THE EFFECT OF GOLF SHOE CHARACTERISTICS ON STATIC BALANCE OVER AN EXTENDED DURATION

by
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ABSTRACT

Golf performance is greatly impacted by balance ability, specifically during a golfer's swinging and putting motion. Previous studies have found that certain shoe characteristics can affect balance; however, no such study has been conducted for golf shoes. This study's objective was to compare balance scores between three different golf shoe styles and determine which style or characteristics serve golfers best in improving balance under quiet standing conditions over time. Twelve adults (age: 23.4 ± 2.2 years; height: 181.5 ± 9.0 cm; mass: 95.8 ± 18.6 kg) participated in this study. Each participant made four visits, one for each footwear condition: barefoot, tennis shoe style, dress shoe style, or minimalist shoe style. The participants walked continuously on artificial turf for four hours and completed the Sensory Organizational Test (SOT) on the NeuroCom Equitest System at every hour mark to assess static balance. The SOT utilizes four testing conditions: eyes open (EO), eyes closed (EC), eyes open sway referenced vision (EOSRV), and eyes open sway referenced platform (EOSRP). From the SOT scores, anterior-posterior (AP) and medial-lateral (ML) sway root mean square (RMS) and AP/ML sway velocity (VEL) were calculated. The results were analyzed using a 4x5 repeated measures analysis of variance (ANOVA), crossing the four footwear conditions with the five SOT times (0, 60, 120, 180, and 240 minutes). If footwear or time main effects were found, a post hoc pairwise comparison using a Bonferroni correction was completed. It was discovered that static balance began to decrease after two hours, and the barefoot condition scored better than the three golf shoes. At the three-hour mark, the three shoe conditions scored superior to the barefoot condition, but no significant differences in balance performance were found between the three golf shoe styles. This

indicates that of the three golf shoes, none would be advantageous or detrimental compared to one another for balance performance.

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CHAPTER I

INTRODUCTION

The historical sport of golf has become an increasingly popular game across the world. According to the International Golf Federation (IGF), early variants of the game were played in the Roman Empire as early as 100 B.C. where players used sticks to hit leather balls ("History of Golf" n.d.). The modern version of the sport is believed to have originated in Scotland during the 15th century ("History of Golf" n.d.). The game quickly gained popularity within European countries, and it soon spread to North America. The governor of Massachusetts purchased golf clubs in 1729, which is the earliest-known evidence of golf in the United States ("History of Golf" n.d.). The U.S. experienced extreme growth in the construction of golf facilities from the 1960s to the 1980s and again from the 1990s to the early 2000s (*Golf Around the World* 2015). Today, 34,011 golf facilities have been accounted for around the world in 206 countries, indicating the widespread popularity of the sport. At its peak, the United States had over 16,052 courses, leveling out to 15,372 in 2015. Impressively, this accounts for 45% of the total number of facilities across the globe (*Golf Around the World* 2015). In 2014, 25 million people in the United States reported they had played at least one round of golf, with 55% referring to themselves as "avid" golfers, which is defined as playing a minimum of eight times per year ("The Goods on Golf" n.d.).

For the year 2011, Stanford Research Institute (SRI) International determined the U.S. golf economy to be $68.8 billion. The economic impact of the golf industry was estimated to be $176.8 billion across the nation. One in 75 U.S. jobs, which approximates to 1.98 million, are impacted in some fashion by the golf industry, with a total wage income of $55.6 billion (*The 2011 Golf Economy Report* 2012). These numbers are shown to be significant in comparison to other industries. The golf economy reached an estimated 74% of the television cable and programming industry's total worth and 83% of the film industry. It exceeds the industries of other spectator sports, such as football, basketball, and baseball (*The 2011 Golf Economy Report* 2012). Attesting to the popularity and prominence of the sport, the 2011 Golf Economy Report stated that Americans spent $5.6 billion on golf-related supplies, $1.6 billion of which were spent on golf apparel (*The 2011 Golf Economy Report* 2012).

The game of golf is defined as hitting a golf ball with a club from the teeing ground through a series of strokes with the end goal of placing the ball into the hole on the putting green ("Rules and Decisions" n.d.). Typically, within a single game, there are 18 holes to be played, and a maximum of 14 clubs can be used ("Rules and Decisions" n.d.). On average, a round of golf lasts approximately four hours on a week day and four and a half hours on a weekend day (*Tracking Research* n.d.). A golfer's swing can be broken down into four main stages: take away, backswing, downswing, and follow through phases (Healy 2009).

Static balance during the swinging and putting motions is an integral part of golf and greatly impacts performance. When driving the ball over a long distance, the golfer executes weight shifts during each phase in order to help increase power production. Weight shift refers to the adjustment of bodyweight from one foot to the other (Healy 2009). The take away phase includes the golfer positioning his or herself in relation to the target and correcting their grip on the club before beginning to swing. During this phase, the player sets their stance with 50-60% of their weight resting on the back foot. The next phase is the backswing where the golfer pulls the golf club backwards from rest to set up an optimal downswing phase (Hume, Keogh, & Reid 2005). For maximum power production, the weight should shift towards the back foot as the player rotates following the club's motion (Wells, Elmi, & Thomas 2009). The downswing occurs from when the golfer reaches the top of the backswing through ball contact with the goal of increasing velocity. In this phase, the weight is quickly shifted from the back to the front foot (Hume, Keogh, and Reid 2005). A larger, quicker shift was associated to greater club head speed before contact with the ball (Heldoorn & Vlasblom 2010). After contact with the ball, the follow through phase occurs to slow the body and club through eccentric muscle actions, ending with the hands behind the left ear and the trunk and head rotated towards the target (Hume, Keogh, & Reid 2005). An almost complete weight shift towards the front foot has occurred at the end of the follow through stage (Williams & Cavanagh 1983). Putting the ball over a short distance contains the same phases, but it is performed to create accuracy instead of power. The overall motion is a slower, smaller one with little weight shift between the feet. (Hume, Keogh, & Reid 2005).

Static balance is defined as the ability to keep the center of gravity (COG) within the base of support (BOS). The COG is the downward, vertical projection of the center of mass (COM). When standing, the feet exert reactive forces onto the ground to maintain balance; the pressure the feet exert due to these reactive forces is averaged into a point termed the center of pressure (COP). The COP can be adjusted by transferring weight between the feet. The ability to move the COP in relation to the COG and remain within the BOS indicates the subject's balance ability (Winter 1995). The body employs three systems to analyze balance based off environmental cues: the visual system, vestibular system, and proprioceptive system (Winter 1990).

In previous studies, golfers have been found to possess greater static balance when compared to the general population in a single-legged stance. The golfers were found to have less postural sway, resulting in better balance test performances (Tsang & Hui-Chan 2010). Within the golfer population, it was found that increasing static balance performances were positively correlated with increasing ability level between elite and less skilled golfers (Hrysomallis 2011). Experienced golfers have executed many golf swings over time, and the repeated practice of static balance within the swing could cause an increase in static balance performance (Tsang & Hui-Chan 2010). Within a game of golf, it may be required of the golfer to play the ball on an unstable surface, such as in a bunker, on the fairway, or in the rough before reaching the green. In situations like these, a greater static balance performance could improve the golfer's ability (Wells, Elmi, & Thomas 2009).

Maintaining static balance when shifting bodyweight from one foot to another during the swing phases can be affected by footwear (Williams & Cavanagh 1983). Past literature indicates that specific shoe characteristics could hinder balance abilities. Previous studies conducted by Chander, Wade, and Garner demonstrated how shoe characteristics affect balance within the work environment. Shoes with a lower ankle shaft height were found to decrease static balance performance, while shoes with a higher ankle shaft height increased it by providing more support (Chander, Wade, & Garner 2014). However, it was found that the higher shaft decreased reaction time by limiting the ankle's range of motion (Chander, Wade, & Garner 2015). An elevated heel height was found to shift the subject's weight anteriorly (Chander, Wade, & Garner 2014). Negative effects on balance were detected when the height exceeded 4.5 centimeters (Chander, Wade, & Garner 2015). Harder, thinner soles were shown to be superior to softer, thicker soles in balance performance measures. A possible explanation is that the softer, thicker soles could possibly block cutaneous receptors from detecting changes in pressure (Chander, Wade, & Garner 2015). An increase in shoe weight was shown to increase stability, but it also increases muscle activation, which could lead to quicker fatigue of the lower extremity muscles and eventually affecting balance outcomes (Chander, Wade, & Garner 2015).

To enhance performance, a golf shoe's design should consider increasing stability and balance, allowing movement when shifting weight, and maximizing force production through the feet while maintaining comfort (Williams & Cavanagh 1983). In this study, balance performances were observed in three golf shoe styles: a tennis shoe style, a traditional dress shoe style, and a minimalist shoe style. The aim of this study is to determine which golf shoe styles serve golfers best in static balance performances under quiet standing conditions over time.

Purpose:

The purpose of this study was to determine the effects of three different golf shoe styles (a dress shoe style, a tennis shoe style, and a minimalist style) on static balance after walking on artificial turf over a four-hour span.

Hypotheses:

Footwear:

H_{01}: There will not be a difference in static balance performance between the different footwear conditions.

H_{A1}: There will be a difference in static balance performance between the different footwear conditions.

Previous literature has shown that various shoe characteristics can impact balance performance, such as heel height, mass, ankle shaft height, and midsole thickness (Chander, Wade, & Garner 2014; Chander, Wade, & Garner 2015; Hosoda et al. 1997). From this, it can be hypothesized that characteristics of the styles chosen for this study will cause differences in the balance results.

Time:

H_{02}: Time will not affect static balance performances.

H_{A2}: Time will affect static balance performances.

Past studies have found that balance generally decreases after standing or walking for two hours or more (Cham & Redfern 2001; Chander, Wade, & Garner 2014). Remaining upright for a long duration could cause a decrease in sensitivity, or fatigue, within the lower leg musculature and the sensory receptors (Corbeil et al. 2003). Thus, it can be theorized that spending an extended period of time in an upright posture will generate the same decline in balance over time as seen in previous studies.

Definitions:

Balance: ability to actively maintain body posture to keep from falling; capacity to keep the center of gravity within the base of support (Winter 1995)

Base of Support: total area under the feet or supporting appendages (Winter 1995)

Center of Gravity: downward, vertical projection of the center of mass onto the ground (Winter 1995)

Center of Mass: intersection of the three mid-cardinal body planes (Rodgers & Cavanagh 1984); the average point in space of each body segment's center of mass (Winter 1995)

Center of Pressure: averaged point of the surface area that is in contact with the ground; the point where the vertical ground reaction force vector is exerted (Winter 1995)

Central Nervous System: receives sensory input from the peripheral nervous system, integrates it, and commands effector systems (Winter 1990)

Dynamic Balance: balance maintained during active movement (Hosoda et al. 1997)

Equilibrium: when the net forces acting on the system are equal to zero (Rodgers & Cavanagh 1984)

Fatigue: decreased sensitivity of receptors to neural signals (Corbeil et al. 2003)

Golgi Tendon Organ: somatosensory receptors in the musculotendonous junction that sense tension (Massion 1994)

Ground Reaction Forces: forces the ground acts on the body in response to the equal and opposite forces the body exerts on the ground (Rodgers & Cavanagh 1984)

Inverted Pendulum Model: biomechanical model to describe how balance is maintained in humans; the feet act as an anchor allowing the body to sway (Winter 1995; Corbeil et al. 2003)

Latency: time that elapses between the stimulus and the response (Hosoda et al. 1997)

Muscle Spindle: somatosensory receptors within the intrafusal fibers of the muscle belly that detect stretch and rate of stretch (Crowe & Matthews 1964)

Musculoskeletal System: executes movements planned by the central nervous system through skeletal muscles to adjust balance (Winter 1990)

Peripheral Nervous System: division of the nervous system that receives sensory information, relays the information to the central nervous system, and sends commands from the central nervous system to effector systems (Winter 1990)

Posture: body's position relative to the gravitational vector (Winter 1995); creates a reference for how body segments create a motor response (Massion 1994)

Postural Control: maintaining body posture; synonymous to "balance" (Winter 1995)

Postural Sway: shifts in center of pressure (Winter 1995)

Proprioception: the ability to detect the current state and location of where the body is located in space (Winter 1990)

Quiet standing: standing without any external perturbations (Winter 1995)

Reaction Time: the time difference between a stimulus and a response; synonymous with "latency" (Hosoda et al. 1997)

Root-Mean-Square (RMS) Sway: amount of area postural sway occurs over (Chander, Wade, & Garner 2014)

Somatosensory System: detects the position and velocity of body segments as well as sense contact from surroundings (Winter 1995); consists of muscle, joint, and cutaneous receptors (Winter 1990)

Static Balance: maintaining balance while no active movement is occurring (Winter 1995)

Sway Velocity: speed of postural sway (Chander, Wade, & Garner 2014)

Vestibular System: within the inner ear; detects linear and angular accelerations of the head (Purves, Augustine, Fitzpatrick et al. 2001)

Visual System: relays where the body is located in space, how it is moving, and environment conditions through the visual information received through the eyes (Winter 1995)

CHAPTER II

REVIEW OF LITERATURE

Balance

Balance is a term generally used to denote how posture is maintained and how falling is prevented (Winter 1995). Posture holds two primary functions. First, it creates an upright stance in humans that acts against gravity, and second, it provides a reference for the body to plan responses and execute actions towards an external object (Massion 1994). Balance refers to the active maintenance of posture in both static and dynamic conditions (Winter 1995).

Biomechanically, balance is defined as the ability to keep the center of gravity (COG) within the defined area of the base of support (BOS). The BOS is the total area on which the system comes into contact with the ground (Winter 1995). For a human standing in the upright position on both feet, this includes the area under the feet as well as the area between them. If the individual is balancing on one foot, the BOS comprises only the area under the single foot that is planted on the ground, reducing the amount to one third. The average of each body segment's mass in space is termed the center of mass (COM) (Rodgers & Cavanagh 1984). In an average person, this is located at approximately two-thirds of the individual's height from the ground (Winter 1995). The center of gravity (COG) is the downward, vertical projection of the COM. Reactive forces are exerted through the feet in order to maintain the COG within the BOS. The pressures the feet translate into the ground are averaged into a point to create the center of pressure (COP). It is through shifting the COP either antero-posteriorly (A/P) or medio-laterally (M/L) in response to the movement of the COG that balance is achieved. The shifts in COP are termed postural sway (Winter 1995). Two indicators of sway as it relates to balance are root-mean-square (RMS) sway and sway velocity. RMS sway is defined as the amount of area postural sway occurs over, and sway velocity is the speed of sway. As these values increase, balance and stability decreases (Chander, Wade, & Garner 2014).

There are two forms of balance: static and dynamic balance. Dynamic balance is used whenever the body is actively moving, such as in gait (Hosoda 1997). Contrastingly, static balance occurs during a normal standing posture. Quiet standing is often used when evaluating static balance. In quiet standing, the body is not influenced by any external perturbations (Winter 1995). Static balance performance is measured by analyzing the subject's center of pressure in relation to the center of gravity when it resides within the base of support (Chander, Wade, & Garner 2015). The inverted pendulum model was created to describe this. The feet act as the stabilizing point, while the rest of the body can sway in the A/P and M/L directions in response to muscular forces attempting to find equilibrium (Corbeil et al. 2003).

In humans, balance proves to be a difficult feat, due to being bipeds. Unlike other quadruped animals, humans use only two feet to support the body's mass, creating a narrow base on which to exert control over balance. This creates unique balance issues due to the small area of support created by the feet compared to height (Massion 1994). On average, two-thirds of an individual's body mass resides a distance of two-thirds of their height above the ground. This relationship causes humans to possess poor balance in the absence of controls acting on it (Winter 1995).

The body uses the somatosensory, visual, and vestibular sensory systems to detect balance discrepancies (Corbeil et al. 2003). All three of these systems contain sensory organs that relay information concerning the state of balance of the individual to the central nervous system for evaluation (Hosoda 1997). Vision is the main sensory system applied for developing movement plans in relation to our surroundings (Winter 1995). Combined with proprioception and the vestibular system, vision aids with determining where a body is located in space. (Winter 1990). When the visual system is used, it has been shown to shorten the reaction time needed for responses to correct balance (Massion 1994).

The vestibular system senses linear and angular accelerations of the head, allowing an individual to orient his or her position in space (Winter 1990). This is accomplished through the otolith organs, the utricle and sacculus, of the inner ear. The utricle detects linear accelerations of the head in the horizontal plane, while the sacculus detects those in the vertical plane. Each of these organs' membranes is covered in hair cells, whose tips are inserted into the otolithic membrane. The otolithic membrane is weighted with small crystalline spheres termed otoconia. When the head tilts in a direction, the weighted otolithic membrane shifts accordingly, bending the hair cells and alerting the otolith organs of the head's position (Purves, Augustine, Fitzpatrick et al. 2001).

The somatosensory system consists of cutaneous receptors that inform the central nervous system about the surrounding environment, such as pressure, temperature, and texture (Winter 1990). Golgi tendon organs and muscle spindles are two important somatosensory receptors for balance maintenance because of their proprioceptive abilities. Proprioception is defined as the sense of where a body segment exists in space with respect to gravity (Winter 1995). The Golgi tendon organs are located at the musculotendonous junctions, the area between the skeletal muscle and the tendon. When the skeletal muscle contracts, the Golgi tendon organ is deformed, allowing it to sense the amount of tension being placed on the muscle and tendon (Massion 1994). The muscle spindle senses stretch and the rate of stretch within a muscle. The muscle spindles are located within the muscle bellies in the intrafusal muscle fibers; thus, as the muscle itself stretches, the muscle spindles also stretch (Crowe & Matthews 1964). The combined proprioceptive information given by the Golgi tendon organs and the muscle spindles inform the central nervous system of the skeletomuscular system's current state (Kistemaker et al. 2013).

The redundancy of the three sensory systems provides verification of each system's input and allows one or more system to overcompensate for another's failings (Winter 1990). The central nervous system integrates the sensory stimuli received from the three systems and sends commands via efferent nervous pathways to the skeletomuscular system. The muscles then correct the body's stance and regain balance (Winter 1995). The central nervous system corrects balance by stimulating muscles in predetermined sets termed synergies. Different muscle synergies are used for varying degrees of imbalance and amount of correction needed (Massion 1994).

In response to perturbations exerted onto the individual, the body utilizes the ankle, the hip and knee, or the step strategy to regain balance by resetting the COG

(Massion 1994). Small disturbances during quiet standing cause the COG to move to the periphery of the BOS and will elicit the ankle strategy. For example, if the COG moves towards the toes, the plantarflexor muscles will flex in response, causing a forward sway and the COP to move anterior to the COG. In response, the dorsiflexors will flex to shift the COP and COG posteriorly. The plantarflexors and dorsiflexors will alternate flexion until balance of the inverted pendulum is reestablished (Winter 1990). Sway in the A/P direction is the most common for the ankle strategy (Winter 1995). As the perturbation intensity increases, the ankle strategy can no longer correct balance, and the hip and knee strategy is employed for moderate perturbations by the flexion or extension of the hip musculature (Winter 1995). By flexing the hip, the COM moves closer to the ground, increasing balance. If the hip and knee strategy is not sufficient for the perturbation's magnitude, then the stepping strategy commences. The individual will take a step in order to reset the COM within the BOS (Winter 1995). These three strategies are not distinct from one another, but rather, they operate on a continuum with increasing disturbance stimulus (Massion 1994). When these strategies are employed, musculature is activated in a distal to proximal relationship (Winter 1990).

External Factors

As demonstrated by the inverted pendulum model, feet are the point of contact with the ground in humans, and thus, play a large role in human balance. For this reason, shoe characteristics and floor surfaces can become important in its maintenance. A decrease in the control of balance can be attributed to fatigue. Muscle fatigue was defined by Corbeil et al. (2003) as a phenomenon in which the force production of muscles is reduced. Fatigue is believed to affect the nervous system through a decrease in sensitivity of the motor neurons and proprioceptive sensory receptors in the PNS (Corbeil et al. 2003). Fatigue can also be measured simply as a level of tiredness and can be quantified by the frequency of shifts in COP from one leg to another in standing (Cham, Redfern 2001). Higher numbers of COP shifts are associated with a decrease in balance performance (Chander, Wade, & Garner 2015). Fatigue causes a need for an increase in regulatory actions to control posture and balance (Corbeil et al. 2003).

Flooring type can influence fatigue according to their hardness. It was found in Cham and Redfern's (2001) study that an increase in energy-absorbing capability or softness of floor material resulted in an increase in fatigue and discomfort. This was determined by the frequency of COP shifts. The hardest floor material also received high subjective discomfort rankings by the study participants. It was determined that flooring with greater elasticity and stiffness with lower energy absorption properties were the most comfortable and gave the best balance performances. Fatigue and balance measures from the different flooring types were shown to become significantly different after the third hour, highlighting the importance of time duration on fatigue (Cham & Redfern 2001).

Shoe characteristics such as weight, ankle shaft height, heel height, and sole hardness can influence balance by affecting fatigue. An increase in shoe weight was found to increase stability. However, higher shoe weights have also been found to correlate with higher rates of fatigue. A possible explanation could be that the additional weight causes greater amounts of muscle activation and thus energy expended to maintain balance (Chander, Wade, & Garner 2014). The quicker fatigue of the lower extremity musculature causes negative effects on balance outcomes in comparison to the less heavy shoes (Chander, Wade, & Garner 2015).

Taller ankle shafts that covered the ankle joint were shown to improve balance performance possibly by providing support to the ankle musculature. Having extra material surround the ankle could keep the ankle steadier, decreasing lower extremity muscle activation and sway measured during static balance tests (Chander, Wade, & Garner 2015). The compression provided by the ankle shaft could also improve balance measurements by reinforcing the cutaneous receptors (Chander, Wade, & Garner 2014). However, taller ankle shafts were also correlated with greater latency times in muscle activation when correcting balance, possibly due to the shaft limiting the ankle's range of motion. The constraints on the range of motion would also affect power production at the ankle joint (Chander, Wade, & Garner 2015).

Elevated heel heights have been shown to decrease balance. At a height of 4.5 centimeters, significant detriments in balance occur (Chander, Wade, & Garner 2015). When heel height is increased, the subject's COM is shifted anteriorly towards the toes, causing posture and COP to alter (Chander, Wade, & Garner 2014).

The soles of the foot contain many nerve endings that send crucial sensory information for balance to the central nervous system. When the sole of the foot is unexposed to the ground, the amount of sensory information it receives from the cutaneous receptors is decreased (Hosoda et al. 1997). When a shoe contains softer, shock-absorbing soles, the latency time in muscle activation to maintain balance increases when compared to barefoot conditions, indicating a decrease in balance performance (Hosoda et al. 1997). Softer soles in shoes have been found to show an increase in subjective comfort rankings, but they show a decrease in balance performance. Harder soles show increased balance measures, possibly by stimulating sensory feedback through applying pressure onto cutaneous receptors. (Chander, Wade, & Garner 2015). An increase in sole surface area was found to increase stability and balance, as it allows more sensory information to be obtained by the soles (Chander, Wade, & Garner 2014).

The shoe characteristics previously discussed have been adequately studied and reported in past research on balance in different occupational settings and within the elderly population. Implications for golf shoe design have been discussed by Williams & Cavanagh (1983). The study suggested that when designing a golf shoe, an increase in stability while allowing an adequate range of motion for weight shifts during the swing phases would be a key factor in golf performance. Comfort should also be considered due to the amount of walking and standing the game requires (Williams & Cavanagh 1983). The purpose of this study is to determine how different golf shoe styles affect standing balance over a period of four hours as measured by a Sensory Organization Test (SOT). To our knowledge, research has not been conducted that compares static balance performance in various golf shoe styles.

CHAPTER III

METHODOLOGY

Purpose:

The purpose of this study was to determine the effects of three different types of golf shoes on balance after walking on artificial turf over four hours. The study focused on how the different styles of footwear affected human balance and postural control under quiet standing conditions.

Participants:

Data were collected on twelve adults, (age: 23.4 ± 2.2 years; height: 181.5 ± 9.0 cm; mass: 95.8 ± 18.6 kg) in this study. Participants were screened using a physical activity readiness questionnaire for any history of orthopedic, musculoskeletal, cardiovascular, neurological and vestibular abnormalities, including any prescribed medications. The university's Institutional Review Board (IRB) approved the study. Preceding data collection, the participants were given a thorough explanation of the goals of this study, and each subject read and signed the informed consent paperwork to participate.

Instrumentation:

Standing balance was evaluated under various conditions on the NeuroCom Equitest System using the Sensory Organization Test (SOT). The test uses an 18x18 inch platform with rotational and translational movement capabilities and a moveable visual surround that is able to tilt anteriorly and posteriorly. These movements attempt to manipulate the sensory systems of the individual in order to evaluate standing balance. The SOT uses the following four testing conditions: eyes open (EO), eyes closed (EC), eyes open sway referenced vision (EOSRV), and eyes open sway referenced platform (EOSRP). COP data were collected from these tests and used to calculate anterior-posterior (AP) and medial-lateral (ML) sway root mean square (RMS) sway and AP/ML sway velocity (VEL) using the equations below:

$$\text{SWAY VEL} = \left(\frac{1}{t}\right)\sum_{i=0}^{n} |COP_i - COP_{i-1}| \qquad \text{Equation 1}$$

$$\text{SWAY RMS} = \sqrt{\frac{1}{n}\sum_{i=0}^{n}\left(COP_i - COP_{avg}\right)^2} \qquad \text{Equation 2}$$

Experimental Conditions:

The participants wore one of the four following footwear conditions for each session: barefoot condition, a traditional dress style shoe, a tennis shoe style, and a minimalist shoe style. The footwear conditions were counter-balanced.

Experimental Procedures:

The study followed a repeated measures design using a with-in subject comparison. Each participant completed four sessions of data collection separated by at least 72 hours; each session lasted approximately four hours. The sessions were performed in the Applied Biomechanics Laboratory in the Turner Center (Division of Exercise Science) at the University of Mississippi. Subjects were asked to not work out their lower extremities at least 48 hours prior to testing.

The participants made an initial visit in order to complete any necessary paperwork. During this visit, the testing days' procedures were described, and the participants performed a practice SOT test. No data were collected on this day; it served only as a familiarization session.

On each of the four testing days, an initial SOT test was conducted to serve as baseline measurements for data analysis. After the initial SOT, the subject was then instructed to walk at their normal pace on artificial turf for the four-hour duration. The subjects were allowed to stand still for brief periods of time, but they could not sit down nor leave the turf, except to perform the SOT tests. At every hour mark from the initial SOT time, the subjects performed an SOT test to assess standing balance over time in each shoe type. Thus, the SOTs were performed at the 0, 60, 120, 180, and 240 minutes.

Statistical Analysis:

The SPSS 22 statistical software analyzed the SOT results with a 4x5 repeated measures analysis of variance (ANOVA) using a preset alpha level of $p < 0.05$. Four footwear conditions (barefoot, dress shoe, tennis shoe, and minimalist shoe) were crossed with five times (at 0, 60, 120, 180, and 240 minutes) for each of the SOT conditions. If statistically significant main effects were found for footwear or time, a post hoc pairwise comparison using a Bonferroni correction was completed. Simple effects were determined if significant interactions were discovered between time and footwear.

CHAPTER IV

RESULTS

Multiple significant time and footwear main effects were found from the SOT results after running the repeated measures ANOVA. For footwear, significant main effects were revealed for RMS sway in the medial-lateral direction (MLRMS) in the eyes open (EO) condition ($F(3,33) = 3.184$, $p = 0.037$) between the barefoot and tennis shoe conditions, with barefoot scoring superior. RMS in the anterior-posterior direction (APRMS) in the eyes closed (EC) ($F(3,33) = 4.249$, $p = 0.012$) and eyes open sway referenced vision (EOSRV) ($F(3,33) = 4.293$, $p = 0.012$) conditions also showed significant main effects between footwear. For time, MLRMS in the EO ($F(4,44) = 3.343$, $p = 0.018$), E0SRV ($F(4,44) = 2.773$, $p = 0.039$), and eyes open sway referenced platform (EOSRP) ($F(4,44) = 4.123$, $p = 0.006$) conditions held significant main effects. Time main effects were also found for APRMS in the EC ($F(4,44) = 3.664$, $p = 0.012$) and EOSRP ($F(4,44) = 4.018$, $p = 0.007$) conditions and for anterior-posterior sway velocity (APVEL) in the EC condition ($F(4,44) = 3.287$, $p = 0.019$). Significant interactions between time and footwear were observed for both medial-lateral sway velocity (MLVEL) ($F(12,132) = 2.474$, $p = 0.006$) and APVEL ($F(12,132) = 4.719$, $p < 0.0005$) in the EOSRV condition.

CHAPTER V

DISCUSSION

The purpose of this study was to determine the effects of three different golf shoe styles on static balance after walking on artificial turf over a four-hour duration. The study focused on how the different footwear affected balance under quiet standing conditions, which was assessed by the Sensory Oganizational Test (SOT) on the NeuroCom Equitest System. The three golf shoe styles that were assessed were a tennis shoe style, a traditional dress shoe style, and a minimalist shoe style. The study was designed to simulate the length and intensity of a full round of golf, so as to gather accurate and relevant information to the golf community. The results revealed that for footwear, the barefoot condition had better balance scores than the other footwear conditions; however, no significant findings were found between the different golf shoe styles. When evaluating time, balance was shown to decrease as time progressed after the study's two-hour mark was reached.

When examining only footwear, the barefoot condition was found to have superior balance compared to the other three footwear conditions. Based upon previous literature, this was an expected result. When barefoot, there is direct exposure between the sensory receptors and the ground, allowing adequate feedback to be sent to the central nervous system about the environment. The sensory information provided by the sole's receptors are crucial for the central nervous system's ability to adjust and maintain postural control (Hosoda et al. 1997). Wearing shoes prohibits the peripheral nervous system from receiving as much input from the cutaneous receptors and nerve endings located on the sole of the foot. Thus, wearing shoes decreases the body's ability to maintain balance.

Over the four-hour duration of the study, it was found that balance generally declined over time. Specifically, balance worsened after the second hour mark of the study. Previous research has observed the same effect and has concluded that standing or walking for extended time durations longer than two hours is correlated with a decrease in balance (Cham & Redfern 2001; Chander, Wade, & Garner 2014). When evaluating the time interactions with footwear conditions, the results revealed that the barefoot condition had better balance than the tennis shoe style at the second hour mark. The advantage of the feet being in contact with the environment seemed greater than the limited support given by the shoes. However, all three golf shoe conditions had statistically better balance performances than the barefoot condition at the three-hour mark. Standing and walking for the extended amount of time could have decreased the sensitivity of the cutaneous receptors in the barefoot condition (Corbeil et al. 2003). This coupled with the lack of support and stability provided by the golf shoes in the other three conditions could account for the diminished balance.

As previously stated, no significant differences were found when comparing the balance scores between the three golf shoe styles for the SOT conditions. Past literature has pointed to shaft height, heel height, and mass as the major footwear characteristics that can alter balance. The three styles used in this study were not designed with a heel height greater than 4.5 centimeters, the height that balance decrements begin to appear

(Chander, Wade, & Garner 2015). When shoes possess a shaft that covers the ankle joint, balance performances have been shown to improve due to the support around the ankle musculature (Chander, Wade, & Garner 2015). However, none of the three shoes possessed ankle shafts tall enough to cover the malleolus. The only balance-influencing characteristic that is supported by previous literature that the three styles possessed was an increased mass. A greater shoe mass has been found to correlate with lower balance performances and higher rates of fatigue in the leg musculature (Chander, Wade, & Garner 2015). This could be due to the greater amounts of muscle activation, and thus energy expenditure, needed to maintain balance from the addition of extra weight (Chander, Wade, & Garner 2014). However, an increased mass could also act as a stabilizing factor for a subject when attempting to maintain balance (Chander, Wade, & Garner 2014). This could be part of the reasoning for the golf shoe conditions having better balance performances than the barefoot condition after an extended period of time. All three shoes had similar masses, with the dress shoe style weighing 1.0 kilogram and both the tennis shoe and casual shoe style weighing 0.8 kilograms. Having heel heights, ankle shaft heights, and masses that were not appreciably different could be the reasoning why there were no statistically significant differences in the balance performances between the shoes.

Conclusion:

It can be concluded that none of the three shoe styles from this study would be more detrimental than the others for static balance. It was revealed that the shoes are all equal candidates with none giving a significant advantage over the other. For future research, it may be beneficial to study golf shoe styles with greater significant differences in mass or to examine the effects of various values of mid-sole thickness and hardness to learn more about their relationship with balance maintenance and control.

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