern (Menant et al, 2008).

Shoe mass can also create a problem for balance ability. It has been found that even as little as a 100 g increase in footwear mass can elevate energy expenditure during walking by 0.7%-1.0% (Jones et al., 1984). In one study, between a tactical boot and a work boot, the tactical boot showed a smaller amount of lower extremity muscle activity. When comparing the two boots, each had a similar boot shaft height, but the work boot had a higher mass due to the steel toe, indicating that mass could be beneficial in maintaining balance (H. Chander et al., 2015). The heavier footwear has been suggested to thereby cause a faster rate of fatigue than a light shoe (H. Chander et al., 2013). Chander, Wade, and Garner (2015) also indicates that footwear with a lighter mass and a medium to hard sole are more efficient for maintaining balance for the human body rather than heavy footwear with a soft sole. Although in the same study, the boots with a heavier mass seemed to provide better balance than the low top shoe with a lighter mass. This could contribute to the fact that the boots had an elevated boot shaft and a larger base of support (H. Chander et al., 2015).

The majority of literature supports the general motion that a boot shaft elevated above the ankle joint increases the support around the ankle and offers greater balance (Chander, Garner, Wade 2013). Shoes with high collars acts to provide extra sensory input by placing compression at the ankle. This has the ability to facilitate joint position sense and improve balance (Menant et al., 2009). It was found that boot shaft heights as high as 16.5-18.5 cm provided that compression and support around the ankle compared to a shoe with a low shaft height of 9.5 cm (Chander, Garner, Wade 2013). The higher shaft height has been found to outweigh other shoe characteristics due to the fact that it carries 60% of the load distribution in a normal stance (Chander, Garner, Wade 2013). Although the work boot and the tactical boot in the experiment had a higher heel height than the low top shoe, they were better suited for maintaining stability due to the higher shaft height.

While characteristics of footwear can cause impairments to balance, the duration that the body needs to maintain correct posture and balance needs to be considered. A prolonged duration of workload could attribute to decreased somatosensory input itself and an inability to recognize inaccurate sensory cues (H. Chander et al., 2013). For one study, it wasn't until the 3rd and 4th hours that subjective ratings of discomfort and fatigue were apparent (Cham, Redfern 2001). In addition, hour 4 was the time that weight shifts, leg skin temperature, and leg volume were the highest compared to the other times (Cham, Redfern 2001). There have been conflicting results concerning subjective and objective measures, which could result from the duration only lasting about 2 hours or less (Cham, Redfern 2001). Therefore, the significant findings concerning balance control in hour 4 of testing indicates that a minimum exposure time of 4 hours is necessary.

Fatigue is associated with decreased balance control. When a muscle is fatigued, it is not able to produce as much force, and sensations of muscle force are decreased (Taylor, 2009). Muscle activity is increased as postural sway increases; especially when one of the three subsystems of balance is defective (Nardone et al., 1997). In relation, strength has been shown as a requirement for the stepping strategy to recover from perturbed balance (Sturnieks, St George, Lord 2008). As mentioned, an extended duration is correlated with subjective fatigue, but it also can be quantified. The increases in fatigue were accompanied by increases in COP weight shift and leg skin temperature (Cham, Redfern 2001).

To be successful in golf, one needs to execute correct balance throughout the weight-shift of the downswing, as well as maintaining it for the duration of the game (Chu et al., 2010). Footwear is crucial in that it should simplify the lower extremity's role in implementing a solid base of support to increase forces, while contributing comfort and relief from strain to muscles (Williams, Cavanagh 1982). As previously mentioned, there have been past studies that look into the relationship between occupational footwear and balance, but lack evidence on footwear meant for the game of golf. In the past, there have also been studies that indicate changes of shoe design for golf-specific footwear could be beneficial in the golf swing. Because of the pressure distribution throughout the swing in both feet, Williams and Cavanagh (1982) suggest design alterations that include a flared outsole of the lateral side of the foot nearest the flag and the medial side of the other foot, a continuous sole and heel wedge, a valgus wedge for firmer support, and specific cleat placement based of center of pressure patterns. However, there is a gap in literature that refers to the best type of golf-specific footwear and maintaining balance in general. The purpose of this study is to examine how contrasting types of golf-specific footwear, including a traditional dress shoe style, a tennis shoe style, and a minimalist shoe style can affect balance ability.

CHAPTER III

METHODOLOGY

Purpose

The purpose of this study was to examine the effects of three different types of golf-specific footwear after standing and walking for an extended duration on static balance. Balance and postural stability were the focus of the study in order to investigate if there is a difference in any of the footwear conditions.

Participants

A total of 14 males were recruited for the purpose of this study. Of the 14, 12 recreationally trained males, ranging from the age of 18 to 35 years, completed the study (age: 23.4±2.2 years; height: 181.5±9.0cm; mass 95.8±18.6 kg). Upon the first visit, participants were required to fill out the Physical Activity Readiness Questionnaire (PAR-Q) in order to determine if they were healthy enough to partake in the study. The questionnaire also checked for any type of history of disorders or injuries. If so, the participants were not able to complete the study. All participants read and gave consent prior to the study through the approved university Institutional Review Board (IRB).

Instrumentation

The NeuroCom Equitest Platform was used to measure the participants' postural stability and balance control under static conditions. The system uses an 18" x 18" force plate along with a visual surrounding that is moveable in anterior and posterior directions and able to alter vision conditions. The NeuroCom used a Sensory Organizational Test (SOT) to determine the participants' limits of stability (LOS). From this range we are able to determine a clinically relevant score, known as the equilibrium score, to determine the body's ability to maintain the center of mass within the base of support, or the feet. A feature called "sway reference" allows for the visual surround force plate to move in response to the participants' anteroposterior sway. This enables an elimination of proprioceptive and visual input. After standing and walking for an extended duration on an artificial turf surface four conditions were tested while standing on the NeuroCom: (1) eyes open (EO) and (2) eyes closed (EC) while the force plate is fixed, (3) standing with eyes open and the visual surround sway referenced (EOSRV), and (4) standing with eyes open and the platform sway referenced (EOSRP). Equilibrium scores were calculated to provide a measure of human balance by averaging the limits of stability for each trial of the four conditions.

Experimental Conditions

The subjects were asked to take part in three experimental conditions. The conditions were counterbalanced prior to the experimental days and included were a traditional dress shoe style, a tennis shoe style, and a minimalist shoe style. The fourth, barefoot (BF), was used as a control variable. Each shoe condition consisted of different mass, but similar soles, shaft heights, and heel heights.

Experimental Procedure

A Repeated Measures Design using within-subjects factor was used for the purpose of the study. Each participant visited the Applied Biomechanics Laboratory at the University of Mississippi to test each condition for a total of four visits. Each visit was separated by at least 72 hours between them. The visits occurred as follows.

Day 1: During the first visit, each participant gave university approved informed consent and was then informed about the testing procedures and the experiment. After, measures on body weight and height were taken along with the physical activity readiness questionnaire (PAR-Q). Each condition was counterbalanced for all participants and they did not know which footwear they would wear. Participants were tested on baseline characteristics before testing began. Following, participants were able to run through the experimental process in order to be familiarized with the study.

Day 2: Participants returned to the Applied Biomechanics Lab to start the experimental testing. They were instructed to walk normally and at a self-selected pace on an artificial turf surface while wearing the footwear being tested. They were allowed to stand still, but asked not to leave the artificial turf or sit down for the duration. The participant was then instructed to stand as still as possible on the NeuroCom for the Sensory Organizational Testing (SOT). Three trials for each condition were performed. This was repeated every hour for the entire 4 hours of the experimental period (i.e. pre, 60, 120, 180, 240).

Days 2, 3, and 4: The days following the second visit were similar in protocol only differing in the type of footwear worn on the day. After the fourth and final day, the participant was asked to fill out a questionnaire ranking each of the types of footwear in the study based on subjective comfort ratings.

Statistical Analysis: The results were analyzed in SPSS statistical software using a 4x5 repeated measures ANOVA, with a predetermined alpha level of 0.05. There are 4 footwear types (barefoot, tennis shoe, minimalist shoe, and dress shoe) to cross with 5 measurement times (pre, 60, 120, 180, 240) for each of the four conditions on the force plate. If a main effect significance was found for footwear, a post hoc pairwise comparison using a Bonferroni correction was used, while simple effects were calculated if significant interactions were found.

CHAPTER IV

RESULTS

A Repeated Measures ANOVA (4X5) was performed to determine the statistical significance of equilibrium scores from the different golf-specific footwear throughout an extended duration. Predetermined alpha level scores were set at $p=0.05$, while post-hoc comparisons were used to determine differences among the footwear using a Bonferroni correction. In the eyes closed (EC) condition, a significant interaction was detected ($F(12,132) = 2.697$, $p = 0.003$). At the three-hour mark, the dress shoe condition demonstrated a significant reduction in balance control when compared to the barefoot condition. The equilibrium scores showed no differences found between the dress shoe, tennis shoe, and minimalist shoe.

CHAPTER V

DISCUSSION

The purpose of this study was to determine balance capabilities among golf-specific footwear over an extended duration. The footwear included a traditional dress shoe (DS), a tennis shoe (TS), and a minimalist shoe (MIN), with a barefoot (BF) condition used as the control. A NeuroCom Equitest Platform performed a SOT to determine equilibrium scores from its four conditions (EO, EC, EOSRV, EOSRP). The equilibrium scores were used to quantify any significant main effects or interactions. Only a significant interaction in the EC condition was found at the three-hour mark between the DS and the BF conditions. There was no significance identified between the three footwear conditions. These results will further be discussed within the contents below.

Footwear

Footwear has the ability and potential to affect balance as it is the interface between the foot and the support surface (Menant et al. 2008). It is also needed to efficiently transform the mechanical power produced from the musculoskeletal system (Cikajlo, Matjačić 2007). In recent studies, optimal footwear characteristics for balance include a higher shaft height, decreased mass, a slightly elevated heel, and a firm midsole (H. Chander et al., 2013; Menant et al. 2008; Menant et al. 2007; Hosoda et al. 1997). However, among the golf-specific footwear used in this study, mass was the only defining characteristic, where the DS was the heaviest shoe. Past literature discusses that mass has an impact on balance, with a heavier shoe mass causing a reduction in balance control (H. Chander et al., 2013). A shoe with a heavier mass will cause more workload and, therefore, more fatigue for the body to withstand (H. Chander et al., 2013). It has also been shown that energy expenditure increases by 0.7-1.0% for each 100g increase in the weight of the footwear (Jones et al. 1984). Although the DS was the heaviest footwear condition, there were no significant differences between the golf-specific footwear. This could mean the mass difference might not have been prominent enough to produce a significant result. The lacking variability between the DS, MIN, and TS conditions could contribute to the nonexistent significant main effects for footwear. However, it seems that the difference in the DS and the BF conditions were sizable enough to cause a significance in the effect of balance at the third hour mark. There has been evidence that a barefoot condition can cause a higher risk of balance decrements than footwear, despite mass (Koepsell et al., 2004). However, they attributed this to the fact that a population that is more prone to falls, such as sedentary adults, is more commonly going shoeless. They also explain that good balance performance in laboratories are associated with the barefoot condition, but the foot is more vulnerable to trauma caused from extrinsic factors like unexpected obstacles outside (Koepsell et al., 2004).

Time

It has been shown that footwear inhibits mechanoreceptors on the soles of the feet from receiving information (Hosoda et al., 1997). One study, based on their findings that a shock absorbent material may cause a drop of the amount of afferent information passing through the soles of the feet, advise that barefoot is the best for balance (Hosoda et al., 1997). The results from Hosoda et al. (1997) are consistent with the results from this study, as there was a significant difference that showed the BF condition retained a better balance in the 3rd hour than the DS condition. Throughout the study, the soles of the feet, and its mechanoreceptors, were continuously exposed to the environment in the BF condition. Specifically, in the EC condition, the body is focusing on the proprioceptive and vestibular systems to maintain a correct balance and posture. However, all participants were healthy, indicating that there is no impairment regarding their vestibular systems. This places an emphasis that the issue is stemming from the proprioceptive system. The fact that the DS condition provided an interface between the soles of the feet and the ground could attribute to the detriment in balance at the 3rd hour. The lack of significance at the second and fourth hours is a question in this study, and also a limitation. The participants may have known that the fourth hour was their last testing period, and shifted more than usual. In addition, it could be the fact that balance performance in general, regardless of footwear or barefoot, decreases around the four-hour period from being tired. In regards to the second hour, there could have been significance. However, equilibrium scores do not take medial and lateral sway into account, as they use limits of stability in the anterior and posterior directions only.

If mass is the main significance in the study, future research may be needed to determine an optimal mass for golf-related footwear over an extended duration. Further, a study that included golf-specific footwear with differing shaft heights and midsole thicknesses could be beneficial, as this study was not able to compare these characteristics.

Conclusion

In conclusion, the results of this study indicated there was only a significant interaction in the EC condition between the dress shoe style and the barefoot (BF) condition at the three-hour mark. This is consistent with past literature, as it has been shown that an extended duration can impair balance control, but only due to the lack of continuous proprioceptive information from the environment (Hosoda et al., 1997). In addition, there was no significance among any of the golf-specific footwear when looking at balance detriments. This could express the fact that golf players may have the ability to choose their own footwear based on personal preferences. Past literature has focused on differing shaft heights, midsole thicknesses, and masses, but the footwear used in this study had minimal distinctions from one another for a static balance setting. Based on the results of this study, future research should focus further on more distinguishing characteristics among the golf-specific footwear.

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