5-11-2013

The Evaluation of Relationship of Club Selection on Measures of Golf Performance

James Riley Galloway

The evaluation of relationship of club selection on measures of golf performance

By

James Riley Galloway

A Thesis
Submitted to the Faculty of
Mississippi State University
in Partial Fulfillment of the Requirements
for the Degree of Masters of Science
in Exercise Physiology
in the Department of Kinesiology

Mississippi State, Mississippi

May 2013

The evaluation of relationship of club selection on measures of golf performance

By

James Riley Galloway

Approved:

John Lamberth
Associate Professor and
Graduate Coordinator of Kinesiology
(Director of Thesis)

Adam C. Knight
Assistant Professor of Kinesiology
(Committee Member)

Andreas N. Kavazis
Assistant Professor of Kinesiology
(Committee Member)

Richard Blackbourn
Dean of the College of Education

Name: James Riley Galloway

Date of Degree: May 10, 2013

Institution: Mississippi State University

Major Field: Exercise Physiology

Major Professor: Dr. John Lamberth

Title of Study: The evaluation of relationship of club selection on measures of golf performance

Pages in Study: 56

Candidate for Degree of Masters of Science

The driver is the club which receives the greatest scrutiny by golfers and the most marketing efforts by manufacturers. One characteristic often indicated and believed to effect driver performance is the degree of loft on the clubface. The purpose of the current study was to investigate club head speed, ball speed, launch angle, descent angle, total spin, carry, and total distance in an attempt to determine performance measures of three different lofted drivers. Fifteen participants were used to test three different degree drivers (9.5, 10.5, and 13 degree) on the variables listed above. Participants performed ten tested swings for each driver and variables were recorded. Launch angle and carry distance produced no significant differences between clubs. Club head speed, ball speed, total spin, descent angle, and total distance resulted in significant differences when between clubs analysis was conducted. The low lofted driver was found to produce the greatest performance measures.

DEDICATION

I would like to dedicate this research to my parents, Jim and Carolyn Galloway, and my sister Leslie Galloway.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

NOMENCLATURE

Rpm	*Revolutions per minute*
STD	*Standard loft setting*
Club A	*Low lofted driver with club face of 9.5 degree*
Club B	*Mid lofted driver with club face of 10.5 degree*
Club C	*High lofted driver with club face of 13 degree*
Yds.	*Yards*
P	*Level of statistical significance*

<u>Symbols</u>

°	*Degree of angle*
±	*Plus or minus symbol representing standard deviation*
<	*Value is less than following number*
>	*Value is greater than following number*
“	*Inches*
*	*Statistically significant*

CHAPTER I

INTRODUCTION

History

According to historians, the Dutch appear to present the first representation of the sport called golf. It is documented that Dutch master painters had created over 450 paintings and drawings depicting subjects participating in a competitive game which resembles the modern game of golf (First Swing 2004). Although the history has not been thoroughly documented, the game of golf as we know it today in its present form is believed to come from Scotland (Barber III 2007). Golf, in the United States, came known to the public around the year of 1888 with the establishment of the first registered golf club, the Golf Club of America, in Yonkers, N.Y. (First Swing 2004). Golf, once a game of noblemen and kings, is now played by people of all ages. As with many sports, golf requires specific equipment to be able to play with any consistency and success. Golf and its' equipment is highly regulated by the United States Golf Association (USGA) to maintain compliance with the established rules and regulations.

Golfers use a unique sense of vocabulary along with their equipment which is likely not recognized by those unfamiliar with the game (Pennington 2009). Several of these terms are loft, impact, ball flight, carry, and total distance. Loft can be referred to as the angle, in degrees, between the face of the club and the shaft (Barber III 2007). As for impact, this is the fraction of time when the club face strikes the ball causing ball flight, the path a ball undergoes after impact while it is in the air (Barber III 2007). Carry and total distance should be distinguished as different qualities of a golf shot. Carry refers to the distance the ball travels through the air after being struck (Barber III 2007). The difference between carry and total distance is considered the roll, the distance the ball bounces and rolls after impacted the ground.

Progression

From a game which began with clubs made of wood and a wooden ball, it has progressed through many stages to what we see today (Barber III 2007). Different clubs have been developed to account for various heights and distances of golf shots. For golf today, wedges are used to produce higher loft, irons for moderate distance, fairway woods for long distance, and the driver from the tee box are used in majority of each players' game. In respect to the driver, manufacturers have resolved to steel, graphite, and carbon fiber for shaft composition and titanium for the head of the club. Golf balls have progressed from the wooden ball to a composition of Surlyn and Urethane with rubber or solid cores (Barber III 2007). Also, the original ball that had a smooth outer covering now has a covering with 'dimples' which lead to increased performance and aerodynamic characteristics. Dimpled golf balls proved to be more aerodynamic and led to better control and further distance from drivers (Burglund and Street 2011). Dimples have been defined as small indentations in the exterior covering of the golf ball that can vary in diameter from two to five millimeters and are approximately 0.2 millimeters deep (Barber III 2007). All these characteristics of dimples and designs contribute to the overall aerodynamics of golf (Burglund & Street 2011). Along with the variations in golf balls, golf clubs also contain a high level of variety. There are numerous considerations which influence a golfer's decision of which equipment to use. In golf, the balls and clubs, specifically the driver, have currently reached the performance limits set by the USGA (Penner 2002). The driver is the club which receives the greatest scrutiny by golfers and the most marketing efforts by manufacturers. In these marketing efforts, the club being promoted is often described to possess the necessary characteristics for best club performance. While this is frequently observed in marketing and advertising, there are few empirical assessments of driver characteristics of performance. Researching efforts for designing golf clubs has been centered around increasing overall drive length and reducing off center impacts (Penner 2002). One characteristic often indicated and believed to effect driver performance is the degree of loft on the clubface. The degree of loft has been suggested to influence golf ball trajectory and distance of ball travel after club impact due to several factors such as spin, Magnus effect, and others. The spin rate, defined as the speed it spins on its axis during flight time, is measured in revolutions per minute (rpm). The spin rate from impact of a driver is normally in the range of 2,000-4,000 rpm (Shienfield 1995). The effect of this spin will be discussed further in following sections. Different degrees of loft possess the potential to change all characteristics of a golf balls' trajectory. A characteristic of the driver club head that will affect the driving distance is the loft which is considered to be the angular difference between the club face and the ground (Penner 2002). In order to determine the optimum loft of a driver, the effect the club head has on all launch and trajectory parameters of the golf ball has to be considered (Penner 2002). The basics of a golf shot are a result of the swinging of the golf club, at a set loft, and hitting the golf ball into the air (Werner 2007). For modeling the impact of the club head with the golf ball, researchers have made simplifying approximations, the primary being the club head is a free-body during the collision (Penner 2002). The distance the ball travels after impact depends on how fast the club is swung and how high the ball is launched (Werner 2007). In order to understand the purposes of this project, it is important to explain the qualities of a ball in flight and why the characteristics of a drive such as spin, launch angle, and speed, have an effect on the performance measures in golf. The following sections provide an explanation of the trajectory and aerodynamics of smooth and dimpled golf balls to provide knowledge of the different trajectories between a smooth ball and golf ball, and also how club selection can affect the performance.

Mechanics behind physics of a projectile

Before the explanation of projectiles, trajectory, and aerodynamics, several equations and principles which govern the flight of a ball should be explored. The principles of physics that apply to this research on the measures of golf are the Magnus effect and force, Bernoulli's Principle, and Reynolds number. When a golf ball is forced into the air after impact with the club face, the flight pattern, or trajectory, is much different if spin is placed on the ball. When a level of spin is induced on the ball, the pressure around the surface of the ball is altered (Burglund & Street 2011). In an approximate time of the late 19th century, Lord Rayleigh accredited a German scientist by the name of Gustav Magnus with the first explanation of this effect and in turn has since been known as the Magnus effect (Mehta & Pallis 2001). With this phenomenon, influences from the conditions in the boundary layer next to the surface can create anomalies in the force if a disturbance, such as turbulent flow, is introduced on the back side of the ball instead of the front (Briggs 1959). This anomaly will create a force, noted as lift, which is stated to be produced from the Magnus effect. The Magnus effect is known as a lift force due to the rotation of a cylinder as it propels through a fluid or gas such as air (Barber III 2007). When backspin is induced on a golf ball as a result of impact, it provides the ball with the ability to gain loft and consequently a longer flight (Burglund & Street 2011). As the ball spins in a backwards manner, air is directed upward in the front and downward behind it, creating a pressure difference, which pushes the ball upward and allowing the ball to remain in flight for a longer period of time (Burglund & Street 2011). This pressure difference is referred to as a 'force' which creates the term Magnus Force. Along with the Magnus effect and Magnus Force imparted on the flight of a spinning ball, Bernoulli's Principle is also presented through research (Walker 1999). Bernoulli's Principle is similar to the Magnus effect but differs slightly because it refers to the pressure difference on the upper and lower surfaces rather than the front and back. The lift force is also created due to the result of spin which creates a region of lower pressure above a ball that has backspin (Barber III 2007). Due to the higher pressure below the ball while it travels, there is a lifting force present after launch. A final term needed to comprehend the following sections is the Reynolds number. In research of aerodynamics, the Reynolds number is considered to be a quantity that represents the importance of inertial forces compared to viscous forces when attempting to determine the path of a projectile through a gas or fluid (Barber III 2007). This number is used to determine a spin rate of the ball that allows for optimal flight performance of the ball during trajectory after launch. When using the Reynolds number in respect to golf research, it is utilized to determine the level of spin which causes the transition from laminar flow to turbulent flow behind the ball during flight (Mehta 1985).

Trajectory of a projectile

Once a golf ball is struck with the club it is in flight for a certain amount of time and this qualifies it as a projectile. A projectile can be considered a body in free fall that is subjected to air resistance and the force of gravity, which is 9.81 meters per second squared (Hall 2006). An object, such as the golf ball, must be thrown upwards or at an angle that produces flight to be considered a projectile. The distance traveled from the launch position, in the horizontal plane, to the landing location is known as the range (Henderson 1996). The path which the projectile travels in referred to as the trajectory, and if gravity were not present the projectile would continue in a continuous straight line (Hall 2006). It is important to first explain the classic parabolic motion in order to understand the flight of a golf ball (Burglund & Street 2011). During projectile motion, the flight is broken into two components to be analyzed. A classic parabolic motion, such as the projectile flight, can be divided to x and y directions, where all forces such as air, drag, Magnus, altitude, and humidity are excluded (Burglund & Street 2011). The components, x and y, are the horizontal motion and the vertical motion. In regards to a parabolic trajectory, the horizontal motion has no force acting upon it after impact with the golf club that would alter the flight pattern. When speaking of a golf ball, the characteristics of its composition present the issue of air resistance which will be addressed later. With a parabolic trajectory, the projectile ascends at a given angle and descends on this same angle because the only force acting upon its distance of travel is gravity. The simplest explanation for a projectiles motion is to consider the single force determining its flight is the weight it carries after being launched (De Mestre 1990). This weight of the object is determined by the force of gravity. Gravity is considered to be a vertical force which, in turn, only affects the vertical motion of trajectory. This can be related to Newton's Second Law of physics which states the acceleration in motion is directly proportional to the net force acting on the object while being inversely proportional to the objects mass (Eagan et al. 2010). Gravity constantly pulls downward on an object in flight. This force will cause the object to reach a vertical velocity of zero at its peak height before beginning the descent phase of motion. The presence of gravity will force a projectile to accelerate downward after its peak height, causing a parabolic trajectory (Hall 2006). During the flight of a projectile, the horizontal velocity will remain constant; while the vertical velocity is altered by gravity (Henderson 1996). Due to the absence of a horizontal force in parabolic motion, a projectile maintains a constant horizontal velocity causing it to cover equal distances over equal time periods (Hall 2006). In other words, the projectile will cover the same distance on ascension when compared to descension. Vertical velocity gradually decreases until it reaches a velocity of zero (Hall 2006). When studying non parabolic trajectories, there are various qualities that determine the traveling distance of the projectile such as velocity, launch angle, resistance, etc. Horizontal distance is dependent upon two factors: the horizontal velocity from launch until landing and the time the projectile is in the air (Henderson1996). The time a projectile remains in the air during flight is a result of the launch angle and the forces acting upon its velocity during travel. As to be explained later, the golf ball is designed to reduce the resistances of external forces to allow for longer travel time resulting in further distance of trajectory. The range of a projectile being launched at an angle depends upon its launch velocity and launch angle (Henderson 1996). The degree of launch angle is considered to be the angle between the direction of launch and the horizontal line, for the golf swing this would be the ground. For a classic parabolic trajectory, the optimal launch angle is at 45 degrees which allows for the longest flight time and furthest distance (Shienfield 1995). The qualities of a parabolic flight are different for the flight of a golf ball after club impact. With a golf ball, due to spin, air and wind resistance, and more factors, the desired angle of launch is less that 45° for maximum distance and this can vary between golf clubs and golf shots (Shienfield 1995). When considering a golf shot, the level of complication is slightly increased as compared to a simple projectile motion (Werner 2007). As mentioned earlier, the characteristics of a golf shot as it leaves the club face now become present during the trajectory and flight of the golf ball. After the golf ball departs from the club face of the driver, its motion is controlled by the gravitational force and aerodynamic forces exerted by the air and its resistance (Penner 2002). In the case of the flight of a golf ball, gravity is always present, but what distinguishes the difference in a golf ball and simple projectile motion is the spin forces on the ball from the golf club and the air resistance of between the ball and the air as it travels (Werner 2007).

Normal Aerodynamics

Aerodynamics is one of the most influential factors when determining the flight of a projectile (Mehta & Pallis 2001). For this case, the flight of sports balls is considered and it is important to understand the mechanics behind the flight of a normal, smooth ball. For a golf ball, the introduction of dimples on the external surface presents alternative aerodynamic qualities, which will be discussed in the next section. Aerodynamics is a prominent factor for defining the flight of a ball after being struck or thrown through the air (Mehta & Pallis 2001). When a ball is traveling through the air during flight, there is a resistance resulting from the contact between the air molecules and the external surface of the ball which creates a surrounding layer of air called the boundary layer (Burglund & Street 2011). The sphere carries the boundary layer with it through the flight (Mehta & Pallis 2001). There is a common explanation that is accepted which states a spinning object creates a type of 'whirlpool' of air rotating around itself (Briggs 1959). On one side of the ball, the 'whirlpool' motion is conducted in the same direction as the wind stream, which increases velocity (Briggs 1959). The opposite side, where the motions of the 'whirlpool' and the wind stream are opposed, the velocity is decreased (Briggs 1959). When the flow around the front of the sphere accelerates, there is a decrease in surface pressure, which will be described by the Bernoulli equation. This occurs until a maximum velocity and minimum level of pressure is achieved half way around the sphere (Mehta & Pallis 2001). The reverse occurs over the opposite side of the ball, the back, so the pressure increases and velocity decreases which creates an adverse pressure gradient (Mehta & Pallis 2001). In accordance to Bernoulli's Principle, where the pressure is lower on one side, the velocity is greater and consequently an unbalanced force is created at right angles to the wind (Briggs 1959). The boundary layer is incapable of negotiating the adverse pressure gradient over the back portion of the ball and it has a tendency to separate from the surface (Mehta & Pallis 2001). When this happens, the air molecules travel past the ball in a parallel manner which creates a laminar flow (Burglund & Street 2011). The force implemented on a ball due to the interaction between its surface and air molecules is called aerodynamic drag or air resistance (Burglund & Street 2011). The pressure reaches a constant level when the boundary layer has become separated and the pressure difference between the front and back portions of the ball results in a drag force (Mehta & Pallis 2001). Resulting from laminar flow, there is a separation around the ball which creates a wake of low pressure behind the ball causing it to decelerate (Burglund & Street 2011). The wake that has been created is an area of low pressure which causes a pressure difference between the front and back sides of the sphere resulting in a pressure drag on the body in motion (Penner 2002). If there is an increase in wake, it results in a corresponding increase of drag force (Penner 2002). The boundary layer can consist of two distinct states: the laminar flow, which causes smooth flow of air passing on top of the other, or turbulent flow, where air moves chaotically through the boundary layer (Mehta & Pallis 2001). When referring to the golf ball, the roughness of the external surface causes this phenomenon known as turbulent boundary layer (Sullivan 2004). The turbulent boundary layer creates increased momentum near the surface, when compared to laminar flow, and this momentum is continually replenished by the mixture and transport from turbulence (Mehta & Pallis 2001). Because of this, it is able to withstand the adverse pressure gradient around the back portion of the ball causing a late separation of the layer which results in less drag (Mehta & Pallis 2001). There is a transition from laminar flow to turbulent flow when a specific Reynolds number is reached. If the ball's velocity continues to increase to reach the specific Reynolds number, the boundary layer that has shifted forward on the ball becomes turbulent and causes this shift to stop and move back downstream to the back side of the ball (Penner 2002). The wake is then dramatically reduced and in return causes a decrease in the drag (Penner 2002).

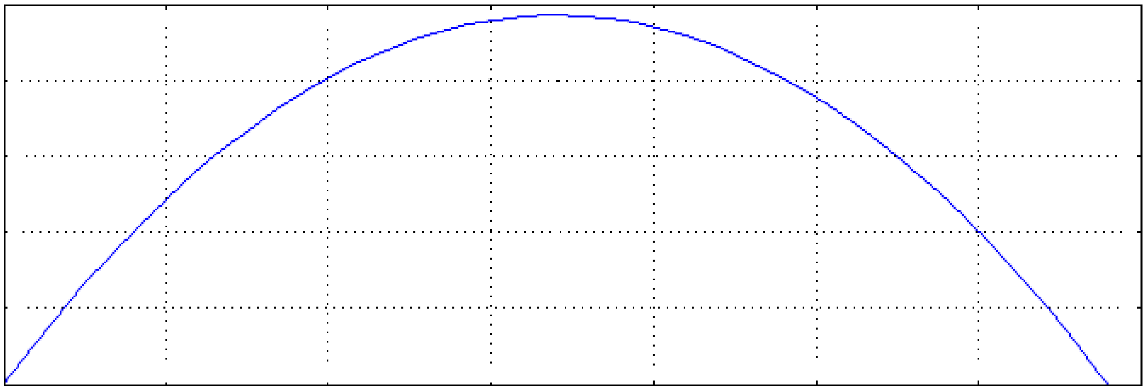


Figure 1 Model of classic parabolic motion.

Recreated from Burglund and Street (2011).

Difference in aerodynamics for a golf ball

The previous section is an explanation of aerodynamic characteristics for a smooth ball in flight. As was previously stated, the external covering of a golf ball has transitioned over the years from a smooth covering to the surface we see today covered with dimples. Through the legend of golf, it is stated around the mid-nineteenth century a professor from Scotland found that a golf ball flew further when the surface was scored and rough (Mehta & Pallis 2001). This was a discovery that eventually led to the dimpled golf ball we see today. The dimples were found to increase the aerodynamics of the golf ball and allow for better spin and control. The ideal ball is one that will carry for a long distance (Shienfield 1995). For a shot where carry is an important factor, such as the one hit with the driver, golfers gain distance by an increased quickness to reach the spin rate of the appropriate level (Shienfield 1995). A golf balls specific flight pattern is directly affected by the presence of air resistance and the rotation of the ball (Burglund & Street 2011). The desired effect of the dimples was to lower the Reynolds number (Mehta & Pallis 2001). With this lowered Reynolds number, at an earlier time the separation point is moved to the rear of the ball and the wake is in turn reduced causing a lower drag force. As mentioned in the previous section, the boundary layer can be laminar or turbulent. The difference between a smooth ball and a dimpled golf ball is the disturbance caused during flight (Burglund & Street 2011). An earlier transition of the boundary layer to turbulent can be induced by 'tripping' the laminar flow using a protuberance or surface roughness, such as dimples (Mehta & Pallis 2001). Dimpled golf balls have had a dramatic effect on ball flight for two key reasons, lift generation and drag reduction, and drag reduction is of the most importance to allow for longer distances (Barber III 2007). In golf ball aerodynamics, the drag force and force of gravitation are important since the main objective is to alter the ball flight (Mehta & Pallis 2001). Because of the dimples, the boundary layer around a golf ball is turbulent and this type of flow is able to remain close to the surface of the ball for a longer period of time (Burglund & Street 2011). The extra momentum that is applied to the back of the ball's boundary layer allows it to negotiate a higher level of pressure rise causing the separation point to move downstream (Mehta & Pallis 2001). With the turbulent flow, there is the ability of the separation of air to remain small around the ball creating a smaller area of low pressure on the back side of the ball, which in turn results in a lower drag force (Burglund & Street 2011). The turbulence, due to the introduction of dimples, decreases the drag by delaying the boundary layer separation on the trailing side of the ball (Barber III 2007). This decrease in drag allows the ball to remain in flight for a longer period of time which increases distance of the drive (Davies 1949). The drag reduction is not the only force that is induced by the spinning of the golf ball as it travels. While travelling through the air, a spinning golf ball will not only have drag, but a force perpendicular to the ball's velocity, which can be referred to as lift (Penner 2002). This lift force is induced due to the separation point being delayed on the upper surface and induced sooner on the lower surface (Penner 2002). This is different from the forces of drag because the forces are on the upper and lower sides rather than back and front. The dimples of a golf ball generate a lift force because of the significant backspin imparted on the ball at impact (Barber III 2007). The ball spin creates lift, resulting in the shot spin rate directly influencing the height of trajectory and its distance (Shienfield 1995). The spin generates an asymmetry in the speeds of air flow over the top and bottom areas of the ball (Barber III 2007). As a result of the difference in air flow speeds over the two surfaces, a net upward force is exerted on the golf ball during its flight until a peak height is reached (Penner 2002). This upward force, or lift, is generated because of the Magnus effect of the spinning ball (Mehta and Pallis 2001). McPhee and Andrews (1988) and Erlichson (1983) proved the drag and lift forces to be directly proportional to the speed of the travelling golf ball. When looking at the correlation of backspin and ball trajectory, especially in shots with the driver, an excessive spin rate can result in the ball taking a soaring trajectory, and this causes a net loss of distance (Shienfield 1995). This loss of distance can be attributed to the higher trajectory, resulting from an increased aerodynamic lift; along with an increase in the drag force imparted on the ball (Penner 2002). Keeping the amount of spin to an appropriate level and using the optimal launch angle and launch speed will result in maximum distance for recreational, amateur, and professional golfers (Penner 2002).

Golf has not been extensively researched in respects to the physics of the sport, but continuous research is conducted by manufacturers to enhance performance. The explanations provided above allow for an understanding of the physics behind ball flight after impact. Also, one could comprehend how different lofted clubs can affect the characteristics of trajectory and launch from the driver. Recently, it has been suggested a driver with higher degree of loft leads to increased performance off the tee. Johnson (2003) has explained as early as four years ago, many players were wanting a ball flight similar to a plane takeoff, starting low then climbing to the peak. A drive was considered optimal if it had low launch and high spin. Using launch monitors it was determined high launch with low spin resulted in the greatest distance for drivers (Johnson 2003). Previous research has explored different aspects of ball trajectory and how it affects total distance from the point of impact (Penner 2000). The control of the characteristics of trajectory allow superior performance, but spin and launch angle are not the only factors effecting projectile motion. Changing the loft of the club may not only change the launch angle, but it could also change both the launch speed and the backspin of the golf ball. The different spin rates can alter the lift and drag forces induced on the ball during flight and both are needed simultaneously for greater distance on a drive. Barber III (2007) found in a simulation study that with reduced drag a higher velocity was maintained throughout the ball's trajectory, which allowed for a further displacement in the horizontal direction. An important factor in this line of study is to distinguish between the distance the ball travels through the air, referred to as carry by golf literature, and the overall drive, which is the sum of the carry and rolling distance after landing, known as the run (Penner 2000).

For Johnson (2003) study, a variety of swing speeds were analyzed using a group of different lofted drivers, consisting of 9, 11, 14 and 16 degrees, that were provided by

Tom Wishon of Tom Wishon Golf Technology. Results indicated that, at the slowest speeds, the 16-degree club performed best, but for the club speeds that represent the majority of average recreational golfers, the driver with the 11 degree loft provided the greatest carry distance (Stachura 2003). One study showed significant results from a sampling of average players whose distance of carry increased by as much as 36 yards from switching to a driver with a higher degree of loft (Stachura 2003). Stachura (2003) stated if the loft on the driver is less than 10 degrees, maximal performance is not being achieved. It is suggested that the average players are using drivers with too little loft (Johnson 2003). About 90 percent of recreational golfers would see better results if they added 1 or 2 degrees of loft to their drivers (Stachura 2003). Professional golfers have reported going to higher lofts to produce maximum distance trajectory (Stachura 2003). To take advantage of the aerodynamics of a golf ball, the proper launch angle and spin allows for optimal performance which is inferred to be affected by the degree of loft. Along with degree of loft, club head speed is another characteristic of the golf swing. Club head speed is known as the velocity at which a golf club is traveling when it impacts with a golf ball and has been suggested to be a valid indicator of performance in golfers. Penner (2001) created a model of a club head as a flat plane because only centered impacts are considered for maximum distance. Using this, a determination was made regarding the dependence of the golf ball's launch speed, launch angle, and spin after launch from the club head. It was found for a designated club head speed, increasing the loft on the face of the club head would result in a lower launch speed, higher launch angle, and increased backspin for the golf ball (Penner 2002). The optimum value for dynamic loft (different than standard clubface loft) was 13.1 degrees which correlates to 10 degrees club face loft (Penner 2002). Golf club technicians have developed new designs in an attempt to improve the results of the driver. The advanced aerodynamics of the club head allows wind to flow more quickly and smoothly over the crown to reduce drag and increase head speed (TaylorMadeGolf 2010). With a linear regression analysis, club head speed was found to be highly correlated with the handicap of golfers (Fradkin et al. 2004). In general it was determined through research of the correlation between club head speed and optimum loft, the greater the club head speed at the time of impact, the lower the desired loft because the greater club head speed will induce a higher spin rate which requires a lower launch angle to eliminate the zone of diminishing returns (Penner 2002). This zone is reached when the spin and launch angle are too high and cause the ball to soar and result in a loss of distance.

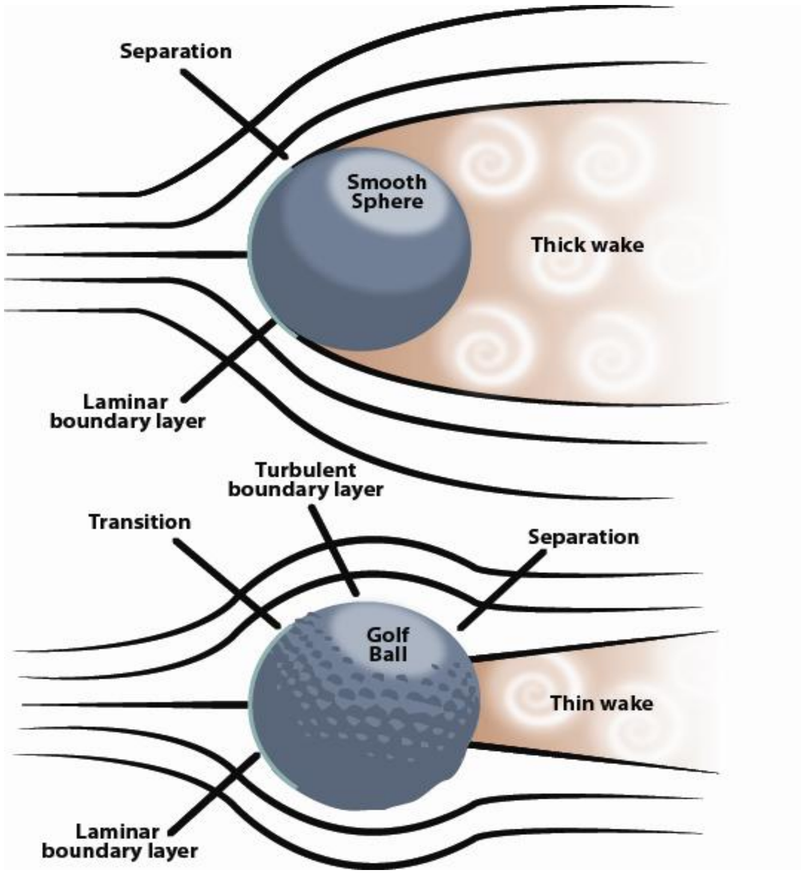


Figure 2 Image of laminar flow and turbulent flow.

Recreated from Barber III (2007).

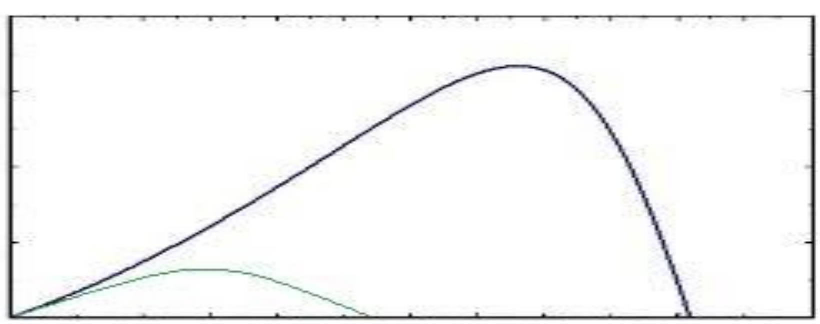


Figure 3 Trajectory with addition of lift force and drag reduction.

Recreated from Burglund & Street (2011).

CHAPTER II

APPLICATION

The purpose of the current study was to investigate club head speed, ball speed, launch angle, descent angle, total spin, carry, and total distance in an attempt to determine performance measures of three different lofted drivers. The variables measured may constitute this study as a pilot study due to limited previous research. Although it has been discussed previously the importance of all the variables being tested, the most important factor to determine performance would be increased total distance (Okuda & Armstrong 2002). Increased total distance is the goal of all golfers, from recreational to professional, when using the driver from the tee box. It is hypothesized the low lofted driver (9.5°) would produce greater performance measures due to an increased distance of run after carry distance which results in a net increase of total distance. This is believed to be true because the subjects being tested are considered above average players which would increase their swing speed and control of the club to place them closer to the level of professionals. As stated earlier, the recreational player should perform to a higher level with an increased loft club, but the participants are considered to have a greater level of skill than recreational golfers.

CHAPTER III

METHODS

Participants

Fifteen participants, (12 males, 3 females) with a mean age of 20.47 ± 1.76 years, were recruited from the Professional Golf Management program at Mississippi State University. Each person in the program is required to maintain a handicap of 8 or lower. Participants had a mean of 10.067 years of experience and played an average of 10.533 rounds of golf per month. Prior to participation each participant was required to provide Informed Consent (IC) for participation in the study. All methodologies were approved by the Institutional Review Board (IRB) for treatment of Human Subjects. Table 1 provides descriptive data for the participants used in this research study.

Table 1 Descriptive data for males, females, and totals from general information.

Gender	N	Average age	Average years of play	Average rounds of golf/month	Average score per 18 holes
Males	12	20.83 ± 1.8	11.25 ± 4.65	11.33 ± 5.0	76.58 ± 2.35
Females	3	19 ± 0.0	5.33 ± 0.58	6.33 ± 1.53	84 ± 4.58
Total	**15**	**20.47 ± 1.76**	**10.07 ± 4.80**	**10.53 ± 4.97**	**78.07 ± 4.10**

Drivers and Equipment

All drivers were 2012 TaylorMade RBZ with Matrix Ozik XCon-5 shafts of Regular Flex. All shaft loft settings were set to Standard (STD) loft. The TaylorMade RBZ drivers are manufactured with optional settings for loft and club face weight. The adjustable dials are used to alter the shaft while the bottom of the club head possesses weights that can be moved from the front to the rear in order to tailor the club to the individual's swing. Driver shafts were a standard 46" (inches) which placed the participant an equal length from the ball between individuals. The experimental protocol used three different loft drivers (9.5°=Club A, 10.5°=Club B, and 13 °=Club C). To reduce potential of variability from the golf ball, all swings were performed using a Titleist Pro-V1 golf ball. All trials were performed on the hitting set-up which consisted of a Callaway turf hitting mat and a two inch standard wooden golf tee. The camera system used for measuring and recording of the variables was the Foresight Game Changer golf analysis system. This high speed system allowed for the capture of impact and flight characteristics and was linked to a computer accessed by the researcher. Due to the link between the two systems, data was recorded by the Foresight Game Changer system and then collected and organized by the computer. The radar was directly connected to the Foresight Game Changer system and used to collect the club head speed at the moment of impact. A projector was used to create a virtual ball flight displayed on a projection screen. In front of the projection screen was a Callaway hitting net, which was used to not only allow for indoor sessions, but also to protect the projection screen.

Driver Testing

Once participants were designated a testing session date, they received two IC forms, one for their own record. Following retrieval of consent, each participant completed all procedures during a single research session with assignment of club order randomized for each participant. Sessions incorporated three trials with ten swings per club. Each trial consisted of a different lofted driver (Club A, Club B, Club C). All testing sessions were conducted in an indoor facility provided by the Mississippi State University Institute of Golf. This indoor facility allowed for a controlled environment to remain homogenous between each participants testing trial. For each session, random order of club assignment was used while all markings of club specifications were covered on each driver for all participants to remain blinded. Non transparent tape was used to cover specifications on club and Club A, Club B, or Club C was marked on the tape to designate the clubs. Participants completed a total of 30 test swings, ten with each driver, to evaluate the measurement variables and eliminate any variability in miss hits. Participants were allotted five minutes for a warm-up process consisting of free swings in an open area with no golf ball. As the warm-up process was in session, the researcher explained how the testing protocol would progress through the session. Following warm-up, participants were assigned a one of the three drivers in random order and at this time the Titleist Pro V-1 golf ball was placed on the two inch (2”) tee for testing to begin. Participants were instructed to swing the club consistent with their normal characteristics for each tested swing. After the swing was performed and data was recorded on the computer monitor, the participant was instructed to back away from the hitting mat to allow investigator to return testing area to previous setting. Also at this time, the researcher placed the next golf ball on a new two inch (2") tee. This process was completed by the researcher to ensure no increased effort was required from the participant other than the swing of the driver. This process remained consistent for a total of ten tested swings with the first driver. Following the tenth swing, participants were allotted a two (2) minute rest period where each participant remained standing in the testing area but did not perform any swings. Also at this time, the second club to be tested (random) was assigned. Once the two minute rest period was completed, the testing of the second driver was begun and the process of testing was repeated from above. Again, after the tenth swing, a rest period of two minutes was incorporated and before the third and final driver testing was completed. As stated earlier, the warm-up process was five minutes long and was directly followed by a five minute testing of the first driver. The rest periods incorporated between driver testing was at length of two minutes. Each session included one warm-up, three testing periods, and two rests which resulted in a total of approximately 25 minutes for each participant's experimental session. All performance characteristics (in Measurements section) were recorded and organized for access via computer and video system. The camera and video system, Foresight Game Changer, is a high speed camera which monitors and records all aspects of impact and ball flight. The computer system, linked to the Foresight Game Changer system, retrieved the data for each swing and listed the variables in a folder created for each participant. The organization of folders, which was completed through the Foresight Game Changer Fitting Assessment, allowed the researcher to retrieve all sets of data following cessation of research study. The manual set up for the testing sessions consisted of a Callaway golf hitting net, projector screen and projector, Callaway turf hitting mat, Foresight Game Changer computer system and camera, and a computer linked to the camera which projected all flight variables following each swing. These variables were not projected on the hitting screen for participants to see, only on the computer screen available to the investigator, in order to eliminate judgment of each club. The projector screen was placed on the wall farthest from the entrance door because the room was greater in length than in width. In front of this projection screen by four feet was the Callaway golf hitting net which stood approximately eight feet in height and allowed ample space for participants to hit anywhere into the net which protected the projection screen. The Callaway turf mat being used for a hitting surface to eliminate variability of surface contact was placed eight feet in front of the hitting net which was designed to provide sufficient space to swing a full length driver with no interference from an external surface. From this point forward, all descriptions of equipment set up will be described in terms of the investigator standing in the room and looking directly forward to the net in front. The Titleist Pro V-1 golf ball was placed on the right side of the turf hitting mat in a designated circle which lied eight inches from the right edge. This circle was used because the high speed camera system required the tee and ball to be placed in a certain area for it to register the characteristics as the ball was struck with the driver. The Foresight Game Changer camera system was aligned two feet to the right of the turf mat and one foot forward from the ball. This placement was necessary to not only capture the point of impact but also the flight of the golf ball as it left the club face. The radar used with the Foresight Game Changer system was aligned directly in line (forward to back) with the golf ball as it was placed on the tee inside the circle and was positioned approximately 10 inches to the right of the turf mat. The computer monitor and system unit were linked to the Foresight Game Changer camera and radar and were placed at a distance to the rear of the room behind the turf hitting mat where the participants performed their testing sessions. The computer system was located approximately nine feet behind and four feet to the right of the turf mat which provided an angle to observe the testing swings and also eliminate a visualization of the performance variables by the participant. The researcher was located at the computer system behind and to the right of the testing area, until swing speed was needed to be recorded directly next to the turf mat. Directly above the testing area, turf mat, was the projector screen which was mounted to the 10 foot ceiling. Below is a diagram to establish the visual concept of the testing set up used for each session.

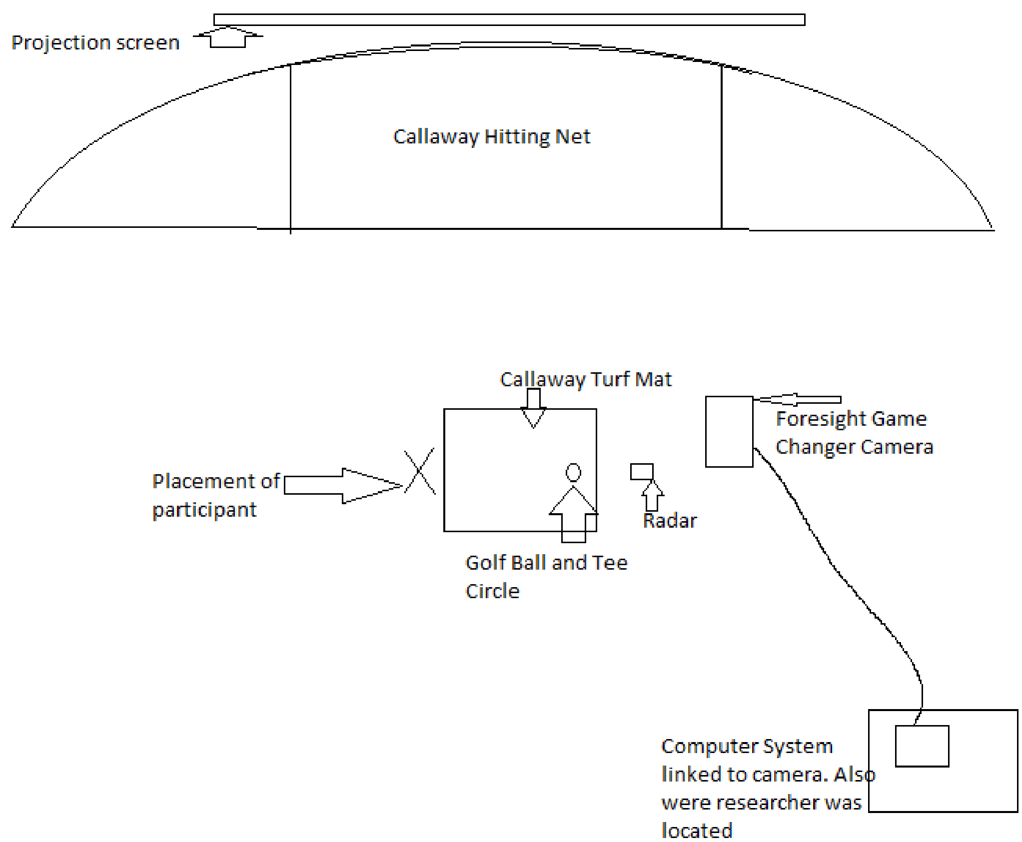


Figure 4 Representation of the testing environment

Measurement Variables

For all swings, ball speed in miles per hour (mph), launch angle, descent angle, total spin in revolutions per minute (rpm), carry measured in yards (yds.), and total distance in yards (yds) was recorded (Foresight Sports Game Changer). This data was organized (Foresight Sports Club Fitting Assessment) for analysis.

Statistical Analysis

The data for this study was organized concurrently with testing sessions through the Foresight Sports Club Fitting Assessment computer program. After all testing sessions were completed, data was retrieved and arranged into Microsoft Excel to determine the averages for each variable for each club and each participant. Seven One Way ANOVAs with repeated measures was used to test for differences in the variables between the different clubs and Tukey post hoc testing was used with the *a priori* level set at $P < .05$.

CHAPTER IV

RESULTS

A total of 450 swings were tested through the process of one experimental session for 15 subjects. With 450 swings and seven variables for each subject, a total of 3,150 data points were analyzed. Table 2 provides a summary of mean values found for each variable organized by club. Significant differences were found for all variables except launch angle and carry. The significant differences include ball speed, club head speed, total spin, descent angle, and total distance. Launch angle produced no significant differences (P=0.118) between Club A, Club B, and Club C (for a comparison of means and standard deviations refer to Table 2). All figures listed in this chapter are found in the Appendix section. Shown in Appendix A, is a graph representing the average launch angle for each club. Carry distance, measured in yards, also did not produce significant differences between clubs (P=0.106). These results are represented in Appendix B. However, ball spin was analyzed and produced spin rates significantly different between clubs (P<0.001). Club A, low loft, possessed a 3.5° difference in club face loft from Club C, high loft. This range in club face loft resulted in a difference of 616 revolutions per minute. Significant differences were seen between Club A and Club C (P<0.001). Also, a significant difference was observed between the low loft and mid loft drivers, Club A and Club B (P=0.02). A representation of these differences is seen in Appendix C. Descent angle was another variable which produced a significant difference between the tested clubs (P=0.004). With the between groups comparison, all groups produced differences large enough to prove significance. When the low loft driver was compared to the high loft driver, a significant difference in the descent angle was seen (P=0.004). Club A, low loft, produced the lowest degree of descent angle while Club B, the mid lofted driver, resulted in an average descent angle which was nearly half way between the low and high loft drivers. The high loft driver showed the largest descent angle of the three tested drivers, this mean angle can be seen in Table 2. Significant differences were produced between Club A and Club B with between club comparison (P=0.035). Also, when Club B was compared to Club C, the difference in angles were shown to be significant (P=0.007). These comparisons are shown in Appendix D. In a reverse order from the ball spin and descent angle, ball speed produced significant differences (P=0.049). Between the three clubs tested Club A produced the fastest velocity; Club B was slightly lower, while Club C resulted in a large decrease. Appendix E illustrates a comparison between these clubs for this variable. Significant differences were seen between Club A and Club C (P=0.049) and also Club B and Club C (P=0.033). Along with the ball speed, club head speed was significantly different (P=0.025). Participants were able produce the fasted club head speed with Club A, possessing a 9.5° club face, and this presented a large difference between clubs. This average swing speed was significantly faster (P=0.025) than the high lofted driver, Club C with a 13° club face, which yielded the lowest mean club head speed. The mid lofted driver, Club B 10.5°, was significantly different from the high lofted driver also (P=0.022) with a between group comparison. Appendix F represents an illustration of the mean club head speeds in mph for Club A, Club B, and Club C. As discussed in the application section, total distance is the most important factor when attempting to increase performance with a driver. This variable is the sum of the carry and the distance the ball rolls after landing. Participants produced significant differences (P=0.001) in the total distance the ball traveled in a forward motion between drivers. When a between groups comparison was performed, the low loft (9.5°) and mid loft (10.5°) did not result in a value great enough to be considered significant, with a difference of only 2.571 yards. However, when the mid to high (13°) and low to high lofts were compared, significant results were presented. With the between club comparison of Club B and Club C a significant difference was presented (P=0.011) while Club A to Club C was also significant (P=0.001). Club B and Club C showed a difference of 6.597 yards and Club A's distance increased by 9.168 yards when compared to Club C. Club A, the low loft driver, produced the longest total distance of the three drivers, and this can be seen in the mean total distances of Table 2. These results are illustrated in Appendix G.

Table 2 Values for Club A, Club B, and Club C used for comparisons.

Variables	N	Mean	SD	Std. Error	SS	P value
Club head speed (mph)						
Club A	15	99.067	12.629	3.261		*
Club B	15	98.867	12.949	3.344	16.133	0.025
Club C	15	97.600	12.960	3.346		
Ball Speed (mph)						
Club A	15	144.013	18.212	4.702		*
Club B	15	143.813	18.688	4.825	22.707	0.049
Club C	15	142.273	18.677	4.822		
Launch Angle (degrees)						
Club A						
Club B	15	12.407	3.519	.909		
Club C	15	12.700	2.249	.581	11.041	0.118
	15	13.620	2.960	.764		
Total Spin (rpm)						
Club A	15	3019.400	606.906	156.703		*
Club B	15	3436.200	875.953	226.170	2845920.0	<0.001
Club C	15	3635.400	702.709	181.439		
Descent Angle (degrees)						
Club A						
Club B	15	38.800	8.222	2.123		*
Club C	15	40.733	6.169	1.593	124.033	0.004
	15	42.867	6.917	1.786		
Carry (yards)						
Club A	15	230.356	42.397	10.947		
Club B	15	231.263	41.745	10.779	151.291	0.106
Club C	15	225.865	40.883	10.556		
Total distance (yards)						
Club A						
Club B	15	257.053	36.731	9.484		*
Club C	15	254.482	39.124	10.102	630.300	0.001
	15	247.885	37.177	9.599		

* Significant

CHAPTER V

DISCUSSION

The variables discussed are all imperative to the flight of a golf ball and ultimately determine the performance of a golfer using the driver. Club face loft, measured in degrees, is a characteristic that possesses the potential to affect each of the variables measured in this research study and can be a determining factor for the success of a golfer when using the driver from the tee box. The purpose of the current study was to investigate club head speed, ball speed, launch angle, descent angle, total spin, carry, and total distance in an attempt to determine performance measures of three different lofted drivers. Variables such as launch angle and carry distance did not present any significant differences between drivers. The drivers used for this study possibly did not contain a large enough difference in loft from the low to high degree to produce an alteration in launch angle. Launch angle, unlike descent angle, is generally not affected by the level of spin and club head speed because the measure of launch angle is taken at the point of impact as it leaves the club before maximal spin is induced (Penner 2002). The researcher of the current study believed this is one critical point which caused this difference and should be assessed further in future examinations.

From the three clubs used by fifteen participants, ball speed, total spin, descent angle, total distance, and club head speed were the variables which presented significant differences for golf performance measures. Total ball spin of all the drivers combined reached a maximum of 7,000 rpm and a minimum of 815 rpm. For this research study, the high lofted (13°) driver resulted in a mean total spin rate significantly greater than the low lofted club. The researcher for the current study believes the higher spin rate seen in this study for the high lofted driver could be linked to the club face which is in agreement with Johnson (2003). With an increased face loft, the upward slant of the club face creates backspin on the golf ball upon impact and the dimples, as discussed earlier, allow for an increase in this spin (Johnson 2003). Ball spin has a direct relationship with the flight of the golf ball following impact (Mehta & Pallis 2001). This is due to the backspin on the ball creating a lift force and reducing the drag as it travels through the trajectory and causing the ball to remain in flight for a longer period (Mehta & Pallis 2001). This lift force is critical to the distance the ball is able to travel (Burglund & Street 2011). Therefore, it is believed the increased degree of loft from the high loft driver (Club C) created a greater level of spin. With the induced spin from the club face and the dimples of the golf ball creating a transition to turbulent flow (Mehta & Pallis 2001), the golf ball in the current study remained in flight for a longer period of time. Although there was an increase in this variable, the golf ball was seen to reach a spin rate of too many revolutions per minute to maintain a horizontal flight pattern. This was believed to be the reason for the ball to continue to climb vertically. Also in the same pattern of increasing values from low to high was the descent angle from each measured club. The descent angle, which presented a maximum of 55° and minimum of 18° in this study, is thought to be affected by the total spin rate of the golf ball (Penner 2002). As stated earlier, it was determined through research of the correlation between club head speed and optimum loft, the greater the club head speed at the time of impact, the lower the desired loft because the greater club head speed will induce a higher spin rate which requires a lower launch angle to eliminate the zone of diminishing returns (Penner 2002). This zone is achieved when spin rate is too fast and causes reverse effect in lowering the drag. It also causes the ball to follow the upward lift pattern resulting in a ball "soaring" to maximum height and returning to the horizontal surface at a greater angle. The descent angle therefore is directly proportional the total spin rate of the golf ball and club face loft (Penner 2002). This relationship can be seen in Appendix E.

As for club head speed, ball speed, and total distance, these variables were seen to have a relationship between them with a decrease in value from the low loft to the high loft. Club head speed can be seen as an important factor when attempting to improve or control performance measures. This variable has crucial effects on the outcome of the trajectory the golf ball possesses following impact (Fradkin et al. 2004). As explained by the physics principles, if the club head speed increases leading up to impact, the point of impact will generate a greater force resulting in a higher velocity of the projectile. Also, Penner (2002) explains that a greater club head speed will induce a higher spin rate resulting in a better ability to avoid the zone of diminishing returns. From the fifteen participants, a maximum club head speed of 113 mph was reached throughout the testing sessions which consisted of 450 total swings. This club head speed is seen to be well above the swing speed described by Lephart et al. (2007) and Thompson (2004) as being the average for recreational golfers . Lephart et al. (2007) found average swing speed of recreational golfers to be 42.4 m/s which is converted to 94.8461 mph. Also, Thompson (2004) states the average swing speed of recreational golfers to range from 90 to 100 mph. For this research study, it is believed the increased club head speed, seen in the results section, could be due to the increased aerodynamics of the club face with the lower lofted drivers. As the club face loft increases, the degree of surface area also increases which results in a resistance force placed upon the driver's club face. The increase in club head speed, as previously stated, will lead to increased ball speed following impact and result in a greater force when travelling in the horizontal direction. This higher velocity in the horizontal direction is a possible explanation for the farther displacement of the golf ball from impact to succession of forward movement with the low lofted driver. Ball speed from all clubs combined ranged from a minimum to maximum of 86.5-164.8 mph. The higher end of the ball speed range produced by the drivers in this study was greater than the average ball speed of recreational golfers described by Lephart et al (2007). Lephart et al. (2007) reported the average ball speed of recreational golfers to be 135 mph. The ball speed is seen to be directly related to the club head speed due to basic physics principles. As the club head speed increased from the high to low loft driver, the ball was believed by the researcher to be impacted with a greater force causing the ball to leave the club face at a speed related to the swing.

The last variable, which is the considered the most important variable by golfers when assessing driver performance is total distance (Okuda & Armstrong 2002). Increasing total distance from the point of impact is believed to receive the most concern from golfers because it has the capability of creating a shorter distance required for the second golf shot on the designated golf hole (Dolan 2011). Consequently, total distance is affected by all the variables previously mentioned in the current study. Club head speed and ball speed, which were recently discussed, are seen in this study to have a relationship with the total distance. This relationship is illustrated in Appendix F. As the club face loft increased from 9.5° to 13°, the total distance ultimately decreased along with the club head speed and ball speed. Total distance reached a maximum distance of 310 yards with Club A when all clubs and testing sessions were combined. This club was the lowest lofted club of the three used for testing and these findings are in agreement with those of Stachura (2003) and Penner (2002). Penner (2002) found the optimal loft which produces the greatest distance to be approximately 10° which related to this study with the greatest distance being produced by Club A, the low loft driver at 9.5°. The difference in mean total distance from Club A to Club C was 9.168 yards. This difference in distance is great enough to result in the golfer needing a different club for the next golf shot or having to alter the technique for the shot following the drive (Dolan 2011). As the club face loft increased, the club head speed and ball speed decreased, and the total spin rate and descent angle increased. The researcher for the current study believed this could cause the ball to be limited in flight distance due to the lack of club head speed which produces the ball speed following impact. Also, the higher spin rate is believed to result in the zone of diminishing returns causing the ball to continue on a vertical path and not follow the pattern of a normal trajectory. This increased height of the projectile causes an increase in descent angle, allowing the ball to return to the horizontal surface with less vertical motion. The decreased vertical motion, or angle, causes the ball to gain rolling distance, which creates the difference between carry distance and total distance (Werner 2007). These factors are not present with Club A, the low lofted club, where club head speed and ball speed were increased, while total spin rate and descent angle decreased. The total spin rate is believed to remain within functional limits of approximately 3,000 rpm (Lephart et al. 2007). The increased club head speed was related to the increased ball speed following impact, and when combined with a decreased angle of descent, the ball was able to accumulate a further rolling distance. The carry distance did not produce any significant differences, but the total distance produced significant differences between the high and low lofted drivers, with the low loft having a further total distance. With no differences in carry, this difference in total distance is believed to be related to the roll distance being produced by the factors previously mentioned.   Research in this area of golf is limited and should be further examined. Limitations of this study include a lack of access to professional golfers. The level of consistency is higher when using the elite population and these variables should be looked at through the professional field (Clark 2005). The participants, PGM members, were the highest level of performance and consistency that was available to the researchers at this time. Also, the number of participants was limited to the PGM program, and should be expanded to contain a larger population. Although limitations were present, significant and results were seen with between group comparisons for low, mid, and high lofted drivers.

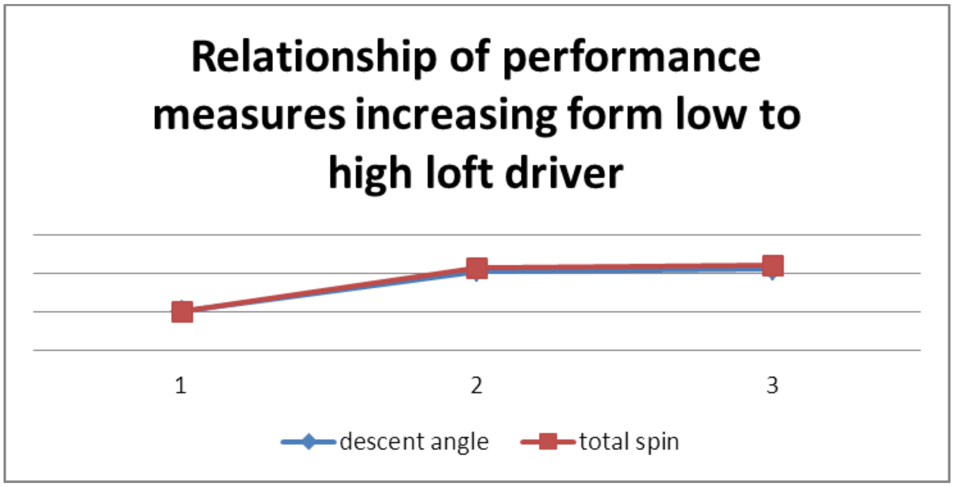


Figure 5 Relationship between descent angle and total spin as the club face loft increases.

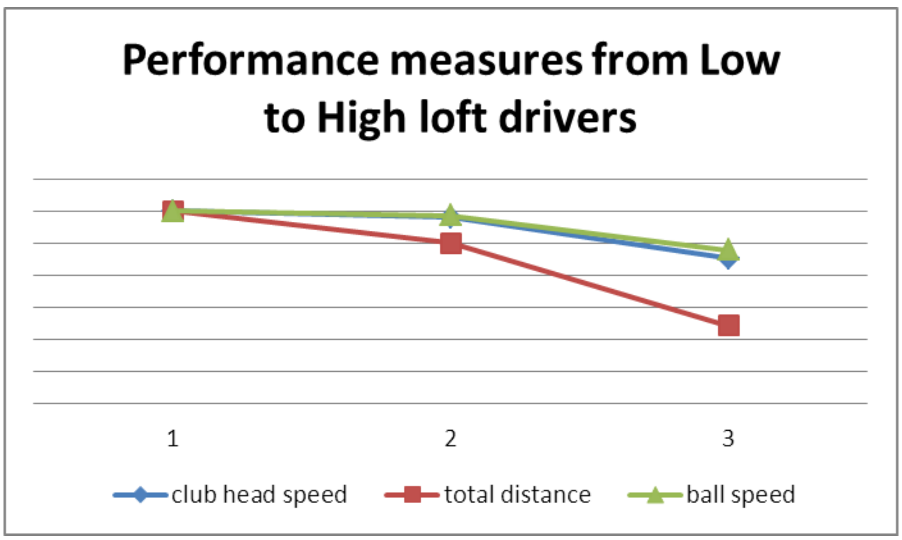


Figure 6 Relationship between club head speed, ball speed, and total distance.

Conclusion

In conclusion, the low lofted driver (9.5°), Club A, was found to produce the greatest total distance and which was seen to be directly related to the other variables which each effect the trajectory of a projectile. The researcher believes the low lofted driver produces lower angles in flight which allows golfers to avoid the flight patterns that cause the zone of diminishing returns. Because of this, the golfer would possibly be able to create a further rolling distance and which could increase the total distance from the point of impact being on the tee box. Further research is needed in this area is needed to determine further correlation between club face loft and driver performance variables. For this study, significant differences were seen to conclude the low lofted driver, at 9.5°, was able to provide the golfer with greatest performance. These findings can be applied to recreational golfers who are able to produce swing characteristics similar to the tested subjects for this study. Golfers should avoid the extreme high lofted drivers in order to create a flight pattern of the golf ball that will optimize not only the performance of the club but also the performance of the golf ball. The degree of loft from the club face is the causing factor for the flight characteristics of the golf ball and should be considered when designing and tailoring a driver to each golfer.

BIBLIOGRAPHY

Shienfield, G. (1995). Golf ball spin. KnetGolf. Retrieved from http://www.knetgolf.com/Topic/25-Golf_Ball_Spin.aspx

Sorenstam, A., Sutton H. (2004). First swing golfer's guide. *PGA of America.* 1-71. Retrieved from http://pdf.pgalinks.com/p-g-a/FirstSwing/First_Swing_Golfers_Guide.pdf

Barber, R. (2007). Golf ball flight dynamics. Cornell University. Retrieved from http://rancebarber.com/resources/AEP434FinalProject_GolfBallDynamics.pdf

Briggs, L. (1959). Effect of spin and speed on lateral deflection (curve) of a baseball; and the magnus effect for smooth spheres. *National Bureau of Standards*. 589-596. Retrieved from http://webusers.npl.illinois.edu/~a-nathan/pob/Briggs.pdf

Burglund, B., Street, R. (2011). Golf ball flight dynamics. Flathead Valley Community College. 1-19. Retrieved from http://home2.fvcc.edu/~dhicketh/DiffEqns/Spring11projects/

Brett_Burglund_Ryan_Street/Diff%20Q/pdfscreen/projectoutline.pdf

Clark, R. (2005). An analysis of players' consistency among professional golfers: a longitudinal study. *Journal of Perceptual and Motor Skills.* 101 (2), 356-372.

De Mestre, N. (1990). The mathematics of projectiles in sports. Australian Mathematical Society. Press Syndicate of University of Cambridge. Oakleigh, Vicotria, Australia. Retrieved from http://books.google.com/books?hl=en&lr=&id=xVXDjDVuhN4C&oi=fnd&pg=PR9&dq=gravity+effect+on+projectile&ots=BKI9msEZHF&sig=C8copaHg5AKv57Lmi0Ho8hvj_KY#v=onepage&q=gravity%20effect%20on%20projectile&f=false

Davies, J. (1949). The aerodynamics of golf balls. *Journal of Applied Physics.* 20 (9), 821-828. doi: 10.1063/1.1698540.

Dolan, P. (2011). The most important golf shot. *Top End Sports.* Retrieved from http://www.topendsports.com/sport/golf/important.htm

Eagan, R., Morton, S., Murphy, C. (2010). Newton's second law of motion. Penn State Worthington Scranton. Dunmore, PA, USA. Retrieved from http://scripts.cac.psu.edu/users/r/e/ree5047/media/phys211_lab4.pdf

Elert, G. (1998). Aerodynamic Drag. The physics hypertextbook. Retrieved from http://physics.info/drag/

Fradkin, A., Sherman, C., Finch C. (2004). How well does club head speed correlate with golf handicaps? *Journal of Sports Science and Medicine.* 7 (4), 465-472. Accessed through PubMed. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/15712503

Hall, S. (2006). Basic biomechanics (5th ed). McGraw-Hill. 1221 Avenue of the Americas, New York, NY.

Henderson, T. (1996). Maximum range explained. *The Physics Classroom.* Retrieved from http://www.physicsclassroom.com/actprep/act3ag.pdf

Johnson, E. (2003). A matter of degrees: players at all levels may not want to admit it, but higher lofts are a key to distance with the driver. *Golf World 7.* 56 (27), 10-11. Accessed through SPORTdiscus. Retrieved from http://ehis.ebscohost.com.proxy.library.msstate.edu/ehost/detail?sid=fe7ddc02-e2ee-40e997139ea4a1fe7cbf%40sessionmgr14&vid=1&hid=2&bdata=JnNpdGU9ZWhvc3QtbGl2ZQ%3d%3d#db=s3h&AN=SPHS-880163

Jorgensen, T. (1999). The physics of golf, (2nd ed.). Springer Paperback. Springer-Verlag, New York.

Lephart, S., Smoliga, J., Myers, J., Sell, T., Tsai, Y. (2007). An eight week golf specific exercise program improves physical characteristics, swing mechanics, and golf performance in recreational golfers. *Journal of Strength and Conditioning Research.* 21 (3), 860-869. Retrieved from http://pitt.edu/~neurolab/publications/2007/LephartSM_2007_JStrengthCondRes_8wkGolfSpecificExerciseProgram.pdf

Mehta, R. (1985). Aerodynamics of sports balls. *Annual Review of Fluid Mechanics.* Vol. 17 151-189. Joint Institute for Aeronautics and Acoustics. Retrieved from http://www.annualreviews.org/doi/abs/10.1146/annurev.fl.17.010185.001055?journalCode=fluid

Mehta, R., Pallis, J. (2001). Sports ball aerodynamics: effects of velocity, spin, and surface roughness. *Materials and Science in Sports.* 185-197. Retrieved from http://iweb.tms.org/ED/01-5085-185.pdf

Okuda, I., Armstong, C. (2002). Biomechanical analysis of professional golfer's swings: Hidemichi Tanaka. Hal Sports Production. *Science and Golf IV*. p 18-27. World Scientific Congress of Golf Trust. Retrieved from http://books.google.com/books?hl=en&lr=&id=bmVk8BkOLH4C&oi=fnd&pg=PA35&dq=average+club+head+speed+for+golfers&ots=U1AMuZerq&sig=jaRlhEapFbusOq0i9kmCiu6qr6w#v=onepage&q=average%20club%20head%20speed%20for%20golfers&f=false

Penner, R. (2000). The physics of golf: The optimum loft of a driver. *American Journal of Physics.* 69 (5), 563-568. doi: 10.1119/1.1344164.

Penner, R. (2002). The physics of golf. *Institute of Physics Publishing.* 66 (2003), 131-171. doi:10.1088/0034-4885/66/2/202. Retrieved from http://baebi-huus.ch.host.setup.ch/koni/golf.pdf

Pennington, B. (2009). Golf's colorful language goes with any green. *New York Edition, New York Times.* p. 7. Retrieved from http://www.nytimes.com/2009/05/11/sports/golf/11pennington.html?_r=0

Smith, C. (2010). Mechanism of drag reduction by dimples on a sphere. University of California – Davis School of Education. Retrieved from http://biosport.ucdavis.edu/labmeetings/Golf%20Ball%20Presentation.pdf

Stachura, M., Wishon, T. (2003). Why everybody needs to try more loft – and that means you. *Golf Digest.* 54 (11), 115-119. Accessed through SPORTdiscus. Retrieved from http://ehis.ebscohost.com.proxy.library.msstate.edu/eds/detail?vid=3&hid=3&sid=54378b16-74b8472fae61d75494cea876%40sessionmgr104&bdata=JnNpdGU9ZWRzLWxpdmU%3d#db=s3h&AN=11196997

Sullivan, M. (2004). Golf Ball Dimples. Barrington, RI, USA. Google patent US6709349B2. Retrieved http://www.google.com/patents/US6709349?pg=PA11&dq=golf+ball+dimples+and+turbulent+flow&hl=en&sa=X&ei=jvhTUMXrD4uc8QTV2oC4Cw&ved=0CDQQ6AEwAQ#v=onepage&q=golf%20ball%20dimples%20and%20turbulent%20flow&f=false

Thompson, C. (2002). Effect of muscle strength and flexibility on club head speed in older golfers. *Science and Golf IV*. p 36-44. World Scientific Congress of Golf Trust. Retrieved from http://books.google.com/books?hl=en&lr=&id=bmVk8BkOLH4C&oi=fnd&pg=PA35&dq=average+club+head+speed+for+golfers&ots=U1AMuZerq&sig=jaRlhEapFbusOq0i9kmCiu6qr6w#v=onepage&q=average%20club%20head%20speed%20for%20golfers&f=false

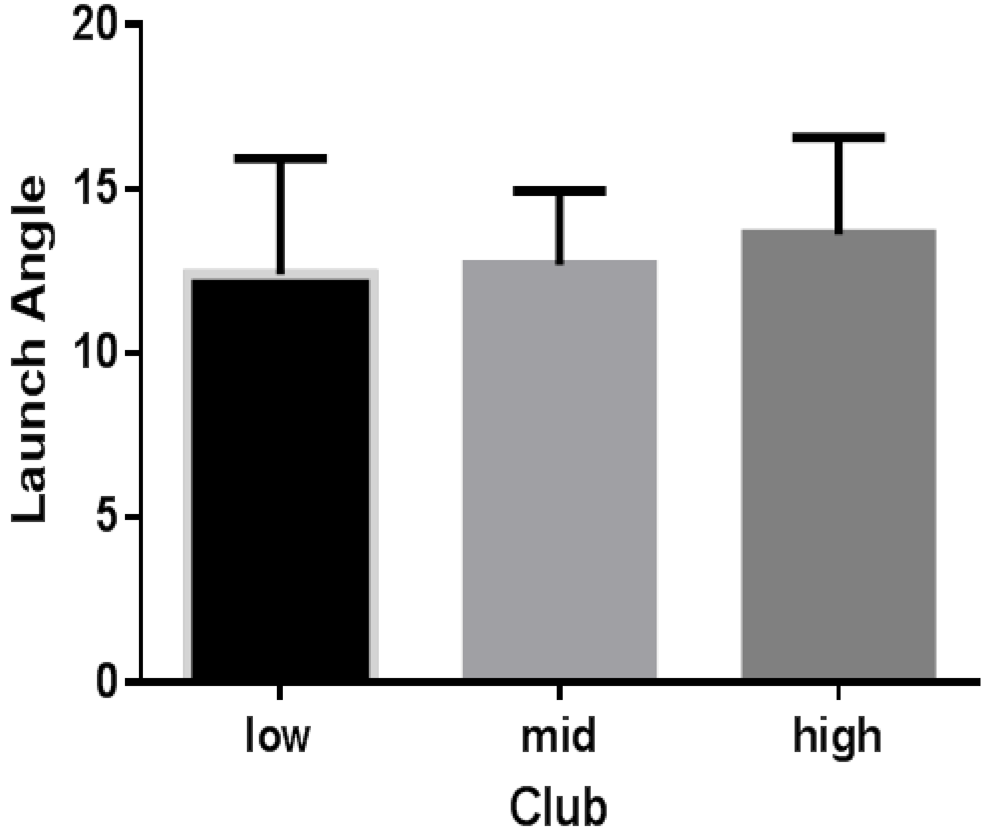
Thompson, C., Osness W. (2004). Effects of an 8-week multimodal exercise program on strength, flexibility, and golf performance in 55- to 79-year-old men. *Journal of Aging and Physical Activity.* 12 (2), 144-156. Accessed through PubMed. Retrieved http://www.ncbi.nlm.nih.gov/pubmed/15223883.

Walker, M. (1999). The physics ball sports. Department of Physics, University of Warwick, Coventry, England. 1-18. Retrieved from http://caiciss.co.uk/ball_sports.pdf

Werner, A. (2007). Flight model of a golf ball. College of Saint Benedict and Saint John's University. 1-13. Retrieved from http://www.users.csbsju.edu/~jcrumley/222_2007/projects/awwerner/project.pdf.

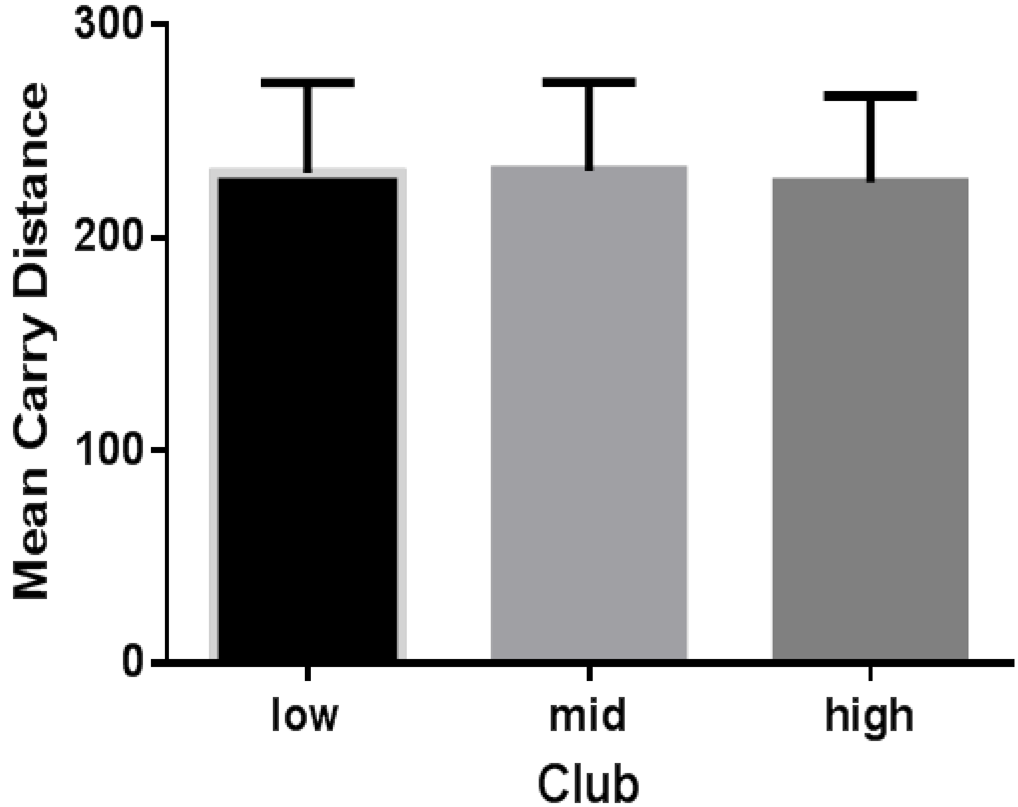
APPENDIX A

LAUNCH ANGLE, MEASURED IN DEGREES, COMPARED BETWEEN LOW, MID, AND HIGH LOFT


20
15
10
5
0
Launch Angle
low
mid
high
Club

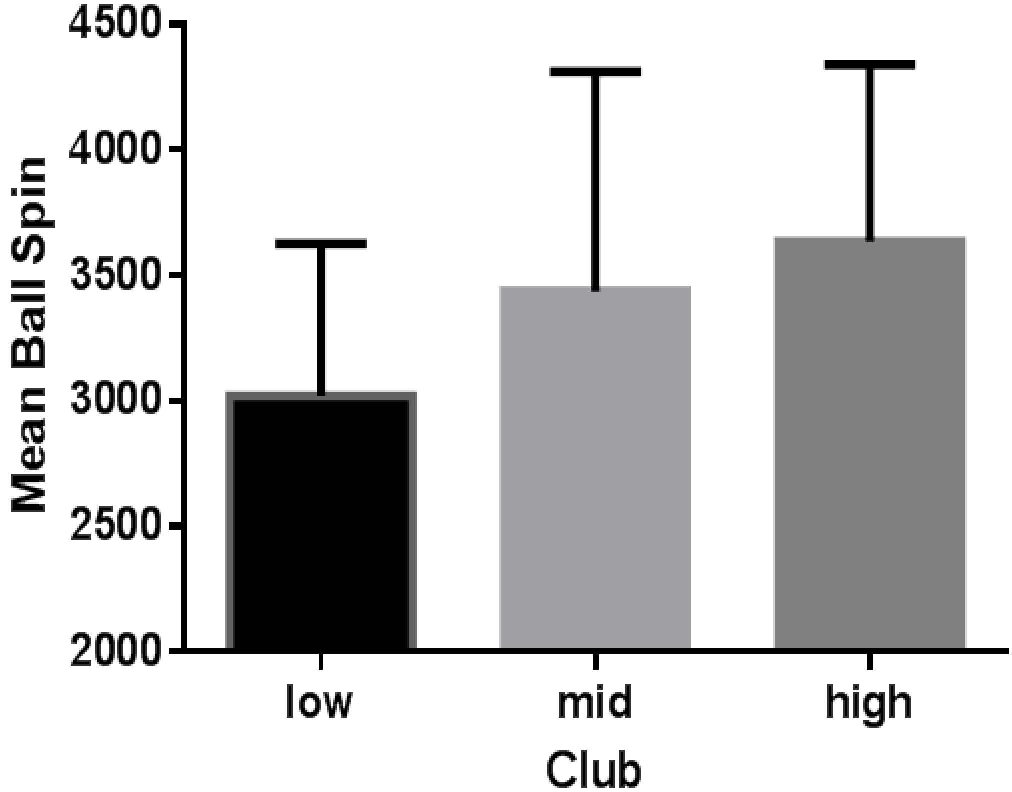
APPENDIX B

MEAN CARRY DISTANCE, MEASURED IN YARDS, FOR LOW, MID, AND HIGH LOFT CLUBS


300
200
100
0
Mean Carry Distance
low
mid
high
Club

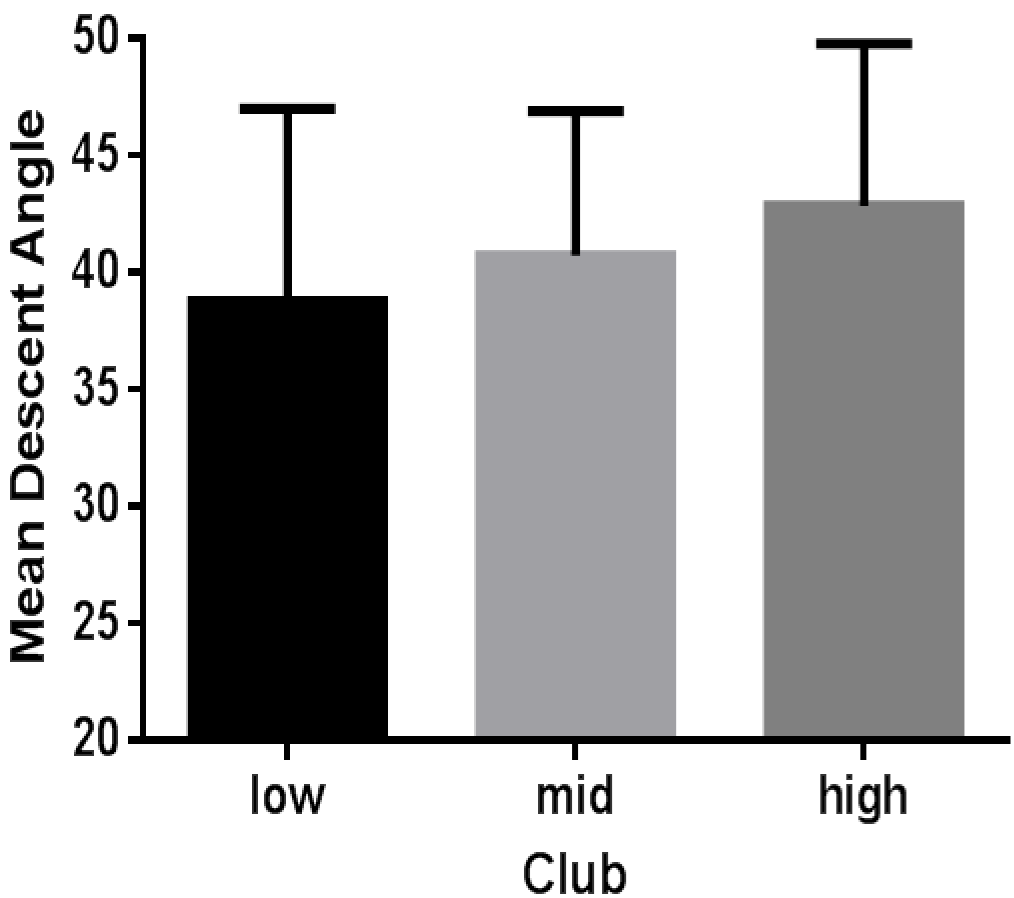
APPENDIX C

COMPARISON OF MEAN TOTAL BALL SPIN MEASURED IN REVOLUTIONS PER MINUTE


4500
4000
3500
3000
2500
2000
Mean Ball Spin
low
mid
high
Club

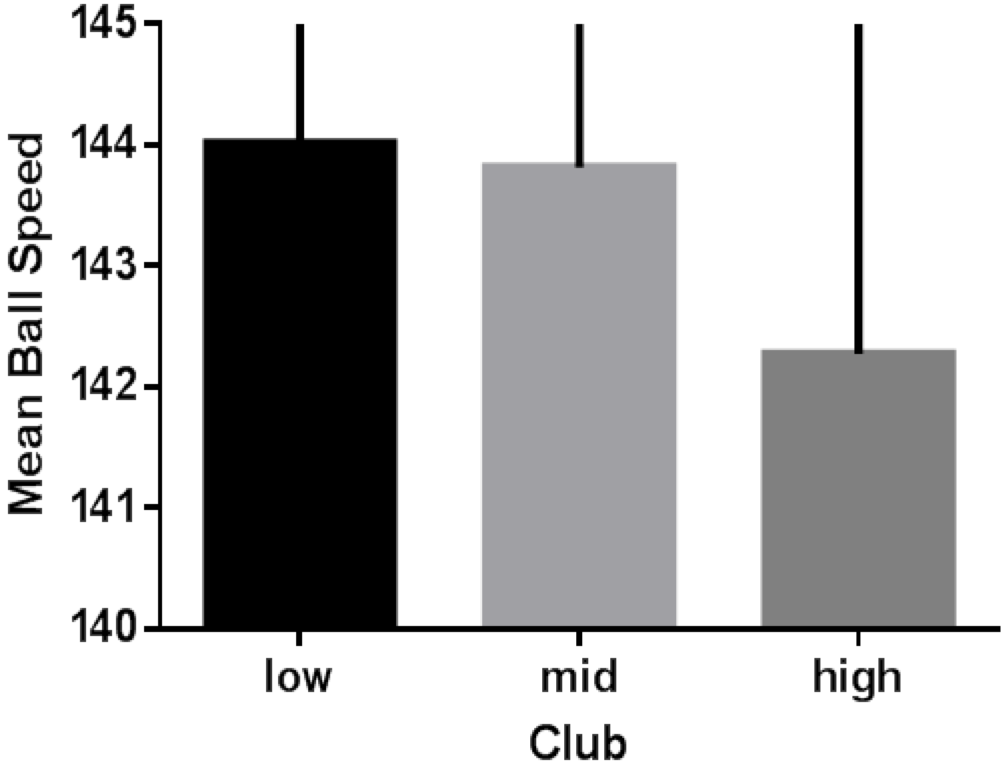
APPENDIX D

LOW, MID, AND HIGH LOFTED DRIVERS' DESCENT ANGLE MEASURED IN DEGREES


Mean Descent Angle
50
45
40
35
30
25
20
low
mid
high
Club

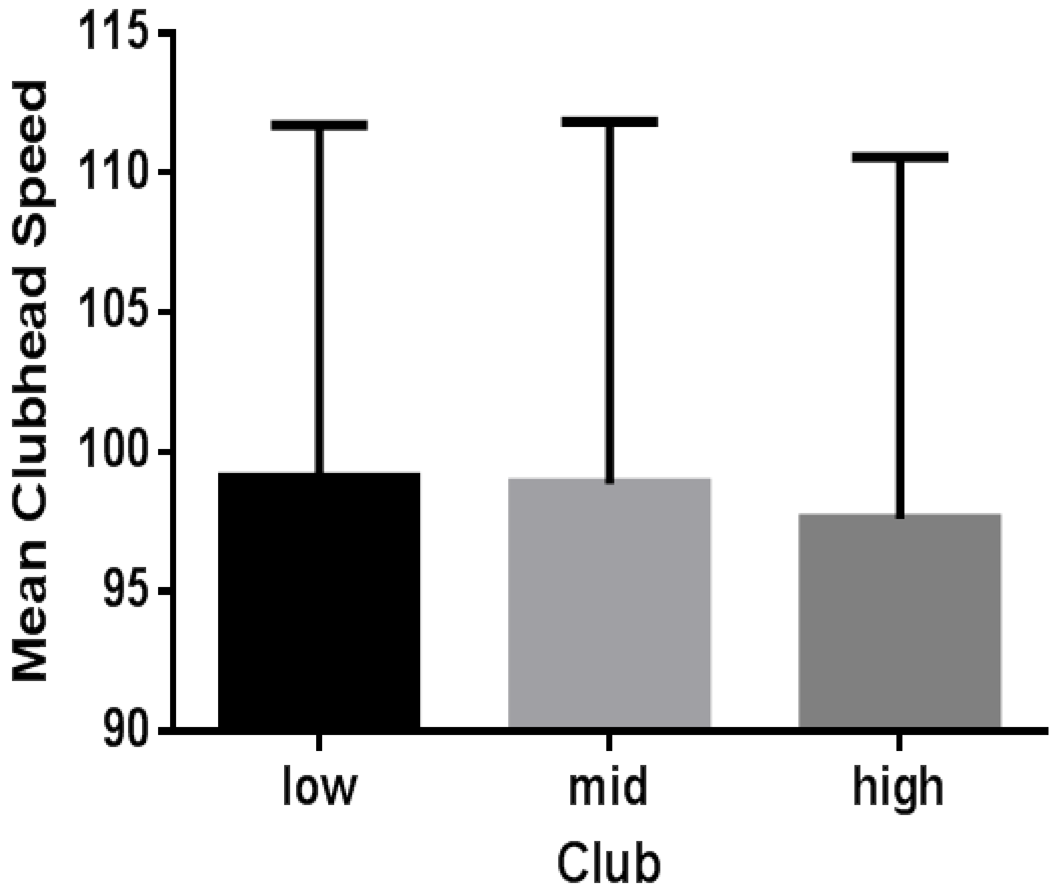
APPENDIX E

COMPARISON OF AVERAGE BALL SPEED, MEASURED IN MILES PER HOUR


145
144
143
142
141
140
Mean Ball Speed
low
mid
high
Club

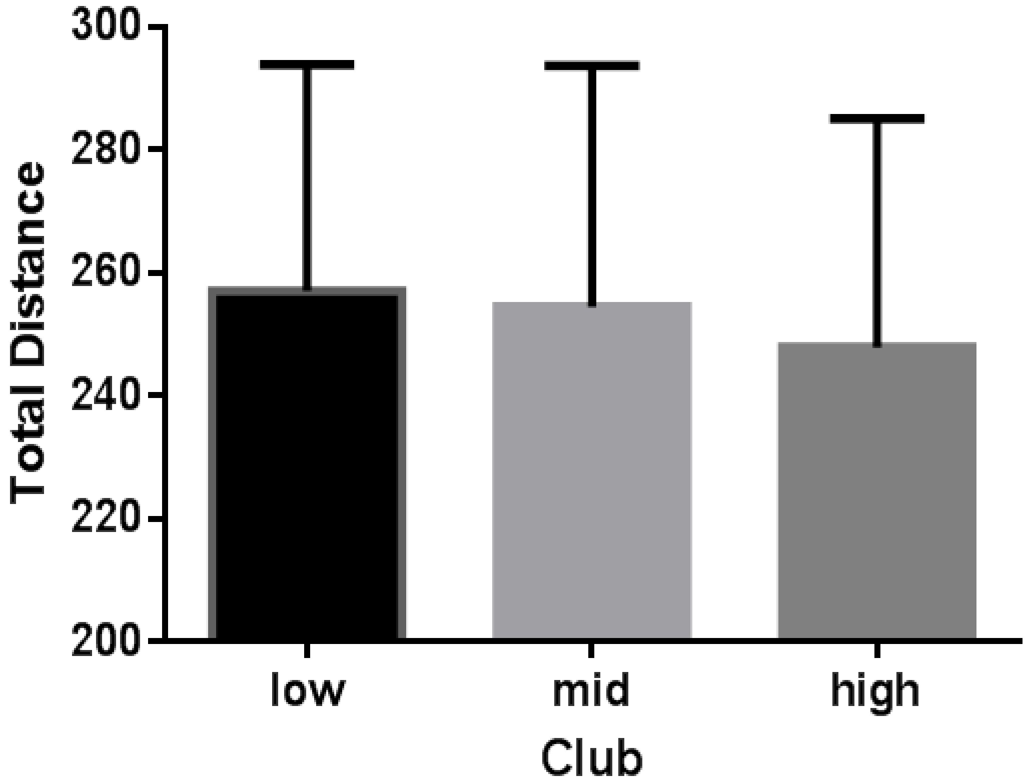
APPENDIX F

AVERAGE SWING SPEEDS FOR DIFFERENT CLUBS, MEASURED IN MILES PER HOUR


115
110
105
100
95
90
Mean Clubhead Speed
low
mid
high
Club

APPENDIX G

RESULT OF TOTAL DISTANCE FROM TESTED DRIVERS, MEASURED IN YARDS


300
280
260
240
220
200
Total Distance
low
mid
high
Club