DIFFERENCES IN BALL FLIGHT PARAMETERS AND IN KINEMATICS BETWEEN TWO GOLF SWING STYLES

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DEDICATION

This dissertation is dedicated to several people. Firstly to my mother, Kusum M. Desai, who thought her two daughters hung the moon. She would have been so proud of this achievement.

This dissertation is also dedicated to my husband, Deepak K. Kanwar and my son Karan D. Kanwar for their moral support (implicit?) and financial support (explicit!).

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ABSTRACT

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This study compared golfers' body and club kinematics with two swing styles (existing swings and The Optimal Performance Swing – TOPS), and two clubs (9- and 6-iron). The aims were to assess whether: (1) body kinematics associated with required TOPS positions and with performance, (2) club movements associated with ball direction and ball trajectory, (3) kinematics associated with low back pain – difference between thoracic and pelvic rotations at the top of the backswing (X-Factor); crunch range (difference between trail side lateral flexion at the top and at impact) and spinal forward tilt at address, would improve with the use of TOPS. Existing and TOPS swings were analyzed, and four TOPS training sessions were provided. Eleven Qualisys cameras collected kinematic data at 400 fps. Fifteen golfers (ages 18-73, handicaps +2 to -20), five females and 10 males, participated. They performed 10 shots per club, per swing style, and the five with the highest club speed were used for further analysis. Three 2 x 2 repeated measures multivariate analyses of variance were used to test the hypotheses. Significant main effects of TOPS across both clubs respectively were a shallowing of club angle of approach (4.84 ± 1.9° vs 2.55 ± 2.21°) and a more in-to-out path (0.13 ±

4.3° vs 3.53 ± 4.33°), as well as a thorax that was more rotated to face away from target at address (4.71 ± 4.61° vs -18.66 ± 7.31°) and impact (9.72 ± 9.09° vs -3.15 ± 7.93°), and had less lead side lateral flexion at the top of the backswing 32.71 ± 5.46° vs 24.12 ± 5.53°). Three important variables associated with low back pain - X-Factor (-45.27 ± 14.55° vs -36.8 ± 8.48°), crunch range (52.22 ± 9.6° vs 42.12 ± 7.74°), and thorax forward tilt at address (36.01 ± 6.99° vs 30.47 ± 6.02°) - were all reduced with TOPS. TOPS could be used for approach shots with the iron clubs by golfers requiring better direction and trajectory of ball flight, consistency of club speed, and a reduction in some kinematics associated with low back pain.

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CHAPTER I

INTRODUCTION

Golf is a popular sport played by over 60 million people globally, with approximately 24 million of them being from the USA alone (Statista, 2019). The game is typically played over 18 holes, and each "hole" comprises the entire distance from the starting point (tee box), to the end point, which is an actual hole located some distance away, on a finely-mown area of grass, termed a "green". The main concept in golf is to progress the ball from tee box to green to hole in as few shots as possible, with the total score being the sum of the scores of each of the 18 holes. Golfers do this with a variety of golf clubs and by using a full swing, or as the ball gets closer to the hole, a partial swing.

The full swing in golf is used when the requirement is to progress the ball a considerable distance accompanied by a good degree of directional accuracy, as the eventual target area is restricted. The full swing is used for the tee shot, which is the first shot of a hole; it is also used for the "approach" shot which is a shot expected to reach the green from some distance. This latter shot requires consistent distance, directional accuracy, and considerable trajectory for the ball to stay on the green once it lands.

The approach shot is considered by many to be the most important of all shots from tee to green, as it results in the golf ball either reaching the green (and thus making the next shot an easier one), or not. In the words of Columbia University Professor Mark Broadie (2015, para. 2), "I've analyzed a mountain of shot data, and one of my most important findings is that approach shots account for 40 percent of the scoring advantage that the best Tour pros have over average Tour pros.” Broadie added that it is the approach shot that matters for average golfers too, with 4 of the 10 strokes that separate a golfer who typically scores in the 90s from one who scores in the 80s being approach shots. For PGA Tour players, in fact, it is “greens in regulation” (green reached in two-under par, likely to result in a birdie or par), which has been most strongly correlated with earnings (Joyce, 2017). Greens in regulation are achieved with the approach shot clubs on holes with a par of four or five.

There is a general desire among amateur golfers to hit the ball further and straighter (more accurately), and among professional golfers to attain accuracy on a more consistent basis. The PGA Tour players are perhaps the best golfers in the world, and yet a look at their year-to-date statistics until the end of August 2019 shows that the number one ranked golfer for driving distance (i.e., while using the longest golf club – the driver) was ranked 175th of 196 for accuracy. Of the top 10 golfers in distance, the best rank for accuracy was 104th. The rest of the top 10 longest drivers on the PGA Tour had accuracy rankings of 153rd or worse (“Driving distance. Y-T-D-statistics through: TOUR Championship”, 2019; “Driving Accuracy Percentage. Y-T-D-statistics through: TOUR Championship”, 2019). It may thus be said that all golfers, both amateur and professional, require good distance as well as the accuracy of direction and the optimization of trajectory, for their full swing shots. Moreover, for the approach shots, consistency of club speed is important, as it would help the ball to stay on the green rather than remain short of, or go past, the green.

The full swing can have a variety of styles with which it is performed. Historically, the swing used to be comprised of body movements that were said to be in the "classic" style. However, after famous golf professional Jack Nicklaus popularized the "modern" swing in the 1960s when he demonstrated that it could give golfers better ball distance and trajectory, the "modern" swing became more frequently used, especially among professional golfers (McHardy, Pollard, & Bayley, 2006). Most golfers today have swings that could be considered to have some elements of both the classic and the modern swing styles (McHardy et al., 2006). When a swing is analyzed, it is typically broken down into several phases, the most important of which are the backswing movement away from the ball, the downswing movement towards the ball, and the follow through which involves the deceleration of the swing past club-ball impact to the end or "finish" position.

The golf swing has been said to be "one of the most difficult biomechanical motions in sport to execute" (Nesbit & Serrano, 2005, p. 520), which might help to explain the lack of distance, direction, and consistency among golfers of all skill levels. The movement has also been described as a "complex movement involving the whole body" which "requires a coordinated sequence of muscle activity" (McHardy & Pollard, 2005, p. 799). Such a coordinated movement involves, among other aspects, a proximal-to-distal kinematic sequence during the downswing. In such a sequence, "The motion is initiated with the larger, heavier, slower central body segments: then, as the energy increases, the motion proceeds outward to the smaller, lighter and faster segments" (Marshall & Elliott, 2000, p. 247).

Sequencing of body segments at the start of the downswing is assessed as a primarily transverse plane rotation of the pelvis preceding that of the thorax (Myers et al., 2008), while at the top of the backswing (Zheng, Barrentine, Fleisig, & Andrews, 2008) there is a complex combination of trunk rotation to face away from target (60 ± 7° for professionals, less for amateurs), and trunk lead side lateral flexion (-9 ± 12° for professionals). How would the larger segments that are moved obliquely during the backswing, with the shoulders being required to rotate around the spine ("Reverse spine angle," n.d.), begin to move in a predominantly transverse plane at the start of the downswing? Moreover, the arms, connected to the thorax at the shoulders, move in quite disparate planes during the backswing, as has been observed through the motion planes of some shoulder/arm points (Kwon, Como, Singhal, Lee, & Han, 2012), making the entire movement even more complex. Given the complexity of the change of direction movements, golfers often initiate the downswing with the shoulders and arms, and this out-of-sequence motion is colloquially termed an "over the top" one. It results in several types of poor-quality golf shots (Henderson, 2014). A further layer of complexity is added because the many movements that comprise the golf downswing must all be completed in the approximately one-third second that the swing phase lasts, for all skill levels of male and female golfers (Horan, Evans, Morris, & Kavanagh, 2010).

Correct proximal-to-distal or kinematic sequencing of the torso is one of many movements that have been identified as important generators of club speed. Other speed-creating movements include "weight-shift" (Hume, Keogh, & Reid, 2005), which involves a lateral shift of the body away from target during the backswing and, more importantly, towards target during the downswing. The vertical lift of the target-side of the thorax close to impact has also been claimed to be an important movement for the creation of club speed, because it serves to lengthen the arm-club lever (Sanders & Owens, 1992). Downswing "wrist release" is another movement that has been described as a creator of speed (Fleisig, 1994); although one review article has stated that downswing ulnar deviation of the wrists is not an important factor in increasing club speed (Lamb & Glazier, 2017).

The movements of the golf swing that are correlated with club speed, which is the main determinant of ball speed, have been researched exhaustively, while no studies have assessed movements which may be related to either directional accuracy or the production of ideal trajectory. Movements that might help to attenuate the injury-causing mechanisms of the swing have also not been researched. Any sports-movement assessment should ideally study what might improve the effectiveness, and simultaneously the safety, of the overall motion.

One golf swing, The Optimal Performance Swing (TOPS), may simultaneously improve consistency of shot distance, directional accuracy, and ideal trajectory, while also increasing some of the safety aspects of the movement. TOPS simplifies the golf swing movement by reducing the overall degrees of freedom involved, so that the central nervous system in not as greatly taxed in its role of having to "address (and solve) problems of coordination, timing and interaction between different neural, muscular and skeletal structures" (Hogan, 1985, p. 315). Specifically, TOPS eliminates those movements that have not been significantly associated with club speed, and reduces the range of motion of those that have been related with club speed, so that the application of force is minimal, and precisely positioned and timed.

TOPS incorporates two main departures from any typical golf swing. It achieves that by a separation of the movement of the torso from that of the arms. The torso is required to rotate to face away from the target, and on the transverse plane only, during the set up or “address” phase. Then, during the backswing, only the arms are allowed to move, so that there is no up-and-down or side-to-side movement of the torso during that phase.

The avoidance of a lateral flexion (side bending) movement during the backswing helps to keep the lead (left, for a right handed golfer) side of the torso, especially the lead shoulder, higher throughout that phase, in order to attempt to produce a longer arms-club lever as well as a shallower angle of approach (the descending or ascending path of the club with respect to the ground as it approaches the ball) to the ball for better ball trajectory (Sanders & Owens, 1992). Secondly, because TOPS’s prebackswing torso rotation is mainly on a horizontal, and not oblique plane, a transverse-plane downswing sequence of the pelvis before the thorax may be more easily accomplished. A correct sequence is said to improve both shot distance and accuracy (Cheetham et al., 2008; Tinmark, Hellström, Halvorsen, & Thorstensson, 2010). Moreover, the plane of torso rotation also helps to keep the golfer’s back facing away from target during the downswing, reducing the likelihood of an out-of-sequence, shoulders-before-pelvis, over the top movement.

TOPS is also expected to reduce some of the kinematics closely associated with low back pain. They include the X-Factor (difference between thoracic and pelvic horizontal rotations as the top of the backswing), the range of crunch (the difference in trail side lateral flexion between the top of the backswing and impact), and spinal forward tilt at address. The latter is expected because TOPS requires the golfer to stand as upright as comfortably possible based on the length of the club being used, at address.

This study was therefore designed to assess how TOPS, as compared to a golfer's existing swing, would affect club performance, and kinematics which have been associated with either performance or with low back pain, during swings made with the 9-iron and 6-iron approach clubs.

Purposes

The purposes of this study were to assess the effects of:

1. Two different swing styles and two different golf clubs on thorax (torso) rotation and lateral flexion at specific events during the set up and swing.
2. Two swing styles and two clubs on club movement.
3. Two swing styles and two clubs on X-Factor, crunch range, and spinal forward tilt at address, all of which have been implicated in low back pain.

Hypotheses

1. The thorax will be more rotated to face away from target at the swing events of address and impact, will have less lead side lateral flexion at the top of the backswing, and will have greater lead side vertical lift at impact with the use of TOPS, as compared to golfers' existing swings.

2. The club’s angle of approach will be shallower, and the club will arrive at the ball from a more inside (closer to the golfer’s body) path when using TOPS.
3. TOPS will significantly reduce some mechanical factors associated with low back pain: X-Factor rotation at the top of the backswing; crunch range between the top of the backswing and impact; and spine forward tilt at address.
4. Club speed with TOPS will stay the same or increase slightly (exploratory hypothesis).

Significance of Study

Golf is a sport with known health benefits (Oja et al., 2015), and yet millions leave the sport, with approximately 4.1 million having left the sport in 2013 alone (Picchi, 2014). One of the main causes cited is that golf is too “hard” (Newsham, 2016). If a golf swing involving less moving parts could give golfers improved performance as well as greater safety, perhaps more golfers would remain in the sport. Additionally, a swing with specific steps would make the training of the movement easier for coaches, and fault-fixing simpler for golfers. This study focused on kinematic changes in order to be of more immediate benefit to golfers and golf coaches with respect to which positions and movements are beneficial for better club, and thus ball, performance for the approach shots hit with the iron clubs. Moreover, this study was the first to use a completely different swing that changes several elements of a golfer’s existing set up and swing, and yet was expected to be able to show beneficial kinematic changes within the limited number of four training sessions.

Assumptions

1. The human body is comprised of a collection of segments, each of which is a rigid body.
2. All body segments are linked through joints that are frictionless pin joints.
3. The length of a segment does not change during movement.
4. Information provided by participants regarding their golf experience as measured by handicap or typical scoring ability, was accurate.

Delimitations

1. Participants were expected to be experienced golfers who had played at least 20 times during the past two years.
2. The golf handicap or typical scoring ability of participants over 18 holes of golf was restricted to a maximum of 24 over par.
3. Participants were required to have a minimum age of 18 years.
4. Only right-handed golfers were included in the study because of laboratory design constraints.

Limitations

1. Smash factor (ball speed ÷ club speed) represents the transfer of energy from the club to the ball, and is a key indicator of swing efficiency. It was not assessed in this study, although it was expected to be significantly greater with the use of TOPS.
2. Club face angle (the aim of the clubface to the right or left of the target line at impact) which is an important determinant of ball direction, and club dynamic loft

(the vertical angle of the clubface at impact), which affects ball trajectory, were not measured.

3. The golf ball's starting speed, trajectory, and direction were not measured.
4. Preintervention swing styles were not differentiated between, nor categorized.

Definitions

Backswing – the movement of the golf club away from the ball. The start of the backswing phase was assessed as being the event when the club's speed first reached 0.2 m/s.

Ball flight – the distance, direction, and trajectory achieved by the golf ball as a result of club-ball collision.

Ball flight parameters – includes club positions and movements at impact, as well as golf ball flight information.

Club angle of approach, or club angle of attack – the descending or ascending path of the club with respect to the ground or horizon as it approaches the ball. In other words, the vertical direction of the movement of the club head's center at impact. It is related to the ball's trajectory.

Club path – the direction of the movement of the club head – right or left with respect to the target line, close to impact. It can be in-to-out (starting closer to the golfer's body and moving further away from it) or out-to-in (starting further away from the golfer's body and moving closer to it). It is related to the ball's direction.

Club speed – the speed of the club head at impact. It is closely related to ball speed.

Club's loft – the angle of the clubface compared to a vertical plane.

Club's sole – the surface of the club head closest to the ground.

Closed position of shoulders – golfer's shoulders facing away from the target (opposite of "open" position of shoulders).

Closed position of pelvis – rotation of the pelvis to face away from the target (opposite of open position of pelvis).

Crunch – the difference in the lateral flexion angles of the thorax between the top of the backswing and impact.

Downswing – the movement of the golf club from the top of the backswing, up to impact.

Driving distance – the total distance travelled by a ball when hit with a driver club. It includes the "air time" or "carry" distance and the "ground time" or roll distance.

Fairway – The well-mown part of a "hole"; it runs from tee to green.

Force – a push or a pull upon one object by another.

Frontal plane – one of three planes of motion in which the human body is capable of movement. A vertical plane that divides the human body into anterior and posterior halves.

Hole – in golf, this refers to both the entire distance between the starting and end points of one of 18 segments to be played on a standard length golf course, and to an actual hole of 4.25-inch diameter located on the "green."

Hub, hub center – the center of rotation of the body or the club.

Impact – the event during which the golf club first connects with the ball. Assessed as the position when the clubhead's targetward axis (Y-axis) is 0.02 m (ball radius) away from the ball.

In-to-out – one of two paths of the arc of the clubhead when it is close to impact during the downswing. The opposite is an out-to-in path. Both are with reference to the target line. "In" implies between the golfer and the target line, while "out" implies further from the golfer than the target line.

Kinematics – a branch of mechanics that studies movement, without considering the cause of that movement.

Lead side – the side of the golfer closer to target (left, for a right-handed golfer).

Par – the score an expert player would be expected to make for a particular hole. Any hole in golf, depending on the distance between tee box and green, among other factors, can have a par of three, four, or five.

Sagittal plane – one of three planes of motions in which the human body is capable of movement. A vertical plane that divides the human body into left and right halves.

Set up or address – the position the golfer assumes before the backswing commences.

Top of backswing – the event that takes place when the club is at the end of its backswing movement away from the target; assessed as the lowest clubhead speed during the change of direction from backswing to downswing.

Torque – the rate of change of angular momentum (similar to force, which is the rate of change of linear momentum). Moment, often used interchangeably with torque, is the tendency of an applied force to cause rotation (about an axis).

Torso – thorax and pelvis together. Also used interchangeably with trunk, in which the upper trunk may be considered the thorax, and the lower trunk, the pelvis.

Trail side - the side of the golfer further away from target (right, for a right-handed golfer).

Transverse plane - one of three planes of motion in which the human body is capable of movement. A horizontal plane that divides the human body into superior and inferior halves.

Trunk lateral flexion – side bend of the thorax segment of the body to the right or the left. A frontal plane movement.

Vertical ground reaction force – the vertical component of the force exerted by the ground on an object.

Vertical lift – also referred to as "launch"; a movement of the lead side of the thorax upwards (or the trail side downwards), during the downswing, close to impact.

Weight shift – a movement of the body's center of mass, either away from, or towards, target. Also, a shift of vertical force under the feet away from, or towards, target.

X-Factor – the difference in the horizontal rotation angles between the thorax and the pelvis at the top of the backswing.

CHAPTER II

REVIEW OF THE LITERATURE

Introduction

The golf swing is known to be a complex and difficult-to-execute movement (Nesbit & Serrano, 2005), with professional and amateur golfers alike producing inconsistency with respect to directional control, trajectory of ball flight and the distance the ball travels. Additionally, golfers are prone to injury, regardless of their skill level. It is essential to understand the current level of complexity of a typical swing before considering the need for, or a method of, swing simplification.

Most golf biomechanics research has studied ways in which club, and thus ball, speed might be increased, while very limited research has focused on the mechanisms for directional accuracy, trajectory, or even for injury. Moreover, existing research involving the golf swing is typically based on comparisons between skilled and unskilled golfers, male and female golfers, or injured and uninjured golfers, while they use a variety of different golf clubs. Limited research exists on the effect of a swing intervention on swing kinematics and the resulting changes to performance measures such as club, and thus ball, movements (comprising ball distance, direction, and trajectory).

This review of the literature explores golf swing-related biomechanical research that reflects past and present concepts which are considered to be important for the successful performance of the golf swing, or for the reduction of injury potential to the lumbar spine. The review begins with an overview of the biomechanics of a typical golf swing. The movements and/or forces known to produce greater club speed (closely related to ball speed), a suitable vertical angle of approach to the ball (partially responsible for ball trajectory), and desirable club path (partially responsible for ball direction), as well as those implicated in low back pain have been reviewed. Finally, a case has been made for a specific method of simplification of the movements involved in the swing, based on factors that may contribute to improving a golf swing's performance and reducing its potential for injury.

Strategy for Literature Search

Literature relevant to the purpose of this study was sourced through an electronic search. The databases used were PubMed, CINAHL Complete, ProQuest Nursing & Allied Health Database, Scopus, SPORTDiscus, Physical Education Index, and Google Scholar. Common keywords, search terms/phrases, and filters used were "golf," "human," "English," and "all adult."

To access research on factors influencing performance in golf, the terms "biomechanics" or "biomechanical phenomena," along with "performance" or "club speed" or "accuracy" were used. To source research on lumbar region injury, the terms used were "etiology" or "cause" or "mechanism," along with the word "lumbar." Additionally, together with golf and injury, "spine" or "lumbosacral region" or "back injuries" or "low back pain" were all used. The Proceedings of the World Scientific Congresses of Golf of 1990, 1994, and 1998 were also searched, and hand searches were performed using Google Scholar to source specific terms. No restrictions were placed on publication dates. Inclusion criteria were studies with adult participants. Exclusion criteria were journal articles using mathematically developed simulation models of the golf swing.

Overview of Golf Swing Biomechanics

Golf researchers have described the biomechanical concepts that relate both to the movements of the golf swing and to the forces that cause those movements. They do so, typically, by dividing the swing into five stages, which are set up, backswing, transition, downswing and follow-through (Fleisig, 1994). Set up, also referred to as the “address” position, is the starting posture. The backswing is the phase from address to top of backswing, at which time the club changes its direction of motion. The downswing takes place from the top of the backswing to club-ball contact. Finally, the follow-through is the movement after impact, and up to the finish of the swing. A compilation of the biomechanics – both kinematics and kinetics - involved in the different phases of the movement as described in some well-known review articles has been presented here. One particularly detailed earlier review was written by Fleisig (1994) in a book titled *Feeling up to Par: Medicine from Tee to Green*, and a later one can be found in a journal article titled “The Role of Biomechanics in Maximizing Distance and Accuracy of Golf Shots” (Hume et al., 2005).

Set up and Backswing

The main aspects of the set up (Fleisig, 1994) are the grip, ball position, weight distribution, stance width and the position of the hips, shoulders, and knees. At this stage, the author suggests that a line from the lead-side to the trail-side shoulder should be titled

15º downwards (lead shoulder higher than trail) and 15º "open" (facing towards target). For the longest club, the driver, the trail knee should be flexed by about 45º and the trunk should also be flexed forwards by 45° from vertical.

The Hume et al. (2005) review, reporting the same positions, states that the knees should be flexed by about 20º - 25º. The trunk should have a forward flexion - primary spinal angle - of 45º, and should also have a trail-side lateral shoulder tilt of approximately 16º, which is termed the secondary spinal angle (similar to Fleisig's 15º downward tilt of the trail shoulder). This secondary tilt is a combination of spinal lateral flexion and a downward movement of the trail arm and scapula, a result of the trail hand being lower than the lead one during the golf grip. The grip, considered to be an essential part of the set up, is said to change the manner in which the ball moves after leaving the club. The posture as described by the authors is thought to be optimal for generating power during the swing. Overall, according to Hume et al., the set up should serve to align the golfer in the direction of intended play and should be an opportunity to establish dynamic and static balance.

At the start of the backswing, the club is moved as the trail foot applies anterior shear force and the lead foot a posterior one, producing a clockwise torque in the torso, which produces a rotation that transfers up the body. The knees, hips (more correctly pelvis), lumbar and cervical spines rotate in that order, while the head remains fairly still. The lead arm is, as the movement continues, flexed forwards and adducted. Both wrists are radially deviated. Also at this stage, the force through the feet is in an away from target direction (Fleisig, 1994). Additionally, according to McCarroll (1994) who wrote a chapter in the same book as Fleisig, the lead hip is rotated, the lead foot rolls inwards towards the trail one, and the lead knee moves until it points behind the ball (away from target) by the top of the backswing.

Hume et al. (2005) stated that there are some important purposes that the backswing must fulfil. It must provide a base for the kinetic chain movement of the downswing, and it should stretch the power-generating muscles so they can contract forcefully during the downswing. The first part of the backswing – the takeaway – should be one-piece, with the arms maintained as a triangle, and during the rest of the movement, the shoulders, and then the hips, should rotate while the arms travel upwards. The club's shaft should travel on a plane, but as the authors explain, the concept of swing plane is controversial. Kwon, et al. (2012) have shown that the club does not travel on one specific plane throughout the motion.

Another commonly advocated backswing move is a "weight shift" of the golfer's body away from target during the backswing. This concept too, according to Hume et al. (2005) has been shown to be a controversial one, with most golfers rotating the torso around a fixed base of support rather than shifting the body laterally in a direction away from target. Finally, at the end of the backswing, the lead arm is adducted across the chest and internally rotated, the lead elbow is extended, and the trail shoulder is abducted and externally rotated. The wrists are "cocked," which means that an angle is created between the lead forearm and the clubshaft.

Transition, Downswing, Impact, and Follow through

The first movement of the golfer towards target has often been referred to as "transition". It is a brief phase between the backswing and the downswing during which the golfer shifts weight back towards the lead foot while the club is still completing the backswing (Fleisig, 1994). The transition phase has also been described as the time during which the pelvis starts to move towards target while the thorax continues to move to face away from target (Sim, Choi, Lee, & Mun, 2017).

After the transition phase, the golfer continues weight shift towards target, while at the same time there is an anterior push through the lead foot and a posterior one through the trail foot. This force couple affects the upper pendulum of the "double pendulum" model. The double pendulum model is an early biomechanical concept, in which the upper pendulum is said to consist of a golfer's shoulders and arms; the lower one comprises the club, while the golfer's wrists serve as the hinge between the two levers. The hinge is said to work only in one plane, and the upper lever is swung about a fixed central hub (Burden, Grimshaw, & Wallace, 1998).

During transition and the early part of the downswing, oppositely-directed forces are seen in golfer-ground interaction, and they create a torque that is passed up the body, while the gluteal, quadriceps, hamstring, and paraspinal muscles add to the torque and force. The torque results in a counterclockwise (when seen from above) acceleration of the upper pendulum. The muscles of both shoulders are active, and the hands "lag" or remain in radial deviation, thus applying a negative torque to the system. A delayed lag is said to allow greater velocity of the upper pendulum as it reduces the moment of inertia of the involved segments. The delay between upper- and lower-pendulum accelerations adds to the total velocity achieved by the club. Once the club is close to horizontal during the latter part of the downswing, the wrists begin to ulnarly deviate, creating a “release” of the hands, which causes the lower pendulum of the club to accelerate as the upper one consisting of the shoulders and arms begins to decelerate (Fleisig, 1994).

Some researchers divide the downswing into two phases, the forward swing followed by the acceleration phase (Hume et al., 2005), and claim that the main purpose of this latter phase is to return the club to the ball with maximum speed and on the correct plane. One important aspect of the downswing is the “kinematic chain,” also known as a proximal-to-distal sequence. This sequence starts at the legs and pelvis and is followed by a movement of the shoulders, arms and finally the club (Chetham et al., 2008). While the downswing movement is said to be initiated by the trunk muscles, golfers are told to maintain cocked wrists for as long as possible during the downswing.

The average time taken by expert golfers to complete the entire downswing is 0.23 s. This time can be slightly greater for less-skilled golfers, up to an average of 0.34 s (Burden et al., 1998; Zheng et al., 2008).

The end of the downswing results in club-ball contact, or impact, which lasts for approximately 0.0005 s. By this time the lead foot supports most of the body’s load, with skilled golfers having more weight in the lead heel, and less-skilled golfers having weight closer to the lead mid-foot area (Fleisig, 1994).

The follow through takes place after impact, and should decelerate the upper and lower pendulums without requiring excessive effort from the muscles according to

Fleisig (1994), and by using eccentric muscle action according to Hume et al. (2005). During this phase, the lead forearm supinates while the trail one pronates, and the lumbar and cervical spines rotate and then hyperextend. Hip rotation is completed, the trail knee flexes, the trail heel is lifted off the ground, and the lead ankle supinates. Some golfers extend their spines into a reverse "C" shape at the end of the follow through, during the finish position (Fleisig, 1994). Overall, the finish should be a balanced pose with the golfer's torso facing target (Hume et al., 2005).

Golf Swing Styles

No two golfers have identical swings, but rather use some combination of movements of the "classic" and "modern" styles, usually based on their age, flexibility, and body type with respect to height and weight. The main differences between the classic and modern styles have been described by McHardy et al. (2006). The classic swing has, during the backswing, late wrist "cocking" (a combination of wrist radial deviation and extension (Hume et al., 2005); equal amounts of shoulder and pelvic rotation; a large amount of movement towards the trail side; and most of the lead foot off the ground. The entire body initiates the downswing, until, at impact, the hips are level with the shoulders, and there is only limited trail side trunk lateral flexion. Finally, in the forward swing, momentum is directed towards target, and the low back remains in a neutral position at the finish.

Conversely, the modern style first popularized in the 1960s, exhibits, during the backswing, early wrist cock; limited pelvic against maximum possible shoulder rotation; limited body movement towards the trail side; and a lead foot fully planted on the ground.

Then the downswing is initiated by a rotation of the hips, followed by that of the shoulders. Impact has considerable trail side lateral flexion, with momentum being directed upwards, and finally, there is hyperextension of the lower back at the finish.

Based on structural constraints, golfers may be coached to, or be more capable of, specific aspects of the classic and modern movements. For instance, in a study of male and female professional golfers (Zheng et al., 2008), females had significantly greater pelvic rotation at the top of the backswing compared to males (49 ± 8° vs 42 ± 7°), as well as significantly greater shoulder rotation (109 ± 7° vs 100 ± 8°). The greater pelvic rotation observed in females might be termed a more classic style.

Golf swing instruction. The above general description of the many movements involved in any golfer's swing serve to indicate that it consists of "highly complex multi-joint motions" (Keogh & Hume, 2012, p. 291) involving all the major segments of the torso and limbs. Moreover, the swing is difficult to teach as there are many factors to be considered while deciding how to make swing improvements.

A typical starting point for a golf instructor hoping to improve the ball flight of a student may be found in the seminal work "Laws, principles and preferences – a teaching model" (Wiren, 1990). According to that paper, in order to produce desired ball flight (distance, direction, and trajectory of a shot), a golf coach must navigate through 14 "principles" and scores of "preferences" to select what might work best for each student. The ideal combination of torso and upper extremity movements that might suit an individual golfer have never been described by either the golf coach or the golf researcher communities. No explicit guidelines have ever been provided for specific positions and movements of the body's many segments, nor for what order they should move in, and to what extent. This lack of specificity of how precisely a golfer might swing to maximize swing effectiveness, efficiency and safety based on human joint constraints may serve to make any individual's movement an increasingly more complex movement that required. That is because several movements, at many joints, moving in up to three planes of motion, must take place in quick and correct succession for the successful execution of the movement.

As a result of the many facets involved in a typical swing, researchers have extracted small parts of the puzzle that constitutes the movement, and assessed limited aspects of those features. They have focused, mainly, on the kinematics and kinetics that correlate with club speed, with little research having been conducted on the kinematics that might improve directional accuracy or the trajectory of the golf ball. Similarly, little research exists on the positions, movements, and loads that may help to reduce the potential for injury from mechanical causes.

Kinematics and Kinetics for Club Speed

Several movements have been correlated with the production of greater club head speed in golf. A few have also been correlated with movements which may result in better directional accuracy of the golf ball.

Lateral weight shift. Weight transfer or weight shift is a term commonly used by golf coaches to explain a lateral bodily movement of a golfer towards target during the downswing. In golf-biomechanics research, it has been varyingly assessed as the ground reaction force readings from force plates, the kinematic calculation of the whole-body center of mass movement, or as changes in foot pressure patterns measured with the use of pressure-sensitive devices. It has been discussed in greater detail in the golfer-ground interactions section of this document.

Backswing stretch shortening cycle. It has been said, for many sports, that the stretch-shortening cycle of muscle activity can be used to increase the force and speed of any movement. The stretch-shortening cycle involves a combination of eccentric (muscle lengthening), followed by concentric (muscle shortening) action, which is said to enhance performance during the concentric phase of a movement, compared to a merely concentric action (Komi, 2000). The stretch-shortening cycle is expected to increase the elastic energy of the involved muscle groups. One constraint for the utilization of the stretch-shortening cycle effect in the golf swing is that the downswing should quickly follow the backswing without much delay. It also requires a greater rate of stretch during the backswing, such as seen in professional golfers who tend to have faster backswings (Hume et al., 2005).

One swing concept that is said to generate a stretch-shortening cycle in golf is the X-Factor. The movement is distinguished by limited pelvic- versus considerable torso-rotation during the backswing, and is said to be able to produce more force because of its greater potential for muscle stretch followed by shortening. It is an important aspect of the modern golf swing. It was a notion devised by a leading golf instructor, Jim McLean, based on his assessment of the movements of the top and bottom five professional male golfers in ball driving distance. Those who hit the ball the furthest had what he termed was the X-Factor (Schiffman, 2010).

The maximum X-Factor differential between shoulder versus pelvic rotation was reported in a study by Burden et al. (1998). Their sample of eight male amateurs of mean golf handicap 7 ± 1, using a driver club showed a difference between shoulder and pelvic rotation of 70 ± 20°. The hip angle here was defined as the angle between the hip joint centers and a line connecting the ball to the target (target line). The shoulder angle was the angle between the shoulder joint centers and the target line. The maximum difference between the shoulder and hip angles was reported by the authors as the X-Factor.

Zheng et al. (2008) compared the X-Factor angle between 25 male and 25 female professional golfers, all of whom used a driver. The shoulder vector was described as the line joining the acromion processes, while the pelvic vector joined the greater trochanters. These two vectors were projected to the plane of the ground to measure their absolute and relative rotation angles. At the top of the backswing, females had 109 ± 7° shoulder, and 49 ± 8° hip orientations, while males had 100 ± 8° and 42 ± 7° orientations respectively for the same vectors. Both orientation angles were significantly greater for females than for males. Zheng et al. observed that females had greater rotation of both the pelvis and the shoulders at the top, but had 10% less maximum trunk angular velocity. Zheng et al. opined that females might depend upon greater lower body strength and thus rotation, because of relatively less upper body strength.

There is conflicting evidence for the correlation between X-Factor and greater club or ball speed, and this is said to be mainly a result of the method of measurement. Some methods of measurements were deemed incorrect as they were two dimensional, while others were claimed to be inappropriate because shoulder rotation was excessively large when measured at the shoulders rather than at the thorax (Keogh & Hume, 2012; Kwon, Han, Como, Lee, & Singhal, 2013).

While the X-Factor may or may not be a reason for more club speed among professional golfers, it is said to create torsion in the lower spine and thus might be a likely cause for lumbar spine injury (Gluck, Bendo, & Spivak, 2008). Moreover, the X-Factor of the modern swing probably does not facilitate much stretch-shortening of the powerful hip lateral rotator group of muscles, because of the intentional limiting of backswing pelvic rotation. However, these muscles are expected to develop a rapid and powerful downswing contraction despite limited backswing stretch, as seen through the 100% activation of the trail side gluteus maximus during the forward swing (Loock, Grace, & Semple, 2012).

Finally, Aggarwal, Shenoy and Sandhu (2008) compared muscle activation pattern differences between the classic swing style (equal pelvic and shoulder rotation) and the modern swing style (limited pelvic with maximal shoulder rotation), and found that the classic style involves greater activation of the muscles of torso rotation (trail side external oblique and lead side internal oblique) during the downswing and at impact than the modern style.

Trail side external oblique activation (as a percent of maximum voluntary isometric contraction while using electromyography) was significantly greater during the downswing of the classic style at 30.47 ± 18.23%, versus 21.46 ± 18.32% for the modern. It also showed significantly greater activity at impact for the classic style compared to the modern: 32.74 ± 19.40% versus 22.85 ± 17.01%. Concurrently, the lead side internal oblique was more active during downswing, impact, and follow through in the classic style compared to the modern one, with downswing muscle activity being significantly different for the classic (39.30 ± 28.53%) versus the modern (24.27 ± 16.73%) styles. At impact, mean internal oblique activity was 37.53 ± 33.79% versus 25.82 ± 15.35% and during the follow through the results were 41.44 ± 35.55% versus 30.70 ± 20.46% for the classic and modern styles respectively. Aggarwal, Shenoy and Sandhu (2008) opined that golfers with more elements of the classic style may have greater downswing force production from the abdominal muscles and less lumbar region injury potential from rotating the hips and shoulders to similar levels (classic style) during the backswing, rather than twisting the thoracic region of the spine over a stable lumbar region (modern style).

Overall, the above studies may serve to indicate that although the X-Factor of the modern swing may be associated with a greater stretch-shortening cycle, the greater amount of pelvic rotation at the end of the backswing of the classic style might be associated with still greater stretch-shortening. It could thus be stated that there are many ways in which to generate the stretch aspect of a stretch-shortening cycle during the backswing, and an ideal movement should stretch the powerful lateral rotator muscles of the hip, besides stretching the muscles of torso rotation.

Downswing stretch shortening cycle. The X-Factor Stretch is a concept that may be better correlated with swing speed than the X-Factor. It is represented by the difference between pelvic and shoulder angles created during the downswing, when pelvic rotation precedes that of the shoulders (colloquially termed "leading with the hips").

Myers et al. (2008) studied upper torso and pelvic rotation angles, specifically the angle between the respective segments and the global x axis, which was defined as a neutral address position during which both upper torso and pelvic rotations were zero degrees. They divided the 100 recreational golfers of their study into three matched groups with low, medium, and high ball velocity, as measured during their data collection. The participants of their research all held a registered USGA handicap and used their own driver clubs. Results revealed that X-Factor Stretch referred to as maximum torso-pelvic separation was: -45.6 ± 8.0°, -51.7 ± 10.3°, and -61.8 ± 7.8° respectively for the low, medium and high ball-velocity groups, all significantly different. All results were negative, based on the definition of neutral rotation at address. Maximum torso-pelvic separation was also significantly correlated with ball velocity, with a correlation coefficient (r) of -.54.

Another research project (Cheetham, Martin, Mottram, & Laurent, 2001) comparing 10 professional golfers with 9 golfers of golf handicap 15 or higher, found that the X-factor stretch was significantly greater (p = .02) for the highly skilled professional golfers compared to the less skilled ones.

The X-Factor Stretch concept involves a downswing in which the movement of the pelvis precedes that of the shoulders. It may also be considered to be a part of the kinematic sequence, involving the proximal segments (pelvis) of the body moving before the distal ones (i.e., thorax, arms and club), in a specific sequence, often referred to as a proximal-to-distal sequence. The X-Factor Stretch, just like the X-Factor, can perhaps be generated by other, less strenuous means through adjustments to body positions prior to the start of the backswing.

Proximal to distal sequencing. The proximal-to-distal (kinematic) sequence has long been considered (Neal, Lumsden, Holland, & Mason, 2007) an important aspect of speed development in many striking and throwing sports. One recent study (Takagi, 2018) assessed the amount of work associated with those joint motions that affect energy transfer to the club. Sixteen skilled golfers with a mean golf handicap of 2.9 ± 1.9 participated in the investigation. The largest contribution was seen to be from the more proximal pelvis angular velocity (with a 45% ratio of segmental work to total work), with similar lumbar and shoulder contributions (24 and 22% respectively), and an 8% contribution from the most distal segments – the wrists. The relationship between the segments involved in a proximal-to-distal sequence is complex mainly because each segment can influence the movements of others linked to it, based on how it is moving and how it is oriented relative to adjacent body parts (Putnam, 1993).

Backswing thorax lateral flexion. One typical movement seen in most golf swings is the lateral flexion of the lead-side of the thorax or upper trunk during the backswing, which is followed by trail side lateral flexion during the downswing. When it is considered that the torso is in trail side lateral flexion at both address and impact, because the trail hand is placed lower on the club’s handle, it is important to understand whether there are any benefits to lead-side torso lateral flexion, and if so, during which of the backswing and downswing phases.

A study of 308 male and female golfers found (Chu, Sell, & Lephart, 2010), from a multiple regression analysis, that top of backswing trunk lateral bend (of the lead-side of the torso) was correlated with ball velocity, and showed a beta coefficient of 0.267, so that a change of one standard deviation of lateral bend was related to 0.267 standard deviations of ball velocity, a non-significant result. However, during the downswing phases of acceleration, during the last 40 ms, and at impact, both thorax lateral bend and lateral bend velocity of the trail side, were correlated with ball velocity. The only significant results of the above were lateral bend angle during acceleration or late downswing, and lateral bend velocity in the last 40 ms and at impact. This late downswing lateral bend of the thorax (with the lead side higher than the trail side) has often been referred to as "vertical lift."

The method of measurement of trunk lateral bend in the above study was defined merely as being positive for "bending towards the trailing side, 0° for neutral position" (Chu et al., 2010, p. 1253). This measurement technique, not described in the article, appears not to take into account the rotations of the thorax in all the three planes of motion in which the golf swing moves. Moreover, the authors found a trail-side lateral flexion of 3.9 ± 7.4° at the top of the backswing, while most other studies have shown a lateral flexion of the lead side at the top (Zheng et al., 2008).

In contrast to the above study, Joyce, Burnett, Cochrane, and Ball (2013) assessing trunk kinematics, did not find the same association of lateral trunk flexion and club speed. In the linear regression model of their study, low handicap golfers using their driver and 5-iron clubs, showed a ß coefficient of 0.194 for trunk lateral bending for the driver, but not the 5-iron club (*p* = .194; not significant). The authors stated that less lead side lateral bending of the trunk at the top of the backswing was associated with greater clubhead speed. In a more recent work undertaken by the same primary author, Joyce (2017), there was an inverse relationship between trunk lateral bending towards the trail side (i.e., lead side vertical lift) at ball impact and clubhead speed ($r = -.61$, $p = .02$), for the 5-iron club. Joyce opined that excessive trunk side-bending at impact could restrict axial torso rotation, which was considered to be the main source of club speed development. From the discussion sections of the two studies in which he is the primary author, Joyce appears to consider both lead side lateral flexion during the backswing, and lead side vertical lift during the downswing, to be detrimental to the production of club speed. This statement is contrary to that of other authors such as Chu et al. (2010) who have found a correlation with a higher lead side of the trunk creating a longer arm-club lever at impact, for greater eventual linear velocity of the clubhead.

Trunk lateral flexion was also assessed in the Zheng et al. study (2008) of 72 golfers divided into Tour professional, low handicap, mid handicap and high handicap groups, all hitting a driver club. There was lead side trunk lateral flexion at the top of the backswing, in all four groups (-9 ± 12°, -6 ± 11°, -7 ± 13° and -8 ±11° respectively). Lateral bend at address was towards the trail side, and returned to that side at ball-contact, having the similar magnitudes of 31 ± 6°, 30 ± 6°, 27 ± 7° and 28 ± 8° at impact, for the four groups respectively. Zheng et al. defined trunk lateral flexion as the angle between the vector of the pectoral girdle and the vector of the pelvic girdle in the frontal plane.

Finally, Okuda, Gribble, and Armstrong (2010), assessing 13 skilled golfers (handicap range 0 to 5) and 17 low skilled golfers (handicap range 20 to 36), defined the upper trunk segment as the line between the right and left acromion processes at the shoulder, and then calculated side bending (lateral flexion) of the upper trunk segment as the angle between the segment and the XY plane (horizontal plane) of the laboratory coordinate system.

Okuda et al. (2010) showed that both low skilled and skilled golfers, at address, had trail-side lateral flexion (12.4 ± 5.0° and 15.1 ± 3.3° respectively). The low skilled and skilled participants then had lead-side lateral flexion, as indicated by negative values, during the backswing (-18.9 ± 7.5° and -17.1 ± 6.9° respectively) and at the top of the backswing (-29.3 ± 7.5° and -25.7 ± 8.6° respectively). This lateral flexion angle remained a lead-side one during the downswing (-25.0 ± 10.5° and -20.0 ± 4.6° respectively). It then changed to a trail-side lateral flexion in time for ball impact (30.0 ± 6.1° and 28.7 ± 5.0° respectively) and increased to 45.2 ± 5.8° and 40.7 ± 6.1° for the low skilled and skilled golfers respectively during the follow through (Okuda et al., 2010). All the above studies together indicate that most golf swings have trail-side side bend at address, lead-side lateral flexion during the backswing, top of backswing and downswing phases, which changes back to trail side lateral bend during impact.

With respect to the advantages of thorax lateral flexion, it may be stated, given all of the above evidence, that lead-side lateral flexion during the backswing may not contribute to club speed, while late downswing trail side lateral flexion (i.e., lead side vertical lift) has been associated by some authors (other than Joyce in 2017) with improved club speed. Backswing lead side lateral flexion may thus be an unnecessary movement of a large body segment (the torso), controlled by many large muscles, which has to compete for sequential dominance with several other vital, speed-developing movements within the downswing's execution time of one-third or less of a second. Moreover, Lindsay, Horton, and Paley (2002) implicated excessive lateral flexion in low back pain occurrence. Lindsay et al. that both directions of movement were greater with the 7-iron than with a driver club. The elimination of backswing torso lateral flexion may thus be an important consideration for the golf swing.

With respect to the measurement of lateral flexion, in biomechanical terms it may be more appropriate to measure torso movements as those of the pelvis and thorax segments, using a Cardan Z-Y-X sequence and in comparison to the Global Coordinate System (GCS), which does not depend upon lines projected onto planes which would result in two dimensional, rather than three dimensional, outputs (Brown, Selbie, & Wallace, 2013).

Downswing thorax vertical lift. A thorax position in which the lead side is higher than the trail side, at or close to impact, may be termed vertical lift. Miura (2001), based on findings from a single low handicap golfer, used the term "parametric acceleration" to explain, through mathematical calculations, how clubhead velocity, kinetic energy and hand force may all increase with an upward and inward pull of the hands. This motion was found to have a magnitude of 0.09 m of hand position change nearing impact. Miura recommended that the pull motion should be generated by "The quick rotation of shoulder / waist and the quick lifting of the left side of the body" (2001, p. 84).

Sanders & Owens (1992) had described an upward movement of the "hub," similar to the "left side of the body" recommended by Miura. The hub was defined as the focal point of the clubhead path where the lines perpendicular to the instantaneous path of the moving club would intersect. For the six elite golfers of Sanders and Owens' study, the hub moved upwards (139.5 ± 4.8 cm) just before impact, allowing for the creation of both a longer radius of movement for the clubhead and a flatter path for the club head through impact. Conversely, for the six novice golfers, the upward hub movement was significantly ($p < .01$) less (118.7 ± 18.3 cm).

The concept of bodily vertical lift during the downswing, rather than merely hand lift as seen by Miura, was corroborated by Chu et al. (2010) through a kinetics analysis. The researchers stated that the decreasing vertical ground reaction force seen in their study (decreasing from 95.1 ± 30.5 %BW in the last 40 ms before impact to 74.7 ± 29.7 %BW at impact) was a result of the upward movement of the body.

Many famous golf instructors teach the active implementation of a countermovement-jump type motion of the lower limbs to create vertical lift in the golf swing. One "Top 100" instructor refers to it as a "Load and Launch" (Adams, 2017), in which the lead side leg is pushed down into the ground during the downswing so the golfer can subsequently use ground reaction force to push forcefully off the ground. This vertical launch is expected to create greater force for more swing speed, as well as, according to Adams, open the clubface up for more ball trajectory. Conversely, Greg

Rose, founder of the premier golf fitness institution, Titleist Performance Institute states that the longest hitters squat down 1 to 2 in. during their backswings to create vertical lift in their downswings (Rose, 2017). It may thus be said that downswing vertical lift of the thorax segment may be an important movement for many ball flight characteristics, and there may be many methods for achieving the requisite motion. One such method could be as simple as maintaining the lead side of the thorax higher than the trail side throughout the backswing, thus maintaining a "vertical lift" throughout the swing, rather than attempting to generate one through complex up-and-down movements within a mostly rotary motion.

Kinematics for Club Angle of Approach and Path

There are said to be nine typical ball flights (directions in which a ball may travel after impact; Bačić, 2014). Of them, three are claimed to be useful as they help the ball move towards (not away from) the green. They are a straight shot, a "pull-fade" that starts left of target and curves right, and a "push-draw" that starts right of the target and curves leftwards towards the green (Mann, 2010). They all depend on the combined effects of the club path and club face angle. Similarly, ball trajectory depends on the club's angle of approach and its dynamic loft at impact among other factors ("Learn to control your trajectory", 2016). No research has been conducted on the actual kinematics that may affect club angle of approach or club path, although one study (Tinmark et al., 2010) looked at body segment kinematics related to directional accuracy while golfers attempted to control ball distance.

Tinmark et al. (2010) discovered that the 11 male professionals, 21 elite male amateurs, and 13 elite female amateurs, had a proximal to distal sequence when hitting to maximal distances and were able to alter their shots to submaximal distances with the same club while still maintaining correct sequencing to produce both appropriate ball speed and suitable directional accuracy. The time for maximum speed of the pelvis was significantly earlier than for the torso, which was significantly earlier than for the hand, regardless of whether the condition was 40-m, 55-m, or 70-m to target, or full-force swings with a 5-iron or a driver club. When a distal segment accelerates as the more proximal one decelerates, and the magnitude of each level of segmental angular speed increases sequentially, accuracy may also be expected. It may thus be said that the correct sequencing of body parts is important in the production of club speed as well as for improved directional accuracy of golf shots. This was the only study that assessed golfers' ability to hit shots with directional accuracy, albeit as a consequence of controlling for distance. For this reason, information regarding kinematics specifically related to club angle of approach and club path has been sourced from the websites of golf ball launch monitor manufacturers, or based on the observations of famous golf instructors or the experiences of leading professional players.

Kinematics Related to Injury

While the kinematics and kinetics linked to the effectiveness of performance are important, they should ideally also be associated with those for safety or the prevention of injury in golfers. The most commonly seen injury in golf is to the lumbar region of the spine. Low back pain is one of the most frequently seen golf injuries and accounts for

26% to 52% of all injuries (Gluck et al., 2008). According to another article, it accounts for about 25% of all golf-related injuries(Lindsay & Vabdervoort, 2014), but incidence rates have been found to range between 18.2% to up to 54%. Moreover, pain in the low back is the most commonly experienced musculoskeletal condition, affecting amateur and professional golfers alike (Lindsay & Vandervoort, 2014).

A recent systematic review and meta-analysis (Smith, Hawkins, Grant-Beuttler, Buettler, & Lee, 2018) reported that the prevalence of golf-related low back pain has ranged from 12.4 to 26.9% in recreational golfers, and from 40.0 to 58.1% in professional golfers. The authors opined that current evidence at the time of their study did not permit the linking of golf related back pain to any specific aspects of swing technique.

Mechanisms of lumbar spine injury. Many swing movements have been associated with low back pain in golfers. One of them is said to be the X-Factor. This movement is considered important for speed development, but involves a twist of the thoracic spine over a fairly stable lumbar spine (Bulbulian, Ball, & Seaman, 2001; Gluck et al., 2008). Another common cause of back pain (Cole & Grimshaw, 2014) is the *crunch factor* (the mathematical product of lateral bending angle and trunk rotational velocity), a term coined by Sugaya, Tsuchiya, Moriya, Morgan, and Banks (1998). The crunch factor was considered important because it is a greater determinant of pain in the lower back than either one of the two factors alone. In their review article on low back pain in golf, Gluck et al. (2008) stated that the most common causes of disc herniation in healthy discs are lateral bending, along with compression and torsion, all of which are seen in golf. Hyperextension of the lumbar spine (McHardy et al., 2006) in the follow through phase has also been implicated in low back pain, as has forward tilt of the thorax and pelvis.

A comparison of six golfers with, and six without, low back pain while playing golf (Lindsay & Horton, 2002) showed that the former had significantly more forward bend at address (37.0 ± 11.4° versus 25.3 ± 6.6°). The angle was measured for the driver club, and is likely to be greater for iron clubs, which are shorter and require a golfer to have even greater forward spinal tilt. It is known that increased forward bending is associated with increased pressure on, and compression of, the lumbar intervertebral discs. Additionally, forward bending places tensile loads on the erector spinae group of muscles of the back, the posterior aspects of the intervertebral discs, the facet joints and the posterior ligaments (Esola, McClure, Fitzgerald, & Siegler, 1996). It was shown in one case study that a more upright stance was a factor that helped to reduce low back pain in a professional golfer (Grimshaw & Burden, 2000).

Lindsay and Vandervoort (2014) have opined that compressive loads on the spine as well side-bend (lateral flexion, which causes mediolateral shear) may both be harmful to intervertebral discs. Hosea, Gatt, and Gertner (1990) conducted a biomechanical analysis of a golfer's back and found that the eight golfers of their study (four male professionals and four male amateurs) who used a 5-iron club (known to require more forward tilt of the spine because of its shorter length than perhaps a driver) experienced between 6000 to 7500 N of compressive loads. Such loads can be compared to the 5448 N known to be able to cause disc prolapse. The high loads experienced by both professionals and amateurs were eight times body weight.

It may therefore be stated that the X-Factor at the top of the backswing; thoracic lateral flexion during the downswing; forward tilt at address and at other swing events; and the velocity of downswing axial rotation of the spine may all be mechanical factors affecting low back pain.

Causes of Golf Swing Complexity

Many golf researchers agree that the golf swing is complex. One explanation for why the movement has been considered "one of the most difficult biomechanical motions in sport to execute" is that a golfer is required is to swing a long club to connect with a relatively small golf ball with maximum possible velocity (Lindsay, Mantrop, & Vandervoort, 2008). The ball, moreover, is on the ground, unlike in other sports where it is off the ground and much closer to the arms that swing the implement that connects with the ball. Other investigators have stated that the complexity stems from the fact that it is a multi-joint movement (Keogh & Hume, 2012).

It is not known whether golf swing complexity could also be ascribed to the fact that there are many joints that are moved away from the target during the backswing, in multiple planes of movement, and must all subsequently be moved in the opposite direction, in a specific sequence, during the downswing. Additionally, it is also not known which aspects of the movement involved in the golf swing might be merely "artificial" or "stylistic" (Handford, Davids, Bennett, & Button, 1997), involving more movements than are strictly necessary. Although motor behavior theory claims that motor abundance (the opposite of redundancy) in movement is desirable (Latash, 2012), it may not be so in the case of golf, which requires sophisticated movements of the torso, a centered contact of the club with a small stationary ball placed on the ground; and a downswing that must be completed within the relatively short time span of 0.34 s or less (Zheng et al., 2008).

The Case for Swing Simplification

Given the limited time within which the downswing takes place, the elimination of those movements that are not associated with club speed, angle of approach, or path, and the reduction in the ranges of motion of those that are, might aid swing simplification. For instance, backswing lead side trunk lateral flexion has not been significantly associated with the abovementioned club parameters and could perhaps be eliminated (Joyce et al., 2013). Similarly, only highly skilled golfers have been able to move through the large ranges of downswing lateral weight shift (Lindsay et al., 2008), torso rotation (Myers et al., 2008; Cheetham et al., 2001), and lead side vertical lift (Sanders & Owens, 1992), that a typical golf swing involves. Therefore, positioning the body suitably during the set up or backswing phases, so that a far smaller downswing movement range would return golfers closer to desired impact locations might simplify the movement for all skill levels of golfers.

It is believed by this author that three major departures from the typical swing might make downswing sequencing simpler, and may lead to both improved ball-striking performance and reduced likelihood for mechanical injury to the lumbar spine. The first change involves the separation of the more horizontal rotation of the torso from the more vertical elevation of the arms during the backswing. This can be achieved by a purely horizontal rotation of the torso to face away from the target before the backswing movement of the arms begins, accompanied by a slight lateral flexion of the head and neck towards the trail shoulder. It would be followed by an arms-only backswing, during which stage the golfer would avoid torso motion, specifically frontal plane lateral flexion of the lead side of the body as well as any sway of the entire body towards or away from target. This removal of considerable body motion is the second important departure from any typically seen golf swing.

A third change in the specific swing simplification is not directly related to swing dynamics. A golfer is required to stand as upright as possible, with the thorax and pelvis in the minimal possible anterior (forward) tilt, and both knees in minimal flexion. This reduction of forward tilt of the entire spine at address may be especially important for the reduction of low back pain.

Prebackswing torso rotation. A purely transverse plane torso rotation before the start of the backswing would negate any requirement of trunk rotation during the swing, prevent an oblique tilt of the torso during the backswing. It would also and serve to separate torso and arm movements. Moreover, avoiding sophisticated torso movements during the backswing would be in keeping with the limited resources the central nervous system apportions to trunk motion. The central nervous system separates its messaging to the torso (proximal segments) and to the extremities (distal segments), so that the system's resources are allocated in proportion to each segment's role in typical human movements such as gait.

Design of the central nervous system. Bressler and Kelso (2001), researchers in motor control, stated that, "To be effective in ongoing dynamic computation, the cortex must resolve the large number of competing constraints acting on its component areas in a rapid manner" (p. 32). Moreover, according to Murayama, Lin, Salenius, and Hari (2001):

> Skilled movements, such as retaining an egg between the thumb and fingers, involve cooperation of many muscles. Such movements are controlled by an intricate communication between the sensorimotor cortex in the brain and the peripheral muscles, through the motoneuron pool in the spinal cord. (p. 1206)

The many areas of the central nervous system all tend to separate the resources allocated to the trunk and to the extremities, with the former being limited compared to the latter. For this reason, Maruyama et al. compared the interaction of four muscles with cortical action, and found that as they had predicted, the corticomuscular interaction was weaker for trunk muscles (abdominal and paraspinal) than for hand (dorsal interosseous) and foot (tibialis anterior) muscles. This difference probably reflects, according to them, a difference in cortical control of proximal and distal muscles, with the authors stating that while proximal trunk movements are less elaborate than the distal finger and foot movements, they are important for changing posture as well as maintaining it. The golf swing, unlike, for instance gait, uniquely requires considerable, sophisticated and fast movements of the trunk, also involving a change of direction.

The body's movement-related areas are represented in the precentral gyrus of the cerebral cortex. Moreover, the area of the cortex dedicated to specific movements is in proportion to the skill involved in performing the movement and is not dependent on the mass of muscle involved in the movement (Snell, 2006). While trunk motion in typical human movements such as gait is not particularly elaborate, the trunk's movement in the golf downswing is.

Many other areas of the brain, such as the cerebellum, the basal ganglia, and the corticospinal tracts, among others, all have distinct pathways for the trunk and the limbs. The cerebellum can be divided into three main areas based on function, with the vermis influencing movements along the long axis of the body, while an intermediate zone influences movements of the hands and feet. The gray matter areas of the cerebellum too have divided roles (Snell, 2006).

The basal ganglia or nuclei are a group of sub-cortical gray matter containing nerve cell bodies, and they are said to not merely influence the execution of a movement of perhaps the limbs, but also aid in the preparation of such movement, through suitable control of axial and girdle movements and the positioning of the proximal limb segments. Thus, the basal nuclei are able to place the trunk and limbs in suitable positions in preparation of discrete hand and foot movement (Snell, 2006).

The nerve fibers of the corticospinal tracts that are involved with the speed and agility of skilled voluntary movements typically cross over in an area of the brainstem. A few of them do not cross over (about 10%) and those are said to connect the brain to the "proximal muscles" ("Descending Pathways," n.d.). If the central nervous system itself bifurcates the resources it allocates to the proximal part of the body – the trunk – to those it reserves for the limbs, allowing only limited ability for sophisticated trunk musculature activation, perhaps a golf swing of similar design might aid in the simplification of the movement.

Backswing trail side lateral flexion. The recommendation, in the proposed simplified swing movement, for maintenance of trail side lateral flexion of the lumbar, thoracic and cervical sections of the spine as well as of the head, from address to impact, also has a credible rationale. If the main downswing movement is expected to be a proximal-to-distal one, with some target-side weight shift followed by some lead-side vertical lift, there would be more time to achieve all those movements if the backswing did not also require lead-side lateral flexion followed by a rapid return to trail side lateral flexion. Ultimately, at both address and impact, the trail side is required to be in lateral flexion. Maintaining trail side lateral flexion during the entire backswing is also expected to allow the arms to drop the club down to a more precise position as the height above ground of the trail shoulder would not have changed, perhaps increasing both the efficiency and the consistency of contact.

Furthermore, a change of direction of thoracic lateral flexion from backswing to downswing also has implications for low back pain. A study that compared 7-iron kinematics to those for the driver, found that there was greater 7-iron backswing lead-side spinal lateral flexion (9.8 ± 5.9° vs 7.1 ± 6.0°; significant) followed by downswing trail-side lateral flexion (27.9 ± 4.8° vs 26.3 ± 5.2°). Trail-side side-bend spinal velocity too was greater for the 7-iron than the driver club (121.7 ± 24.8°/s vs 109.2 ± 25.3°/s). Lindsay et al. (2002) observed that both side bending and forward bending of the spine during the swing have been associated with pain in the lower back.

Hitherto Attempted Swing Changes

Very few interventional studies have been conducted in golf to date. Lemak, Fleisig, Welch, Marting, and Zvijac (1994) tested eight Ladies Professional Golf Association (LPGA) Tour players in an attempt to assess the benefit of partial swings for golfer rehabilitation. These female golfers attended a single session and used their driver, 5-iron, and pitching wedge clubs. They were asked to hit two shots each with a full swing, a ¾ swing, and a ½ swing, for each club. Maximum downswing club angular velocity was significantly lower for the successively shorter swings. While this may not precisely be an intervention, the participants were required to make some different ranges of movements.

Two groups of investigators attempted a shortening of the backswing to reduce spinal rotation and thus loads on the spine that are related to low back pain. In 2001, Bulbulian et al. conducted a single-session test and compared muscle activity between participants' existing swings and a shortened swing using electromyography. Seven participants, of mean handicap 16.3 ± 8.2 were included in the study as they had a "full recoil backswing" with at least 90° shoulder turn combined with a restricted pelvic turn, similar to the X-Factor movement. Participants hit 10 shots with a 7-iron club before the interventional movement was introduced, and then hit a further 10 shots after being trained on the shortened swing for 20 to 30 min by one accomplished golfer, and one local area golf instructor. The interventional swing, which "hindered" the uncocking of the wrists for a portion of the downswing, as recommended by Jorgensen (1970), was shorter in length by 46.5 ± 24.7° and showed no significant reduction in clubhead velocity or change in directional accuracy. It used a vigorous weight shift combined with pelvic rotation to prestretch torso muscles that could then initiate a forceful torso rotation towards target during the downswing.

The other experiment with a shortened backswing was conducted in 2016 (Dale & Brumitt) on 13 participants who had 16 ± 1.4 years of playing experience, and a mean handicap of 7.1 ± 0.8. Participants were trained in the shortened backswing by a professional golf instructor who was a member of the PGA of America. The lead shoulder was required to be moved until it was above the lead knee and no further, to reduce trunk rotation. The rest of the movement was expected to be a participant's usual swing. This too was a single-session study, participants used their 7-iron club, and were told to alternately hit five shots with their usual, and then five shots with the shortened backswing, until 20 shots had been hit. The X-Factor separation angle (49.9 ± 3.0° full swing vs 45.4 ± 3.0° short) and compressive force (7.6 ± 0.4 N full swing vs 7.0 ± 0.5 N short, all values normalized to body mass) on the lumbar spine were both significantly reduced with the shorter swing. However, clubhead velocity (33.2 ± 0.6 m/s full swing vs and 31.3 ± 0.7 m/s short) and shot distance were also significantly reduced, while accuracy of shot distance from target improved, but not significantly (3.3 ± 0.4 m short swing vs 4.9 ± 1.2 m full). All of the above studies involved a single swing change conducted over one session and using a sample size of 13 or less.

One recent study of 22 senior golfers of ages ranging from 54 to 81 years attempted similar movements to those that will be used for the present study (Kanwar & Mann, 2018). Golfers used both their 6-iron and driver clubs and attended 11 sessions, the first of which was a pretest session of their existing swings, while two further sessions mid-intervention and two at the end of the intervention, assessed postintervention changes. There were six training sessions interspersed evenly between the midintervention and the postintervention measurement sessions. A mixed-effects model was used to analyze results and there was a significant effect of session on ball speed and trajectory for the 6-iron, with an increase of 0.2 m/s in speed and of 0.3° of trajectory, per session. There was also an effect of session on speed for the driver, with an increase of 0.2 m/s per session. For both clubs, ball direction moved slightly and significantly to the right (0.6° and 0.9° respectively) for the two clubs per session, from being more to the left during the pretest. The limitations of this study may have been that 11 sessions were considered excessive by some of the participants, and some aspects of the movements trained, such as the magnitude of torso rotation, might also have been excessive.

Finally, the two previous single-session interventions used a 7-iron club, perhaps because a medium-length iron is easier to begin to effect a swing change with. Moreover, the irons are important clubs as they are the “approach” clubs and require a relevant angle of approach, an in-to-out (starting closer to the golfer’s body compared to the target line, and then moving away from it after impact) path, besides consistent speed, to land on, and remain on, the green. For the above reasons, the number of training sessions was reduced from six to four (Kanwar & Mann, 2018), to avoid the likelihood of exhausting participants; and the 6-iron and the 9-iron were used, to allow for a maximal range between modern day irons, while excluding the shortest and longest clubs which may require further training.

The Dependent Variables of this Study – Club Body Kinematics

The present study assessed the effects of a swing change when using two important approach clubs – the 6-iron and the 9-iron. The club movements that were measured were club angle of approach and club path at impact. The other important aspect of club movement – club speed – has not been included in the statistical analysis, but will be reported in the Results section, because it was discovered by this author, based on prior research to be sensitive to the amount of torso rotation at address, although it was not known what quantity of preswing torso rotation was too great.

The angle of approach is the angle between the club's arc and the ground (Wiren, 1990), and helps to determine the trajectory of the ball and thus how easily it will stop once it lands on the ground, as well as the distance travelled by it. For iron shots, it is said that most golfers have a too-steep, descending angle of approach (Trackman, n.d.a). An excessively steep angle of approach can reduce the distance the ball travels and also reduce control of the ball on approach shots (Trackman, n.d.a). For an average golfer a recommended descending approach angle to the ball should be approximately 3.2° with a 6-iron and 3.9° with a pitching wedge club, so that a 9-iron should have an angle of approach that is between the other two (Trackman, n.d.a). As a comparator, the male professional golfers of the PGA Tour have an angle of approach of 4.1° with a 6-iron, while the female professional golfers of the LPGA, with relatively slower club speeds, have an average angle of approach of 2.3° with the same club. The present study was expected to shallow out the descending angle of the club into the ball to within commonly recommended ranges (Trackman, n.d.a).

Club path is the direction of the club's arc as it approaches the ball, and it affects the direction of the ball. Club path can be (Trackman, n.d.b) in-to-out or out-to-in relative to the target line. The intervention of this study was expected to produce a more in-to-out path. An in-to-out path is considered to be a cure for the "over the top" movement, which is said to cause many bad shots such as slices, pulls or even topped shots (Suttie, 2008). Such a path is also required if a golfer wishes to hit a "draw" type of shot (Trackman, n.d.b), which many consider helps the ball to travel further.

Kinematic measurements of thorax and pelvis angles that are indicative of either required TOPS positional changes or of performance changes were taken at specific swing events. The kinematics indicative of TOPS are a more "closed" or rotated away from target thorax at address, and less lead-side lateral flexion of the thorax at the top of the backswing. The results were expected to be significantly greater for both variables, as golfers were trained in those positions during all four training sessions.

Two kinematic changes related to performance were selected of several possible ones. They were chosen because each of them is said to contribute to two important aspects of approach shots - club angle of approach and club path -, which contribute to ball trajectory and direction respectively. The first kinematic change associated with performance was expected to be a thorax that was more rotated to face away from the target at impact with the use of TOPS. According to a recommendation by leading golf instructor and biomechanist Jim Suttie (2008, para. 11), "Try to keep your back to your target as long as you can". This movement allows the club to get into a "slot," which is a position that would prevent an over-the-top, out-to-in club movement. When the trail shoulder is rotated forward and downward at the start of the downswing (an out-of-sequence movement), the club is forced into a more out-to-in path (Suttie, 2008). A thorax that remains closed to the target line until later in the downswing would thus be indicative of a more in-to-out path of the club.

The second change related to performance was expected to be significantly greater vertical lift of the lead side of the thorax at impact with the use of TOPS. The resulting increased height of the lead side would imply an increased radius of the swing's arc for greater club, and thus ball speed, as well as a shallowing of the club's angle of approach (Sanders & Owens, 1992), for improved ball trajectory.

Other kinematic measurements, all of which have been implicated in low back pain in golfers, include the X-Factor (the difference between thoracic and pelvic transverse plane rotations) at the top of the backswing, the range of crunch during the downswing (the difference between trail side lateral flexion at the top of the backswing and at impact) and spinal forward tilt at address. They were all expected to be significantly reduced with the use of TOPS.

Summary

The main golf swing movements that have been shown through research to improve club speed include, during the downswing, toward-target weight shift, a proximal-to-distal torso rotation, and a vertical lift of the torso close to impact along with the straightening of cocked wrists. Additionally, the proximal-to-distal sequence is said to contribute to directional accuracy of the golf shot, while the vertical lift aids in the shallowing out of the club's angle of attack. There are two perhaps unnecessary backswing movements that may prevent effective downswing sequencing within its one-third second duration. The first might be the sophisticated downswing torso rotation (required in both the classic and modern versions of the golf swing), which involves an oblique plane of backswing rotation to be changed, during the downswing, to a horizontal plane movement followed by a frontal plane one. The second could be lateral flexion of the lead side of the body during the backswing. Both of them together may impede the rapid sequential movements of the downswing.

One golf swing, TOPS, proposes a horizontal plane rotation of the pelvis and thorax to face away from target in advance of the commencement of the arms' backswing movement. The arms-only backswing then involves no lateral flexion or mediolateral (side-to-side) movements of the torso, and thus serves to maintain trail side lateral flexion of the head and trunk. The preswing torso rotation is expected to improve club path as the thorax remains closed to the target line for a longer time during the downswing. The maintenance of trail side lateral flexion during the backswing is expected to keep the hub of the swing higher from address to impact, increasing vertical lift for an improved club angle of attack. Finally, a reduced X-Factor, a smaller range of crunch from the top of the backswing to impact, and a more upright posture at address, may be important in reducing some of the known mechanical risk factors of low back pain and injury.

CHAPTER III

METHODS

The purpose of this study was to assess how ball flight parameters, specifically club speed, angle of approach, and path, as well as related body kinematics and ground reaction forces would change with TOPS movement as compared to golfers' existing swings, while using the 9- and 6-iron clubs.

Participant Sampling and Recruitment

An *à priori* power analysis using G*Power 3.1.9.2 software was conducted to determine the minimum sample size required for statistical significance while using three 2 (swing style) x 2 (club type) repeated measures multivariate analyses of variance (RM MANOVA). With a desired level of power set at .80, an alpha (α) level at .05, and the lowest effect size of 0.39 (*f*), it was determined (Cohen, 1988) that a minimum of 15 participants would be required to ensure adequate power for the proposed design. This lowest effect size was calculated from the results of a previous study (Kanwar & Mann, 2018) that compared golfers' existing swings with a swing style almost identical to TOPS.

Ethics approval was granted from the Texas Woman's University and the University of Southern California's Institutional Review Boards. The accessible population consisted of experienced golfers of the Los Angeles area. Sampling comprised convenience and snow-ball procedures, which meant that all accessible golfers who met the inclusion criteria were accepted for the study, and they were also requested to inform other golfers about the investigation. Recruitment was conducted through flyers placed at the golf course where the training was conducted, and by word-of-mouth requests to local area golfers and golf instructors.

Inclusion and exclusion criteria

Participants were included in this study if they were male or female experienced golfers over 18 years of age, who had played golf at least 20 times in the past two years. They were required to have a golf handicap of 24 or less, which is a scoring ability of 94 or less over 18 holes of golf. Participants were excluded from the study if they had had any orthopedic surgery or musculoskeletal injury during the past four months.

Participants

Protocols

A total of 15 golfers participated in this research project. Participants were required to attend one data collection session at the beginning, and one at the end of the study, at the University of Southern California Division of Biokinesiology and Physical Therapy's Musculoskeletal Biomechanics Research Laboratory (MBRL). Between those two days, they attended four training sessions at the Driving Range of the Don Knabe Golf Center, Norwalk, CA.

Participants were asked to use their own 6-iron and 9-iron (approach) clubs, as well as golf gloves (if required) and spikeless golf, or other, athletic shoes. Which club was to be used first was randomized across participants, and they started with the same club for both laboratory sessions. Additionally, for the laboratory sessions, they were required to wear spandex shorts and no shirt if male, and spandex shorts with a sports bra or sleeveless shirt, if female.

On the first day, after signing an informed consent form, each participant warmed up in his or her typical fashion and then hit balls with each of their 6-iron and 9-iron clubs, using their existing swings. A plastic ball was hit off a mat for both clubs. Participants were asked to aim towards a target marked on a screen 5.6 m away. Club movement and body kinematics data as well as ground reaction force data were collected. Participants then received four training sessions on TOPS movement at the Driving Range, at which time they were asked to wear any suitable clothing but the same shoes. During the final session in the laboratory after the four golf lessons, club movement, kinematic and kinetic data were collected once again, as participants hit shots with their 6-iron and 9-iron clubs, while using TOPS. During both laboratory sessions, participants hit 10 shots per club. Any shots that the principal investigator (PI) and the participant felt were incorrect were discarded.

Instructions for the interventional (TOPS) style

At the very first swing-training session, participants were asked to describe which of their shoulders was lower at address, and which was lower at impact. They were then asked to look at which shoulder was lower at the top of the backswing. They discovered that although the trail side was lower at both address and impact (because the trail hand is positioned lower on the club's handle), it was higher at the top. They were then asked what sense that made, and then told that the "magic move" of TOPS was to keep the trail side of the trunk lower than the lead side throughout the backswing, as it is at both address and impact. Subsequently, the following instructions were given to all participants:

- Set up: Center the ball's position between the two feet. Get into as upright a posture as possible, using minimal thorax, pelvis, and knee flexion depending on the height of the club being used. Pick the club up slightly so that it is no longer touching the ground, then rotate the torso (head, thorax, and pelvis together) to face away from target. The rotation should be on a horizontal, not oblique, plane. Finally, tilt the head slightly towards the trail shoulder.
- Backswing: Make sure the hands' grip is fairly loose and that the lead elbow is not stiff. While maintaining the trail-side lateral flexion of the torso, and keeping the lead arm close to the chest, lift the lead upper arm until the lead elbow is approximately as high as the face. Avoid any side-to-side and up-and-down movements of the torso during the backswing. Also, avoid any intentional wrist movement.
- Downswing: Continue to maintain the head's trail-side lateral flexion, and swing through in your normal manner. No downswing thought is required.

Experimental Set-up and Instrumentation

A total of 97 retro-reflective markers were placed on the golfer, the mat, and the club (see Table 1). Only the PI placed the markers at the respective locations. A reliability assessment was made on five participants who were assessed on two occasions, one week apart. This was done to ensure that marker positions were reproduced correctly. The standard error of measurement (SEM) was calculated using the standard deviation

(SD) as SEM = SD * (SQRT (1-R)), where R was the intra class correlation assessed through SPSS. Next, the 95% confidence interval (CI) was calculated as CI = SEM * 1.96 so that any change greater than or less than the 95% CI value would be because of random error, and not significant. The 95% CIs calculated from the assessment were: ± 1.34° for thorax forward tilt, ± 0.51° for thorax lateral flexion, ± 1.06° for thorax rotation on a horizontal plane and ± 0.65° for pelvic rotation on a horizontal plane.

Table 1

The Set of Retroreflective Markers

Segment	Markers (quantity)	Markers (location); R = right, L = left (S) = static trial only
Mat and Ball	7	Target line (2). Mat location (4). Ball (1, S).
Club	7	Clubface (4, S), Clubshaft (3)
Pelvis	11	R and L iliac crests, R and L greater trochanters, R and L anterior superior iliac spines, sacral plate (5)
Thorax	10	R and L acromion processes, R and L inferior angle of scapulae, C7, manubrium, T12 plate (4)
Leg, Shank, Foot	32	R and L lateral femoral epicondyles, R and L medial femoral epicondyles (S), R and L lateral malleoli, R and L medial malleoli, R and L heels, R and L toes, R and L 1^{st} metatarsals, R and L and 5^{th} metatarsals, thigh plates (4 x 2), shank plates (4 x 2)
Arm, Forearm, Hand	26	R and L anterior shoulders (S); R and L posterior shoulders (S); R and L triad of upper arm markers (3 x 2) R and L lateral humeral epicondyles, R and L medial humeral epicondyles (S), R and L triad of forearm markers (3 x 2) R and L lateral styloid processes (S), R and L medial styloid processes, R and L middle metacarpals
Head	4	R and L anterior head, R and L posterior head

After the calibration of the 11-camera Oqus 5+ motion capture system (Qualisys, Göteborg, Sweden), a static trial that included the mat, the clubs and the golfer (T pose) was recorded (see Figure 1). The motion capture frequency used was 400 frames per second (Foxworth et al., 2013), for both golfer and club markers. Golfers were asked to stand with one foot on each force plate when hitting shots, with the direction the (right-handed) golfer faced while addressing the ball being the global -X-axis, the direction of target being global -Y, and the vertical direction being global Z.

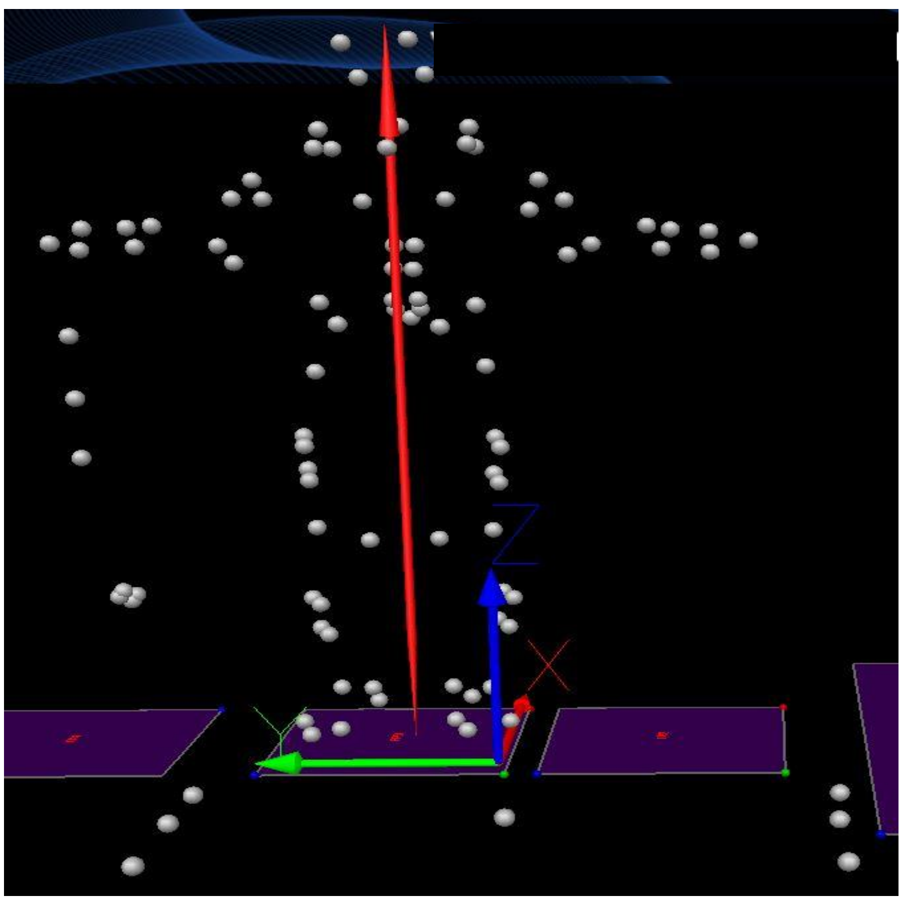


Figure 1. The Static Trial.

Data Processing, Reduction, and Analysis

The five trials with the highest clubhead speeds were used for all statistical analyses, both before and after the swing change. Motion capture data from Qualisys was cropped from address to mid-follow through, labelled and interpolated, then processed to generate c3d files. These files were then processed in Visual3D (C-Motion, Inc., Germantown, MD). Raw coordinates were filtered to eliminate noise using a Butterworth zero phase-lag, 4th order, low-pass filter, with a cut off frequency of 10 Hz for club and body markers. The cut-off frequency was based on prior research (Beak et al., 2013), and an inspection of several cut-off frequencies for this specific data.

Three events were determined for golfers' existing swings and TOPS: ball address/start of backswing, top of backswing, and ball impact. Ball address, or more accurately, in the present study, the start of the backswing, was the first instant when the club's speed was at least 0.2m/s. The top of the backswing was the point at which the speed of the clubhead was lowest, during its change of direction. Impact was the position of the club (in the club's Y direction) which was as close to 0.02 m (ball radius) as possible, from the ball's center.

Club movement data

Club movement was measured as that of the center of the clubface, calculated as the mid-point of the four clubface markers. The three movements of the club that were measured were club speed, club angle of approach and club path. These latter two angles were calculated as the angle between a line joining the center of the clubface at the frame of impact and one frame prior to that; and the target line. Club angle of approach was the vertical angle thus calculated, and club path, the horizontal one. The formula used was considered to closely represent the tangent to the club's arc at impact ("Slope of a Line and Angle Between Two Lines", n.d.): $\theta = tan^{-1}\frac{(m_1 - m_2)}{1 + m_1 m_2}$, where m_1 is the slope of the club and m_2 that of the target line. The target line was determined by two markers placed on either side of the position of the golf ball on the mat. This position of the golf ball was calibrated based on the retro-reflective tape-covered ball used in the static trial (Kwon et al., 2012).

Swing kinematics

Thoracic and pelvic angles were extracted for the two swing styles. The rotation sequence used was the Cardan Z-Y-X. It was preferred to the recommended (Kwon, 2008) Z-X-Y sequence for central segments because the most important movements of the present analysis are rotations about the longitudinal (Z) and anteroposterior (Y) axes, with sagittal movements about the mediolateral (X) axis being ascribed less preference. The thorax/abdomen was defined as a cylinder between the right and left iliac crests and the right and left acromion processes, and thus incorporated both the thoracic and lumbar spines. The pelvic segment was defined by the right and left iliac crests, the right and left greater trochanters and the right and left posterior superior iliac spines (the top two markers of the sacral plate). Positions of the thorax and pelvis for the different hypotheses were extracted for the relevant events of address, top of backswing or impact.

The X-Factor was calculated as the difference in the Z rotations (around a vertical axis) between the thoracic and the pelvic segments at the top of the backswing, when both were measured with respect to the global coordinate system (Brown et al., 2013).

The range of the crunch was calculated as the difference between thoracic lateral flexion at the top of the backswing and at impact.

Six degrees of freedom were assigned to each of the pelvic and thoracic reference frames, and all motions were calibrated with reference to the global reference frame.

Statistical Analysis

The two independent variables of this study were swing style (two levels: existing golf swing and TOPS) and club (two levels: 9-iron and 6-iron). Outcome variables with respect to club movement were club angle of approach and club path at impact. Outcome variables that measured swing-related kinematic changes were the thorax segment's transverse plane rotation away from target (closed) at address and at impact, and thorax frontal plane lateral flexion at the top of the backswing and at impact. Finally, outcome variables considered risk factors for low back pain were X-Factor at the top of the backswing, thorax crunch from top of backswing to impact, and thorax forward tilt at address.

Three 2 x 2 within factor repeated measures multivariate analyses of variance (RM MANOVA) statistics were used to test the hypotheses of this study.

1. The first 2 x 2 RM MANOVA had two independent variables, of swing style and club, each with two levels. The dependent variables were thorax rotation at address and at impact, and thorax lateral flexion at the top of the backswing and at impact.

2. The second 2 x 2 RM MANOVA also had the same independent variables of swing style and club, with the same two levels each. The dependent variables were club angle of approach and club path.
3. The third 2 x 2 RM MANOVA once again had the same independent variables with the same levels as before. The dependent variables were X-Factor at the top of the backswing, crunch range from top of backswing to impact, and thorax forward tilt at address.

The main assumptions tested for the three RM MANOVA statistical tests were normality, univariate and multivariate outliers, and linearity among the dependent variables without either multicollinearity or singularity. When partial eta square (η^2) was reported as a measure of effect size, it was considered to be low when it ranged from 0.01 to 0.06, medium if it was between 0.06 and 0.25, and large if it was found to be above 0.25 (Hauer et al., 2012). A significance level of α =.05 was set, and the null hypothesis rejected if $p \leq \alpha$. SPSS ver. 25 (SPSS Inc., Chicago, IL) was used for the statistical analysis.

Additionally, the standard deviations of club speed, angle of approach and path were all assessed as an indication of consistency, which is an important requirement for the approach shots. Club speed was not included in the main analysis of club movements, because other, more important aspects of approach shots were assessed.

CHAPTER IV

RESULTS

Participants

Sixteen Los Angeles area golfers volunteered to participate, and as they all met the inclusion criteria, they were enrolled in the study. Fifteen participants, of whom five were female and 10 were male, completed the study (see Table 2). Their ages ranged from 18 to 73 years, and their handicaps from +2 to -20. Their number of years playing golf ranged from 8 to 50 years.

Table 2

Participant Characteristics

	Mean	Standard Deviation
Age (years)	40.5	16.4
Mass (kg)	79.6	9.2
Height (cm)	173.4	7.8
Years playing golf	23.3	14.2
Golf handicap	-8.6	8.0

Effects of Swing Style and Club Type on Body Kinematics

Multivariate results indicated that there was no interaction effect ($F = 1.071$, $p = .416$), but there were main effects (see Tables 3 and 4) of both swing style ($F = 36.46$, $p < .001$, $\eta^2 = .93$), and club ($F = 4.39$, $p = .023$, $\eta^2 = .615$).

Table 3

Main Effects of Swing Style on Body Positions

	Existing Swing	TOPS
Thorax rotation at address (º)	4.71 ± 4.61	-18.66 ± 7.31*
Thorax lead side lateral flexion at the top (º)	32.71 ± 5.46	24.12 ± 5.53*
Thorax rotation at impact (º)	9.72 ± 9.09	-3.15 ± 7.93*
Thorax lead side vertical lift at impact (º)	-19.54 ± 6.58	-17.96 ± 4.22

Notes. Negative thorax rotation = "closed". Negative thorax lateral flexion = lead side higher. *Significantly different with TOPS ($p < .001$).

Table 4

Main Effects of Club Used on Body Positions

	9-iron	6-iron
Thorax rotation at address (º)	-7.064 ± 4.78	-6.89 ± 4.83
Thorax lead side lateral flexion at the top (º)	28.97 ± 5.15	27.87 ± 4.86*
Thorax rotation at impact (º)	2.66 ± 7.09	3.91 ± 8.48*
Thorax lead side vertical lift at impact (º)	-18.45 ± 5	-19.05 ± 5.31*

Notes. Negative thorax rotation = "closed". Negative thorax lateral flexion = lead side higher. CI = ±1.06 for thorax rotation and ± 0.51 for thorax lateral flexion
*Significantly different with TOPS ($p \leq .035$).

Effects of Swing Style on Club Parameters

Multivariate results indicated that there was no interaction effect (F = .085, p = .919, η^2 = .01), and no main effect of club used (F = .502, p = .616, η^2 = .007). However, there was a main effect (see Table 5) of swing style (F = 60.64, p < .001, η^2 = .90).

Table 5

Main Effects of Swing Style on Club Movements

	Existing Swing	TOPS
Club angle of approach (°)	4.84 ± 1.9	2.55 ± 2.21*
Club path (°)	0.13 ± 4.3	3.53 ± 4.33*
Club Speed (m/s)	31.53 ± 4.06	29.52 ± 3.92*

Notes. Larger angle of approach implies steeper angle. Larger path angle implies a more in-to-out path. *Significantly different with TOPS ($p \leq .001$).

A comparison of the standard deviations for each golfer's five best trials before and after the swing change was made (see Table 6) to assess the consistency of TOPS as compared to golfers' existing swings, with respect to club speed, club angle of approach and club path.

Table 6

Standard Deviations for Club Parameters

	9-iron		6-iron	
	Existing	TOPS	Existing	TOPS
Club speed (m/s)	0.57	0.42	0.57	0.54
Club angle of approach (º)	1.06	1.2	1.24	1.39
Club path (º)	1.23	1.3	1.08	1.21

Effects of Swing on Factors Affecting Low Back Pain

There was no interaction effect (F = .33, p < .806, η^2 = .08), but there were main effects (see Tables 7 and 8) of both swing style (F = 22.32, p < .001, η^2 = .85) and club (F = 10.25, p = .001, η^2 = .72).

Table 7

Main Effects of Swing Style on Factors Associated with Low Back Pain

	Existing Swing	TOPS
X-Factor at the top of backswing (°)	-45.27 ± 14.55	-36.8 ± 8.48*
Crunch range (°)	52.22 ± 9.6	42.12 ± 7.74*
Thorax forward tilt at address (°)	36.01 ± 6.99	30.47± 6.02*

Notes. Negative X-Factor indicates thorax more closed than pelvis.
*Significantly different with TOPS ($p \leq .003$).

Table 8

Main Effects of Club Used on Factors Associated with Low Back Pain

	9-iron	6-iron
X-Factor at the top of backswing (°)	-40.42 ± 10.56	-41.65 ± 11.39*
Crunch range (°)	47.42 ± 8.19	46.93 ± 8.26
Thorax forward tilt at address (°)	34.16 ± 5.99	32.33 ± 6.06*

Notes. Negative thorax rotation = "closed". Negative thorax lateral flexion = lead side higher. CI = ±1.06 thorax rotation and ± 0.51 thorax lateral flexion. *Significantly different with TOPS ($p \leq .035$).

CHAPTER V

DISCUSSION

This study was designed to investigate the differences in body kinematics and in club performance between golfers' existing golf swings and a new swing (TOPS), while using two different clubs – the 9-iron and 6-iron clubs. Those clubs are typically used to hit approach shots to the green from some distance. Such shots require a combination of consistent speed, directional accuracy, and trajectory. TOPS required golfers to rotate the torso to face away from target before the commencement of the backswing, tilt the trail side of the head slightly towards the trail shoulder, and then to make an arms-only backswing so that, during that phase, the body would not have any lateral motion as assessed by weight shift, or any lead side lateral flexion. Participants were given four training sessions to learn TOPS.

Two body positions were identified to assess whether participants had complied with the main requirements of TOPS – the positioning of the thorax to face away from target at the start of the backswing, and the maintenance of the trail side thorax lower than the lead side, throughout the backswing. For both clubs, the existing backswing had a thorax that was open to target at address, and it was significantly ($4.71 \pm 4.61°$ vs $-18.66 \pm 7.31°$) closed, and facing away from target, with TOPS, as hypothesized (see Table 3).

Additionally, participants were able to maintain their trail side thorax in significantly (32.71 ± 5.46° vs 24.12 ± 5.53°) greater lateral flexion (i.e., significantly less lead-side lateral flexion) until the top of the backswing, with TOPS, for both clubs, as hypothesized (see Table 3).

The significant effect of club choice on three body positions (see Table 4) was combined across two very different swing styles, so that there was no specific reason for the difference, which was a maximum of 1.25° between the three measures. Moreover, the 95% confidence interval for thorax rotation and lateral flexion was 1.06º and 0.51º respectively, accounting for some of the difference seen.

One important finding of this study was that the standard deviations of club speed, angle of approach, and path were similar for existing swings and TOPS, indicating that golfers were able to consistently produce the new movements within four training sessions.

Club Angle of Approach and Related Kinematics

It is known that with a too-steep angle of approach, the clubface becomes delofted at impact, which then reduces the amount of backspin put on the ball. Golfers are therefore advised, by leading golf instructors, to acquire a shallower angle of approach (between 0° to 3° downwards), so that the clubface is not delofted, and can help the ball to “check” or stop on the green after it lands (Kinetek Sports, 2017). In the present study, the main effect of swing style on club movement was to make club angle of approach significantly shallower with TOPS, (4.84 ± 1.9° vs 2.55 ± 2.21°) for both clubs combined, as hypothesized, putting the club's angle of approach into the more desirable range of 0° to 3°, for greater ball trajectory.

Club Path and Related Kinematics

The club path is part of what influences the ball's starting direction. An "in-to-out" club path is necessary to hit a draw (Trackman, n.d.b); which is a shot that adds to the distance travelled by the ball, a desirable result for most golfers. The effect of swing style on club path resulted in a significantly more in-to-out club path with TOPS, as hypothesized (0.13 ± 4.3° for the existing swing vs 3.53 ± 4.33° with TOPS).

The path angle achieved by TOPS is in keeping with golf instructor Christoph Bausek's (Trackman, n.d.b) preference for a club path which is in the 3° to 6° range, because, according to him, a path of zero combined with a non-square (i.e., not perpendicular to the target line) direction of clubface aim at impact, will turn the ball to move away from target.

The opposite of the in-to-out path is the out-to-in one, created by an out-of-sequence over-the-top movement of the upper body or thorax when it precedes the pelvis in the downswing. Como (2018), has said that an over the top motion is not good from either a performance, or a safety, perspective. It is not good for swing speed, or in order to hit a straighter ball, or for solid contact. Additionally, from the safety perspective, an over the top motion inappropriately creates a lot of movement and power from the spine. The out-to-in path, moreover, is said to result in a pulled shot (left of target for the right-handed golfer) if the face of the club is "square" (perpendicular), to that club path, and results in a shot that is sliced to the right (for a right-handed golfer) if the clubface is open, a measure that was not assessed in the present study ("Over the Top," n.d.).

The kinematic movement that was assessed in this study to indicate a closed torso, which is associated with an in-to-out club path, was thorax rotation at impact. With their existing golf swings, across both clubs combined, golfers' mean thoracic rotation was open or facing target (9.72 ± 9.09°). With TOPS, mean thoracic rotation (-3.15 ± 7.93°) was significantly away from target. Golfers thus simultaneously had a more open thorax at impact with an almost-square (0.13 ± 4.3°) club path (neither in-to-out nor out-to-in) with their existing swings. With TOPS, golfers had a more closed thorax at impact and an in-to-out path (3.53 ± 4.33°).

It has been stated that when a closed thorax is combined with an in-to-out path and a shallower angle of approach, it is expected be difficult (Kanwar & Mann, 2018) to pull the arms across the chest and to the left (for a right-handed golfer) and thus TOPS may remove the likelihood of the pull group of shots which include a pull, a pull hook and a pull slice (Brad, 2009). Moreover, golf instructors recommend a closed position of the thorax at impact, in order to avoid an over the top downswing (Breed, 2015). Thus, TOPS may be able to eliminate the over the top movement as well as the resulting out-to-in path.

Club Speed Findings

In the present study, club speed was significantly less with TOPS as compared to the existing swing. This contradicts a previous study using a similar swing (Kiran & Mann, 2018) in which senior golfers were able to produce slightly greater ball speed with both the 6-iron (33.0 ± 9.9 m/s before, vs 33.3 ± 9.1 m/s after) and the driver clubs (41.9 ± 12.0 m/s before, vs 42.0 ± 11.6 m/s after). There was only one change between the instructions of the present study and the previous one using the TOPS methodology (Kanwar & Mann, 2018). In the present study, golfers were asked to lift the clubhead slightly off the ground in order to attempt to enable a greater torso rotation facing away from target during the address stage, while in the previous study the club remained grounded while torso rotation was made. It is believed that this difference, along with an inadequate emphasis on the direction of the arms' movement during the backswing, may have prevented golfers from a desirable downswing movement, with respect to club speed.

Low Back Pain and Associated Mechanical Causes

The statistical test for this hypothesis revealed that there was a significant main effect of club, across swing styles, for X-Factor and for thoracic forward tilt at impact. However, as the X-Factor difference in means across swing styles was 1.23°; probably the result of the combination of positions of two very different swing styles; and with a 95% confidence interval of 1.06º for thorax rotation and 0.65º for pelvic rotation, it need not be discussed further. Thoracic forward tilt at address was expected to be different for the two clubs across swing styles because the 9-iron is a shorter club than the 6-iron, and greater forward tilt is required when the ball is addressed with it. Therefore, no further discussion of this result is required.

With respect to swing styles, many body positions and movements have been considered mechanical factors affecting low back pain. They include the X-factor at the top of the backswing, trail side lateral flexion range or crunch range during the downswing, and a forward tilt of the spine at address. The X-Factor, which has been intentionally trained by instructors of the modern swing, has been defined as the difference between thoracic and pelvic rotations on a horizontal plane at the top of the backswing, and it is said that this differential rotation of the two segments can increase torsional loads on the spine (Cabri, Sousa, Kots, & Barreiros, 2009).

At address, both segments are said to have similar amounts of rotation. Then, while approaching the top of the backswing, the X-Factor becomes maximal, with the thorax having rotated considerably more than the pelvis (Lindsay & Vandervoort, 2014). Lindsay and Horton (2002) looked at six professional male golfers who always had back pain resulting from golf and six who never had back pain. They first assessed participants' (all right handed) maximal thoracic rotation to the right from an upright standing posture, thus testing what might be termed an active range of motion. Next, all participants hit shots with their driver clubs. During the golf backswing, those with low back pain made a thoracic rotation of 108.3 ± 20.0% of their neutral-posture rotational capabilities, while those without made 88.0 ± 24.9%. Although Lindsay and Horton did not directly discuss the X-Factor, if golfers' backswing thoracic rotations were to be reduced, they would perhaps be more likely to remain closer to their active ranges of upright rotary motion, rather than getting into what Lindsay and Horton described as "supramaximal" rotation, thus increasing spinal safety.

Lateral flexion (crunch) of the trail side of the torso during the downswing has been associated with low back pain separately (Gluck et al., 2008), and in combination with the velocity of axial rotation (Sugaya et al., 1998). In fact, the mathematical product of downswing lateral flexion angle and axial rotation velocity was termed the *crunch factor* by Sugaya et al., who opined that lateral bending angle and axial rotation velocity together contribute to trail side lumbar injury, including osteophyte formation and facet joint degeneration as seen in their radiographic study.

In a review article, Lindsay and Vandervoort (2014) have stated that reducing the amount of lateral side bend would reduce the lateral shear forces that contribute to low back pain. The problem of injury due to downswing lateral flexion is exacerbated because the movement takes place at great speed. The authors (Lindsay et al., 2002) of research involving male professional golfers were surprised to discover that the velocity of the downswing with a 7 iron (121.7 ± 24.8°/s) was significantly greater (p = .02) than with a driver (109.2 ± 25.3°/s), which is a club that is moved with greater overall velocity. Downswing velocity of trail-side lateral flexion could be an important factor in the exacerbation of the effect of crunch. As the 7-iron club whose velocity was assessed by Lindsay et al., is similar in its length and design to the 9- and 6-irons of the present study, the velocity for these clubs too would be expected to be greater.

In the present study, golfers' crunch range went from 52.22 ± 9.6° with existing swings to 42.12 ± 7.74° with TOPS, an approximately 10° of reduction. The reduction of trail side crunch from top of backswing to impact might serve to reduce shear loads on the low back.

Forward tilt of the spine, assessed in the present study as forward thoracic tilt (the thorax here encompassing both the thoracic and lumbar spinal regions), was seen to be greater in the Lindsay and Horton (2002) study. Using a Lumbar Motion Monitor, they measured angles formed between the mid- and lower-backs, while golfers hit shots with their driver clubs. Golfers with low back pain had a greater amount of forward tilt (not significant), with a mean spinal angle of 37.0 ± 11.4°, while those without had a mean of 25.3 ± 6.6°, leading Lindsay and Horton to opine that greater forward tilt at address may have led to pain. The difference between the two groups was approximately 12°, but was only approximately 6° in the present study. However, Takahashi, Kikuchi, Sato, and Sato (2006) demonstrated that the difference in load on the L4-L5 intervertebral disc was almost doubled when participants (non-golfers) were in 10° of forward tilt, compared to when they were upright (1277N vs 645N). TOPS' more upright posture might help to reduce loads on the low back, and the difference of approximately 6° between the existing swing set up and TOPS' is encouraging, given the shortness of the iron clubs of this study.

Additionally, and although not a part of the low back pain analysis, Lindsay and Horton's (2002) participants with low back pain had significantly (p = 0.01) greater lead side lateral trunk flexion at the top of the backswing (6.7 ± 3.2°) compared to those who did not (0.5 ± 3.1°). The quantity of lateral flexion reported was for the driver club, and so is likely to be greater for the iron clubs, as seen in the comparative study of the driver and 7-iron clubs of Lindsay et al. (2002). Lindsay and Horton were unclear as to the reason for those with low back pain having significantly greater lead lateral flexion at the top of the backswing. Regardless of the reason, the TOPS swing is designed to reduce, or ideally eliminate, lead side lateral flexion during the backswing. Lead side lateral flexion in the present study was significantly ($p < .001$) lower with TOPS than with existing swings (see Table 3). It may thus be stated that TOPS is able to reduce many of the mechanical factors that either have been correlated with low back pain, or have been observed to be greater in those with existing low back pain.

It may thus be concluded that the implementation of the new swing style showed that golfers were able to produce a more desirable club angle of approach and club path to the ball, perhaps indicating the swing style's ability to produce shots without a leftward miss and with expectedly better trajectory. The body movements representative of TOPS, and one of two movements that indicate desirable club movements, were also demonstrated with the use of that swing style. Finally, with TOPS, many of the factors commonly implicated in low back pain were significantly reduced. Importantly, based on the range of participant characteristics of this study, TOPS may be beneficial for many golfers, with respect to their gender, age, handicap, and golf experience.

From the findings of this study, it may be concluded that golfers are, within four training sessions, able to:

1. Make desired TOPS changes because it has very specific steps that are required to be repeated.
2. Generate desirable angles of approach and path, so that approach shots hit with the 9- or 6-iron approach clubs would be more likely to land on, and stay on, the green.

3. Make swing changes that stabilize adequately to be measured and produced variance (measured through standard deviation) in club speed, angle of approach and path that are similar to golfers' existing swings (see Table 6).

Limitations

The main limitations of this study were that ball parameters at impact (speed, starting direction, and starting trajectory) were not measured. Thus *smash factor*, which is calculated as ball speed divided by club speed could not be assessed. It is indicative of the amount of energy passed on to the ball from the club, and may have been greater with TOPS because golfers do not move off their starting positions excessively, and are more likely to deliver the club to the correct part of the ball. While the club's angle of approach to the ball was assessed, it, together with the club's dynamic loft at impact determines the ball's trajectory, but the latter was not calculated. Similarly, while club path was assessed, the direction in which the clubface was pointing was not, and these two factors together determine the ball's direction. It is expected, that with TOPS the dynamic loft would be greater, and the clubface would be pointing either at or slightly right of target.

Future Research Recommendations

Future studies with TOPS should include the measurement of ball movement, and should also incorporate the use of longer clubs such as the driver. Joint forces and moments at the lumbar spine and at other joints such as the hips and knees could be calculated to assess the swing's ability to increase golfer safety. Additionally, a longitudinal study could be conducted using a commonly used pain assessment instrument such as the visual analogue scale for pain (VAS), to assess participants' level of low back pain before and after the intervention.

Research involving both existing swings and TOPS that included electromyography would be beneficial in shedding light on the activation levels of the important muscles of the golf swing. Other golf swing styles that have specific movements that are trained should also be tested for their ability to help golfers' performance and increase the safety of the movement, as golfers in general have both inconsistent performance, and suffer golf swing-related injury. The reason for testing swing styles that have precise steps to be followed is that golfers could benefit from being given specific guidelines for the positions and movements they should make, so that those movements may be learned faster and would be easier to self-regulate.

REFERENCES

Adams, M. [Golf Education Asia]. (2017, June 5). *Load and launch* [Video file]. Retrieved from https://www.youtube.com/watch?v=_OwN-m92b8E

Aggarwal, A., Shenoy, S., & Singh, S. J. (2008). Comparison of lumbar and abdominal muscle activation during two types of golf swing: An EMG analysis. *RICYDE. Revista Internacional de Ciencias del Deporte*, *4*(12), 59-71.

Bačić, B. (2014). Learning golf drive: Natural swing path tendency to slice, fade or pull. *ISBS-Conference proceedings archive* (pp. 276-279).

Beak, S. H., Choi, A., Choi, S. W., Oh, S. E., Mun, J. H., Yang, H., ... & Song, H. R. (2013). Upper torso and pelvis linear velocity during the downswing of elite golfers. *Biomedical Engineering Online*, *12*(1), 13.

Brad. (2009, August 1). Ball flights: Pull, pull-hook and pull-slice. [Blog post]. Retrieved from https://www.americangolf.com/blog/golf-tips/ball-flights-pull-pull-hook-and-pull-slice/

Breed, M. [Golf Channel] (2015, April 6). *The golf fix – stop coming over the top* [Video file]. Retrieved from https://www.youtube.com/watch?v=SYtoiQBXOFc

Bressler, S. L., & Kelso, J. S. (2001). Cortical coordination dynamics and cognition. *Trends in Cognitive Sciences*, *5*(1), 26-36.

Broadie, M. (2015, January 2). Improving your approach shots is the fastest way to lower scores. Retrieved from https://www.golf.com/instruction/mark-broadie-new-approach-golf-mag-jan-2015

Brown, S. J., Selbie, W. S., & Wallace, E. S. (2013). The X-Factor: An evaluation of common methods used to analyse major inter-segment kinematics during the golf swing. *Journal of Sports Sciences*, *31*, 1156-1163.

Bulbulian, R., Ball, K. A., & Seaman, D. R. (2001). The short golf backswing: effects on performance and spinal health implications. *Journal of Manipulative and Physiological Therapeutics*, *24*, 569-575.

Burden, A.M., Grimshaw, P. N., & Wallace, E. S. (1998). Hip and shoulder rotations during the golf swing of sub-10 handicap players. *Journal of Sports Sciences*, *16*, 165-176.

Cabri, J., Sousa, J. P., Kots, M., & Barreiros, J. (2009). Golf-related injuries: a systematic review. *European Journal of Sport Science*, *9*, 353-366.

Cheetham, P. J., Martin, P. E., Mottram, R. E., & St Laurent, B. F. (2001). The importance of stretching the "X-Factor" in the downswing of golf: The "X-Factor Stretch." In P. R. Thomas (Ed.), *Optimising Performance in Golf* (pp. 192-199). Brisbane, Australia: Australian Academic Press.

Cheetham, P. J., Rose, G. A., Hinrichs, R. N., Neal, R. J., Mottram, R. E., Hurrion, P. D., & Vint, P. F. (2008). Comparison of kinematic sequence parameters between amateur and professional golfers. In D. Crews & R. Lutz (Eds.). *Science and golf V: Proceedings of the world scientific congress of golf* (pp. 30-36). Mesa, AZ: Energy in Motion.

Chu, Y., Sell, T. C., & Lephart, S. M. (2010). The relationship between biomechanical variables and driving performance during the golf swing. *Journal of Sports Sciences*, *28*, 1251-1259.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, NJ: Lawrence Erlbaum Associates.

Cole, M. H., & Grimshaw, P. N. (2014). The crunch factor's role in golf-related low back pain. *The Spine Journal*, *14*, 799-807.

Como, C. [Golf Channel]. (2018, November 13). *'Como Concepts': Multidisciplinary experts improve your game* [Video file]. Retrieved from https://www.golfchannel.com/video/como-concepts-experts-join-chris-comos-series

Dale, R. B., & Brumitt, J. (2016). Spine biomechanics associated with the shortened, modern one-plane golf swing. *Sports Biomechanics*, *15*, 198-206.

Descending pathways. (n.d.). Retrieved from https://courses.washington.edu/conj/bess/motor/descendingpathways.html

Driving distance. Y-T-D-statistics through: TOUR Championship. (2019, August 26). Retrieved from https://www.pgatour.com/stats/stat.101.html

Driving accuracy percentage. Y-T-D-statistics through: TOUR Championship. (2019, August 26). Retrieved from https://www.pgatour.com/stats/stat.102.html

Esola, M. A., McClure, P. W., Fitzgerald, G. K., & Siegler, S. (1996). Analysis of lumbar spine and hip motion during forward bending in subjects with and without a history of low back pain. *Spine*, *21*, 71-78.

Fleisig, G. S. (1994). The lower extremity. In C. N. Stover, J. R. McCarroll, & W. J. Mallon (Eds.), *Feeling up to par: Medicine from tee to green* (pp. 17- 26). Philadelphia, PA: F. A. Davis Company.

Foxworth, J. L., Millar, A. L., Long, B. L., Way, M., Vellucci, M. W., & Vogler, J. D. (2013). Hip joint torques during the golf swing of young and senior healthy males. *Journal of Orthopaedic & Sports Physical Therapy*, *43*, 660-665.

Gluck, G. S., Bendo, J. A., & Spivak, J. M. (2008). The lumbar spine and low back pain in golf: a literature review of swing biomechanics and injury prevention. *The Spine Journal*, *8*, 778-788.

Grimshaw, P. N., & Burden, A. M. (2000). Case report: reduction of low back pain in a professional golfer. *Medicine and Science in Sports and Exercise*, *32*, 1667-1673.

Handford, C., Davids, K., Bennett, S., & Button, C. (1997). Skill acquisition in sport: Some applications of an evolving practice ecology. *Journal of Sports Sciences*, *15*, 621-640.

Hauer, K., Schwenk, M., Zieschang, T., Essig, M., Becker, C., & Oster, P. (2012). Physical training improves motor performance in people with dementia: a randomized controlled trial. *Journal of the American Geriatrics Society*, *60*, 8-15.

Henderson, M. (2014, August 20). Instruction: How to stop coming over the top. Retrieved from https://www.pgatour.com/instruction/2014/08/20/golf-tips-driving-stop-coming-over-top-swing.html

Hogan, N. (1985). The mechanics of multi-joint posture and movement control. *Biological Cybernetics*, *52*, 315-331.

Horan, S. A., Evans, K., Morris, N. R., & Kavanagh, J. J. (2010). Thorax and pelvis kinematics during the downswing of male and female skilled golfers. *Journal of Biomechanics*, *43*, 1456-1462.

Hosea, T. M., Gatt, C. J., Gertner, E. (1990). Biomechanical analysis of the golfer's back. In C. N. Stover, J. R. McCarroll, & W. J. Mallon (Eds.), *Feeling up to par: Medicine from tee to green* (pp. 97 - 108). Philadelphia, PA: F. A. Davis Company.

Hume, P. A., Keogh, J., & Reid, D. (2005). The role of biomechanics in maximising distance and accuracy of golf shots. *Sports Medicine*, *35*, 429-449.

Jorgensen Jr, T. (1970). On the dynamics of the swing of a golf club. *American Journal of Physics*, *38*, 644-651.

Joyce, C., Burnett, A., Cochrane, J., & Ball, K. (2013). Three-dimensional trunk kinematics in golf: between-club differences and relationships to clubhead speed. *Sports Biomechanics*, *12*, 108-120.

Joyce, C. (2017). The most important "factor" in producing clubhead speed in golf. *Human Movement Science*, *55*, 138-144.

Kanwar, K. D., & Mann, M. D. (2018). Effects of a golf swing intervention on senior golfers' ball striking and motivation to play golf. *International Journal of Sports Science & Coaching*, *13*, 607-615.

Keogh, J. W., & Hume, P. A. (2012). Evidence for biomechanics and motor learning research improving golf performance. *Sports Biomechanics*, *11*, 288-309.

Kinetek Sports. (2017, October 30). Know your numbers: Angle of attack [Blog post]. Retrieved from https://www.clubhubgolf.com/know-numbers-angle-attack/)

Komi, P. V. (2000). Stretch-shortening cycle: A powerful model to study normal and fatigued muscle. *Journal of Biomechanics*, *33*, 1197-1206.

Kwon, Y. H. (2008). Measurement for deriving kinematic parameters: Numerical methods. In Y. Hong & R. Bartlett (Eds). *Routledge handbook of biomechanics and human movement science* (pp. 156-181). London: Routledge.

Kwon, Y. H., Como, C. S., Singhal, K., Lee, S., & Han, K. H. (2012). Assessment of planarity of the golf swing based on the functional swing plane of the clubhead and motion planes of the body points. *Sports Biomechanics, 11*, 127-148.

Kwon, Y. H., Han, K. H., Como, C., Lee, S., & Singhal, K. (2013). Validity of the X-factor computation methods and relationship between the X-factor parameters and clubhead velocity in skilled golfers. *Sports Biomechanics*, *12*, 231-246.

Lamb, P. F., & Glazier, P. S. (2017). The sequence of body segment interactions in the golf swing. In M.Toms (Ed.), *Routledge international handbook of golf science* (pp. 26–34). London: Routledge.

Latash, M. L. (2012). The bliss (not the problem) of motor abundance (not redundancy). *Experimental Brain Research*, *217*, 1-5.

Learn to control your trajectory. (2016, August 16). Retrieved from https://pluggedingolf.com/learn-control-trajectory/

Lemak, L. J., Fleisig, G. S., Welch, C. M., Marting, B., & Zvijac, J. E. (1994). Usefulness of Partial Swings in the Rehabilitation of a Golfer. In A. J. Cochran & M. R.

Farrally (Eds). *Science and golf II, Proceedings of the first world scientific congress of golf* (pp. 14 – 19). London: E & FN Spon 50-58.

Lindsay, D., & Horton, J. (2002). Comparison of spine motion in elite golfers with and without low back pain. *Journal of Sports Sciences, 20*, 599-605.

Lindsay, D. M., Horton, J. F., & Paley, R. D. (2002). Trunk motion of male professional golfers using two different golf clubs. *Journal of Applied Biomechanics*, *18*, 366-373.

Lindsay, D. M., Mantrop, S., & Vandervoort, A. A. (2008). A review of biomechanical differences between golfers of varied skill levels. *International Journal of Sports Science & Coaching*, *3*, 187-197.

Lindsay, D. M., & Vandervoort, A. A. (2014). Golf-related low back pain: A review of causative factors and prevention strategies. *Asian Journal of Sports Medicine*, *5*(4), e24289.

Loock, H. V., Grace, J. M., & Semple, S. J. (2013). Core muscle activation and activity throughout the different phases of the golf swing: A literature review. *Strength & Conditioning Journal*, *35*(5), 1-15.

Mann, J. (2010, June). Ball flight laws. Retrieved from http://perfectgolfswingreview.net/ballflight.htm

McHardy, A. J., & Pollard, H. P. (2005). Golf and upper limb injuries: A summary and review of the literature. *Chiropractic & Osteopathy*, *13*, 7.

McHardy, A., Pollard, H., & Bayley, G. (2006). A comparison of the modern and classic golf swing: A clinician's perspective. *South African Journal of Sports Medicine,* *18*(3), 80-91.

Marshall, R. N., & Elliott, B. C. (2000). Long-axis rotation: The missing link in proximal-to-distal segmental sequencing. *Journal of Sports Sciences*, *18*, 247-254.

McCarroll, J. R. (1994). The lower extremity. In C. N. Stover, J. R. McCarroll, & W. J. Mallon (Eds.), *Feeling up to par: Medicine from tee to green* (pp. 165-169). Philadelphia, PA: F. A. Davis Company.

Miura, K. (2001). Parametric acceleration–the effect of inward pull of the golf club at impact stage. *Sports Engineering*, *4*(2), 75-86.

Murayama, N., Lin, Y. Y., Salenius, S., & Hari, R. (2001). Oscillatory interaction between human motor cortex and trunk muscles during isometric contraction. *Neuroimage*, *14*, 1206-1213.

Myers, J., Lephart, S., Tsai, Y. S., Sell, T., Smoliga, J., & Jolly, J. (2008). The role of upper torso and pelvis rotation in driving performance during the golf swing. *Journal of Sports Sciences*, *26*, 181-188.

Neal, R., Lumsden, R., Holland, M., & Mason, B. (2007). Body segment sequencing and timing in golf. *International Journal of Sports Science & Coaching*, *2*, 25-36.

Nesbit, S. M., & Serrano, M. (2005). Work and power analysis of the golf swing. *Journal of Sports Science & Medicine*, *4*, 520.

Newsham, G. (2016, August 6). Millenials are ditching golf because it’s too hard and boring. Retrieved from https://nypost.com/2016/08/06/millennials-are-ditching-golf-because-its-too-hard-and-boring/

Oja, P., Titze, S., Kokko, S., Kujala, U. M., Heinonen, A., Kelly, P., ... & Foster, C. (2015). Health benefits of different sport disciplines for adults: Systematic review of observational and intervention studies with meta-analysis. *British Journal of Sports Medicine*, *4*(49), 1-22. doi:10.1136/bjsports-2014-093885

Okuda, I., Gribble, P., & Armstrong, C. (2010). Trunk rotation and weight transfer patterns between skilled and low skilled golfers. *Journal of Sports Science & Medicine*, *9*, 127.

Over the top. (n.d.). Retrieved from http://www.mytpi.com/improve-my-game/swing-characteristics/over-the-top_v2

Picchi, M. (2014, May 23). Where have all the golfers gone? Retrieved from https://www.cbsnews.com/news/where-have-all-the-golfers-gone/

Putnam, C. A. (1993). Sequential motions of body segments in striking and throwing skills: Descriptions and explanations. *Journal of Biomechanics*, *26*, 125-135.

Reverse spine angle. (n.d.). Retrieved from http://www.mytpi.com/improve-my-game/swing-characteristics/reverse-spine-angle_v2

Rose, G. [MyTPI]. (2017, May 9). *Breaking down the relationship between vertical jump and power in golf* [Video file]. Retrieved from https://www.youtube.com/watch?v=zeFCPaYFTzo.

Sanders, R. H., & Owens, P. C. (1992). Hub movement during the swing of elite and novice golfers. *International Journal of Sport Biomechanics*, *8*, 320-330.

Schiffman, R. (2010, October 16). Jim McLean’s new X-Factor. Retrieved from https://www.golfdigest.com/story/jim-mcleans-new-x-factor

Sim, T., Choi, A., Lee, S., & Mun, J. H. (2017). How to quantify the transition phase during golf swing performance: Torsional load affects low back complaints during the transition phase. *Journal of Sports Sciences*, *35,* 2051-2059.

Slope of a line and angle between two lines. (n.d.). Retrieved from https://byjus.com/maths/slope-of-line/

Smith, J. A., Hawkins, A., Grant-Beuttler, M., Beuttler, R., & Lee, S. P. (2018). Risk factors associated with low back pain in golfers: A systematic review and meta-analysis. *Sports Health*, *10*(6), 538-546.

Snell, R. S. (2006). *Clinical neuroanatomy*. Philadelphia, PA: Lippincott Williams & Wilkins.

Statista. (2019, August 23). Number of participants in golf in the United States from 2006 to 2018 (in millions)* [Graph]. Retrieved from https://www.statista.com/statistics/191907/participants-in-golf-in-the-us-since-2006/

Sugaya, H., Tsuchiya, A., Moriya, H., Morgan, D.A., & Banks, S. A. (1998). Low back injury in elite and professional golfers: An epidemiologic and radiographic study. In M. R. Farrally & A. J. Cochran (Eds.), *Science and golf III: Proceedings of the world scientific congress of golf 1998* (pp. 83-91). London: E & F Spon.

Suttie, J. (2008, May 14). The most important move in golf…get in the slot. Retrieved from http://archive.naplesnews.com/sports/golf/jim-suttie-the-most-important-move-in-golf--get-in-the-slot-ep-401732634-344512472.html/

Takagi, T. (2018). Joint motions affecting the energy transfer to the club during the golf swing. *ISBS Proceedings Archive*, *36*, 972.

Takahashi, I., Kikuchi, S. I., Sato, K., & Sato, N. (2006). Mechanical load of the lumbar spine during forward bending motion of the trunk–a biomechanical study. *Spine*, *31*, 18-23.

Tinmark, F., Hellström, J., Halvorsen, K., & Thorstensson, A. (2010). Elite golfers' kinematic sequence in full-swing and partial-swing shots. *Sports Biomechanics, 9*, 236-244.

Trackman. (n.d.a). What is attack angle [Blog post]. Retrieved from https://blog.trackmangolf.com/attack-angle/

Trackman. (n.d.b). What is club path? [Blog post] Retrieved from https://blog.trackmangolf.com/club-path

Wiren, G. (1990). Laws, principles and preferences: A teaching model. In A. J. Cochran (Ed.), *Science and golf: Proceedings of the first world scientific congress of golf* (pp. 3-14). London: E and FN Spon.

Zheng, N., Barrentine, S. W., Fleisig, G. S., & Andrews, J. R. (2008). Kinematic analysis of swing in pro and amateur golfers. *International Journal of Sports Medicine*, *29*, 487-493.

APPENDIX A

TWU IRB

Institutional Review Board
Office of Research and Sponsored Programs
P.O. Box 425619, Denton, TX 76204-5619
940-898-3378
email: IRB@twu.edu
https://www.twu.edu/institutional-review-board-irb/

DATE: February 6, 2019

TO: Ms. Kiran Kanwar
Health Promotion & Kinesiology

FROM: Institutional Review Board (IRB) - Denton

Re: Approval for Differences in Ball Flight Parameters and in Kinematics between two Golf Swing Styles (Protocol #: 20429)

The above referenced study was reviewed at a fully convened meeting of the Denton IRB (operating under FWA00000178). The study was approved on 1/30/2019. This approval is valid for one year and expires on 1/30/2020. The IRB will send an email notification 45 days prior to the expiration date with instructions to extend or close the study. It is your responsibility to request an extension for the study if it is not yet complete, to close the protocol file when the study is complete, and to make certain that the study is not conducted beyond the expiration date.

If applicable, agency approval letters must be submitted to the IRB upon receipt prior to any data collection at that agency. A copy of the approved consent form with the IRB approval stamp is enclosed. Please use the consent form with the most recent approval date stamp when obtaining consent from your participants. A copy of the signed consent forms must be submitted with the request to close the study file at the completion of the study.

Any modifications to this study must be submitted for review to the IRB using the Modification Request Form. Additionally, the IRB must be notified immediately of any adverse events or unanticipated problems. All forms are located on the IRB website. If you have any questions, please contact the TWU IRB.

cc. Dr. George King, Health Promotion & Kinesiology
Dr. Mark Mann, Health Promotion & Kinesiology

APPENDIX B

USC CEDED IRB

Institutional Review Board (IRB) Authorization Agreement

Name of Institution Providing IRB Review:	Texas Woman's University (TWU)
IRB Registration #:	0000506
Federalwide Assurance (FWA) #:	FWA 00000178

Name of Institution Relying on Designated IRB:	University of Southern California (USC)
IRB Registration #:	IRB00000484, IRB00002880, IRB00002881
FWA #:	00005906

The Officials signing below agree that University of Sourthern California may rely on the Texas Woman's University IRB for review and continuing oversight of its human subjects research described below:

IRB Protocol # 20429

Study Title: Differences in Ball Flight Parameters and in Kinematics between two Golf Swing Styles

PIs Kiran Kanwar

The review performed by the TWU IRB will meet the human subject protection requirements of *USC*'s OHRP-approved FWA. The TWU IRB providing the review will follow written procedures for reporting its findings and actions to appropriate officials at *USC*. Relevant minutes of IRB meetings will be made available to *USC* upon request. *USC* remains responsible for ensuring compliance with the TWU IRB's determinations and with the Terms of its OHRP-approved FWA. This document must be kept on file by both parties and provided to OHRP upon request.

Signature of TWU Signatory Official:

[signature] Date: 2/1/18

Alan Utter
Provost

Signature of the USC Signatory Official:

[signature] Date: 2-4-2019

Name of Signatory Official Kristin Craun
Title of Signatory Official Senior IRB Director

APPENDIX C

INFORMED CONSENT FORM

University of Southern California
Division of Biokinesiology and Physical Therapy
and
Texas Woman's University
School of Health Promotion and Kinesiology

INFORMED CONSENT

TITLE: DIFFERENCES IN BALL FLIGHT PARAMETERS AND IN KINEMATICS BETWEEN TWO GOLF SWING STYLES

PRINCIPAL INVESTIGATOR: KIRAN KANWAR, DOCTORAL CANDIDATE
kkanwar@twu.edu (314) 488-5981

FACULTY ADVISORS: Mark Mann, PhD mmann2@twu.edu (940) 898-2578
George Salem, PhD gsalem@pt.usc.edu (323) 442-3113

We invite you to take part in a research study. The study has two parts. The golf swing testing at USC's Division of Biokinesiology and Physical Therapy's Musculoskeletal Biomechanics Research Laboratory (MBRL), and the swing training at Don Knabe Golf Center, Nowalk, CA.

KEY INFORMATION
This study is being conducted for research.

Purpose: Golfers are always seeking ways to improve the distance, direction and trajectory of their golf shots. This study will compare a novel golf swing to your existing golf swing to study the differences in the two swing styles with respect to club speed, club path and club angle of approach. It will also study the differences in your body's positions and movements with the two swing styles. The differences will be studied for the 6-iron and 9-iron clubs. The new swing is expected to improve performance and reduce some injury risk factors.

Main activities and procedures: There will be one testing session in the laboratory to study the movements of your body and clubs with your existing swing. You will then be given four training sessions in the novel golf swing at a local driving range. Finally, there will be a testing session in the laboratory to study your body's movements with the new golf swing. You will use a 6-iron and a 9-iron club for all sessions. During laboratory sessions, you will be asked to wear no shirt if male and a sleeveless shirt if female along with spandex shorts. You will also be asked to wear firm-soled athletic/tennis shoes, and gloves if required.

Total time commitment: Your total time commitment for all six sessions will be 11 hours.

Major risks associated with participation in this study: There is a risk of loss of confidentiality and/or anonymity. There is the risk of embarrassment. There may be discomfort during motion capture and/or fatigue from hitting golf balls. Other risks include the risk of muscle soreness, injury, loss of time and changes to your existing swing. In all of the above cases you are free to discontinue participation. You can also return to your existing golf swing once the study ends.

Inclusion and exclusion criteria: Inclusion criteria are right-handed golfers who are 18 or more years old. Participants should have played golf a minimum of 20 times during the past two years and have a golf handicap of 24 or less or a scoring ability of 94 or less. Exclusion criteria are any musculoskeletal injury or orthopedic surgery during the past four months.

Key information specific to this study: The new golf swing requires you to "address the ball" (set-up to the ball in preparation for starting the backswing) standing in a stance which is as upright as comfortably possible. You will then be asked to rotate your torso to face away from the target. Additionally, you will be asked to tilt your head slightly, towards your right shoulder, as you are a right-handed golfer. The backswing will be made with your arms only, while your torso and head should not move. During the downswing, you will be asked to continue to maintain the position of the head that you set-up with (tilted slightly towards your right shoulder) and no other swing thought is required.

The concept behind this swing is that it reduces unnecessary movement during the entire swing, and places all the body's joints in positions they can be more effective from. This type of study has not been conducted previously, and may offer valuable insight to all skill levels of golfers, regarding ways and means to improve set-up and backswing positions, which could lead to better ball flight and which may also reduce some of the risk factors of low back pain.

RESEARCH QUESTIONS

- Will the new golf swing - The Optimal Performance Swing (TOPS) -improve your club-speed, club path and club angle of approach with the 6-iron and the 9-iron clubs, compared to your existing golf swing?
- Will there be a difference in the positions of the body with the use of TOPS compared to your existing golf swing?
- Will some of the positions or movements known to cause injury to the lower back be changed with the use of TOPS compared to your existing golf swing?

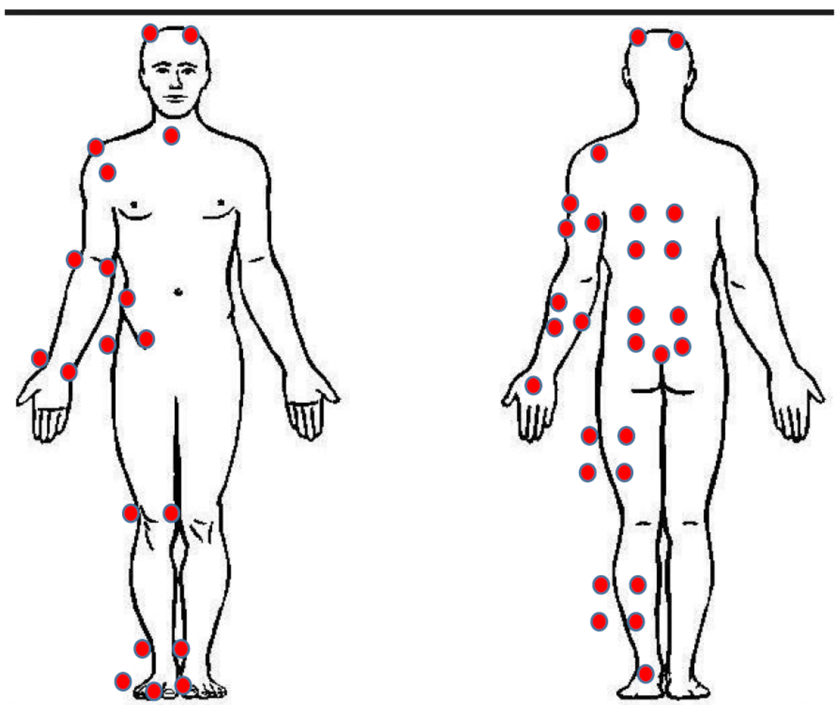
RESEARCH PROCEDURES

If you are willing to participate, there will be a total of two (2) visits to the Musculoskeletal Biomechanics Research Laboratory (MBRL) at USC in the Center for Health Professionals Building (CHP). These two visits will take place at the beginning and at the end of the study, and each of them will last up to a maximum of 2.5 hours. Between those two dates, there will be four (4) golf swing training sessions at the Don Knabe Golf Center's Driving Range. Each training session will last up to a maximum of 1.5 hours. All six sessions will be completed within seven to ten days.

Once you agree to participate in the study, you will be asked to arrive at University of Southern California's Division of Biokinesiology and Physical Therapy's Musculoskeletal Biomechanics Research Laboratory (MBRL). It is located at 1540 Alcazar St., Los Angeles, CA, 90033. You will be requested to be shirtless if male and wear a sleeveless shirt if female, along with spandex shorts during data collection. You will also be requested to wear athletic/tennis shoes with a tough sole. You may wear a glove/gloves if you wish to.

You will be taken to the privacy of the laboratory and allowed to read the Informed Consent Form. Once you have read, understood and signed the Informed Consent Form, the golf study will commence.

Forty three reflective markers and 10 marker plates have been placed on your head, arms, chest, hips and legs (see diagram below). These markers will be placed on you in order for the cameras to pick up the movement of the various body parts as you perform the golf swing. The tape used to attach the markers is designed for sensitive skin.



Location	Total
Individual Markers	
Head: front (2) back (2)	4
Shoulder, per side top, front, back 3 x 2 sides	6
Base of neck, front, one	1
Elbow, per side, outer, inner, 2 x 2	4
Wrist, per side, outer, inner 2 x 2	4
Hand per side 1 x 2	2
Pelvis, per side, hip, top of pelvis, front of pelvis 3 x 2	6
Knee, per side, outer, inner 2 x 2	4
Ankle, per side, outer, inner 2 x 2	4
Foot, per side, outer, inner, front, back 4 x 2	8
Total individual markers	**43**
Marker Plates	
Thigh, per side, one plate x 2	2
Lower leg, per side, one plate x 2	2
Upper back, one plate	1
Lower back, one plate	1
Upper arm, per side one plate x 2	2
Fore arm, per side one plate x 2	2
Total marker plates	**10**

After the markers have been placed on your body, you will be given time for a warm-up and familiarization period. This will provide adequate time to raise your core temperature which will serve to warm up all body tissue, thus reducing the possibility of muscle soreness, and ensuring good quality of movement. This period will also help you to familiarize yourself with hitting a plastic ball off a golf mat, while using your 6-iron and then 9-iron clubs.

DETAILED PROCEDURES

First Visit:

The total visit will last no more than 2.5 hours.

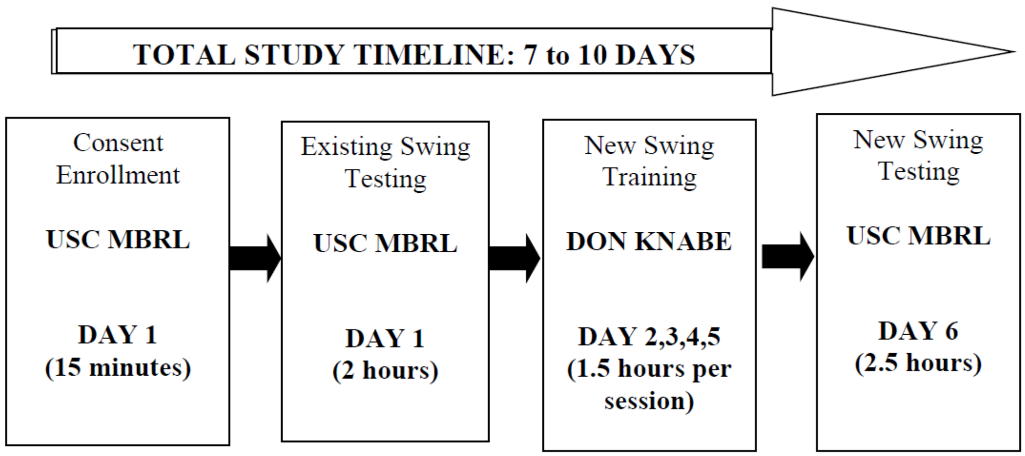
1. We will measure your weight and height.
2. We will place retroreflective markers and marker plates on your body, then request you to warm up in your usual manner.
3. We will ask you to hit 10 shots each with your existing swing, using your own 6-iron and 9-iron clubs while hitting a plastic ball placed on a mat.
4. You will be given as much rest between shots as required.
5. We will request you to complete a brief survey about your current golf shots.

Second to Fifth Visits:

1. You will receive instruction with the new swing while using your 6-iron and 9-iron clubs at the Don Knabe Golf Center's Driving Range.
2. You will be able to hit as many practice shots as you wish to, to learn the new swing.
3. You will be given as much rest between shots as required.

Sixth Visit:

1. We will place retroreflective markers and marker plates on your body, then request you to warm up in your usual manner.
2. We will ask you to hit 10 shots each with the new swing, using your own 6-iron club and your 9-iron club while hitting a plastic ball placed on a mat.
3. You will be given as much rest between shots as required.
4. We will request you to complete a brief survey about your opinion of the new swing



WHAT ARE THE POSSIBLE BENEFITS OF TAKING PART IN THIS STUDY

Your involvement in this research study is completely voluntary, and you may discontinue your participation in the study at any time. The direct benefits of this study to you is from four free golf lessons from an LPGA Master Profession Golf Instructor with 30 years of teaching experience, and you will also be provided golf balls for use during the four training sessions, at no cost to you. Additionally, a summary of the results will be shown to you, if requested, upon completion of the study. If you have any further questions you are welcome to contact the principal investigator and set-up an appointment for a private consultation to discuss your individual results. The time, date, and location will be determined at the time of contact.

WHAT ARE THE POSSIBLE RISKS AND DISCOMFORTS

Loss of Confidentiality: You, as a participant, will be identified by a unique participant ID code. All computer files associated with you will be identified solely by this code and will not contain any identifying information. The master cross-reference list, which will also not contain your name, but will contain your unique ID code and details regarding your date of birth, height, weight, golf handicap and years playing golf. It will be saved electronically, separate from all other data collected, and will be accessible only to the principal investigator, in her password protected TWU student google-drive. No other identifying information will be collected.

Upon completion of the entire study, all your identifiable private information will be destroyed as follows: Swing Trial Information Sheet will be destroyed by deletion. As other computer files (such as data analysis files in Excel or SPSS) will not contain any identifying information, erasure of computer files is not considered necessary to protect confidentiality after destruction of the Swing Trial Information Sheet. All recorded motion-capture and video files are stored only in the MBRL's Data Drive, and will once again be referenced only by your unique identification code. All collected data will be erased from the devices immediately upon completion of the study. Information about you collected as part of this research study, even after all identifiers are removed, will not be used or distributed for future research studies.

There is a potential risk of loss of confidentiality in all email, downloading, electronic meetings, and internet transactions. Confidentiality will be protected to the extent that is allowed by the law.

If you would like to participate in the current study but not allow your de-identified data to be used for future research, please initial here________________________

Embarrassment: If you feel uncomfortable at any time during data collection or golf training, you are free to terminate any session or discontinue your participation with the research study, according to your preference.

Possibility of Injury: The potential for muscle soreness will be minimized by allowing you adequate time to warm-up and adjust to the conditions of the laboratory and to hitting golf balls off a golf mat, while having markers placed on your body. Adequate time will also be provided for you to adjust to the golf swing style being used by you for each set of swing trials. You will also be given adequate time to warm up at the start of all the driving range golf training sessions. If you feel uncomfortable at any time during data collection, with any of the testing conditions, or during the golf swing training sessions, you are free to discontinue your involvement in this research project at any time.

There may be a risk of muscle soreness, falling or injury; however, the risk is no greater than performing these activities in your daily life. In case of injury, first aid will be administered to you and you will be referred to your doctor/health care professional.

Discomfort during motion capture: There may be slight discomfort at the site on the skin where the motion capture markers or small pieces of tape are placed even though the tape is specifically designed to be safe for sensitive skins.

Fatigue: If you feel uncomfortable or tired in between testing sessions, you will be allowed to rest until you feel capable of continuing with the required procedures.

Loss of Time: There is a risk of loss of time to you. The loss of time will comprise time required for you to warm up, for the data collection, for the golf lessons, and travel time to and from the laboratory and the golf driving range. There will not be any monetary compensation for this loss of time.

Changes to Existing Golf Swing: Your swing may change as a result of the swing intervention. You are free to stop participation in the study at any time. You may also return to your original swing after the study.

Loss of Anonymity: Although all attempts will be made to protect your anonymity by not disclosing your identity to anyone present, your anonymity cannot be completely prevented. You are free to discontinue this study at any time.

The researchers will try to prevent any problems that could occur because of this research. You should let the researchers know at once if there is a problem and they will help you. However, neither Texas Woman's University nor University of Southern California can provide medical services or financial assistance for injuries that might occur because you are taking part in this research.

WHAT OTHER OPTIONS ARE THERE?

You may choose not to participate in the study. Your relationship with the researcher will not be affected in any way regardless of whether you participate in this study or not.

WILL YOUR INFORMATION BE KEPT PRIVATE?

We will keep your records for this study confidential as far as permitted by law. However, if we are required to do so by law, we will disclose confidential information about you. The Texas Woman's University's Institutional Review Board (IRB) and/or the University of Southern California's Human Subjects Protection Program (HSPP) may access the data. Both TWU IRB and USC HSPP review and monitor research studies to protect the rights and welfare of research subjects. We may publish the information from this study in journals or present it at meetings. If we do, we will not use any identifiable information.

All of the study data that contain your name will be stored in locked cabinets and will be available only to study personnel. Only Kiran Kanwar will see your records. Any identifiable information obtained in connection with this study will remain confidential.

The data from this study will be stored on a password protected computer in the researcher's office for three years after the study has been completed and then destroyed.

WHAT HAPPENS IF YOU GET INJURED OR NEED EMERGENCY CARE?

If you think you have been hurt by taking part in this study, tell the study investigators immediately. The researchers will contact emergency medical care if you are injured. You or your health plan/insurance will be billed for the cost of any required treatment.

There are no plans to offer any type of payment for injury. However, by signing this form you have not given up any of your legal rights.

WHAT ARE THE COSTS?

You will not be required to pay for any of the Laboratory equipment or testing procedures. You will also not be required to pay for the cost of golf lessons or golf ball rental at the driving range during the four swing training sessions. You will be responsible for bringing your own 6-iron and 9-iron clubs to all sessions and for transportation costs to and from the testing and training sites.

DISCLAMER STATEMENT

The researchers will try to prevent any problem that could happen because of this research. You should let the researchers know at once if there is a problem and they will help you. However, neither TWU nor USC provide medical services or financial assistance for injuries that might happen because you are taking part in this research.

WHAT ARE YOUR RIGHTS AS A PARTICIPANT AND WHAT WILL HAPPEN IF YOU DECIDE NOT TO PARTICIPATE?

Your participation in this research is VOLUNTARY. You are not waiving any legal claims or rights. There are no penalties or consequences for withdrawing from the study. If you do decide to participate, you are free to change your mind and stop being in the study at any time without affecting your relationship with researchers or any other personnel at USC and TWU.

WHOM DO YOU CALL IF YOU HAVE QUESTIONS OR CONCERNS?

You will be given a copy of this signed and dated consent form to keep. If you have any questions about the research study you should ask the researchers; their phone numbers are at the top of this form.

If you have questions about your rights as a participant in this research study or the way this study has been conducted, you may contact Texas Woman's University Office of Research and Sponsored Programs at (940) 898-3378 or via e-mail at IRB@twu.edu.

INVESTIGATOR CONTACT INFORMATION

Principal Investigator Kiran Kanwar, PhD cell phone (314) 488-5981, email at kkanwar@twu.edu

IRB CONTACT INFORMATION

Texas Woman's University Office of Research and Sponsored Programs at (940) 898-3378 or via e-mail at IRB@twu.edu.

AGREEMENT:

I have read (or someone has read to me) the information provided above. I have been given a chance to ask questions. All m y questions have been answered. By signing this form, I am agreeing to take part in this study.

Name of Participant	Signature	Date Signed and Time

I have personally explained the research to the research participant and answered all questions. I believe that he/she understands the information described in this informed consent and freely consents to participate.

Name of Person Obtaining Informed Consent	Signature	Date Signed and Time

Approved by the
Texas Woman's University
Institutional Review Board
Approved: January 30, 2019

APPENDIX D

RAW DATA

Participant	Age (years)	Mass (kg)	Height (cm)	Years Playing Golf	Handicap
1	58	81.0	164	42.0	-10
2	49	88.6	177	10.0	-18
3	24	75.8	168	16.0	-1
4	73	80.8	176	50.0	-17
5	42	97.8	181	10.0	-12
6	61	77.2	178	50.0	-7
7	39	81.2	171	15.0	-18
8	29	65.1	164	19.0	0
9	18	66.0	165	11.0	2
10	19	73.7	180	13.0	-2
11	36	75.0	186	25.0	-1
12	30	93.1	185	25.0	0
13	40	71.0	162	8.0	-20
14	58	81.2	169	30.0	-18
15	32	86.0	175	25.0	-7

Participant	ThxZAdd9iPre	ThxZAdd9iPost	ThxYTop9iPre	ThxYTop9iPost	ThxZImp9iPre
1	9.62	-9.33	24.92	19.33	23.62
2	3.66	-20.39	30.69	17.18	12.78
3	9.05	-20.70	28.52	22.63	2.59
4	13.06	-5.25	25.70	16.74	-0.45
5	-4.16	-10.59	28.47	25.43	-5.59
6	7.88	-21.57	39.35	28.50	15.65
7	3.86	-26.77	39.24	23.16	13.83
8	-1.31	-17.95	34.03	27.52	16.77
9	6.12	-18.88	32.35	18.23	7.36
10	0.53	-21.10	32.59	31.58	16.42
11	5.98	-14.89	41.85	34.12	17.39
12	2.71	-35.60	37.29	29.47	7.91
13	6.94	-16.79	33.95	18.62	-3.41
14	-2.69	-16.70	29.98	24.54	-0.15
15	3.37	-20.02	40.16	32.82	9.58

Participant	ThxZImp9iPost	ThxYImp9iPre	ThxYImp9iPost	ClubSpeed9iPre	ClubSpeed9iPost
1	4.56	-27.58	-17.75	24.62	24.12
2	0.82	-17.41	-19.01	33.40	30.68
3	-10.69	-19.83	-15.85	29.98	27.13
4	-6.67	-10.73	-13.91	25.12	26.02
5	-6.20	-4.32	-9.25	31.30	26.36
6	-7.92	-21.51	-18.04	31.02	27.61
7	-1.63	-24.52	-23.10	32.72	30.66
8	-4.43	-26.82	-20.62	25.40	25.00
9	1.74	-21.36	-22.97	32.33	28.38
10	1.23	-24.02	-19.70	34.64	34.90
11	5.34	-23.16	-23.30	32.42	33.26
12	-12.87	-21.98	-16.79	36.98	33.77
13	-17.45	-12.68	-11.73	25.12	22.51
14	-6.21	-16.73	-19.09	33.43	32.13
15	5.78	-12.91	-16.88	34.10	32.78

Participant	ClubAngle9iPre	ClubAngle9iPost	ClubPath9iPre	ClubPath9iPost
1	2.70	0.41	3.75	5.35
2	0.69	-0.36	-7.66	-4.36
3	4.43	-0.62	5.27	7.02
4	2.22	0.49	-0.74	4.71
5	7.61	6.09	-5.32	-3.89
6	5.40	3.20	-5.29	0.95
7	6.09	0.92	6.40	6.75
8	8.24	4.87	5.63	8.58
9	4.86	1.98	3.84	8.55
10	9.25	6.05	1.07	3.28
11	4.65	2.97	3.44	5.65
12	2.44	2.92	-0.53	5.78
13	4.25	3.22	-4.21	-0.22
14	5.91	4.14	-2.27	0.62
15	5.98	3.65	-1.49	5.79

Participant	ThxZTop9iPreForXFactor	ThxZTop9iPostForXFactor	PelZTop9iPreForXFactor
1	-73.90	-81.45	-44.70
2	-60.85	-62.23	-31.00
3	-102.12	-89.34	-48.90
4	-66.85	-65.30	-44.16
5	-96.35	-63.10	-40.00
6	-47.98	-57.81	-24.39
7	-64.65	-62.03	-34.72
8	-109.89	-87.55	-51.90
9	-104.57	-76.71	-38.24
10	-78.03	-82.12	-29.53
11	-75.64	-81.38	-36.92
12	-83.40	-89.24	-35.34
13	-95.49	-77.82	-38.87
14	-89.46	-83.60	-39.40
15	-87.83	-69.54	-31.09

Participant	PelZTop9iPostForXFactor	ThxYTop9iPreForCrunch	ThxYTop9iPostForCrunch
1	-48.05	24.92	19.33
2	-36.06	30.69	17.18
3	-42.76	28.52	22.63
4	-38.21	25.70	16.74
5	-26.96	28.47	25.43
6	-36.55	39.35	28.50
7	-32.79	39.24	23.16
8	-42.96	34.03	27.52
9	-36.92	32.35	18.23
10	-35.05	32.59	31.58
11	-48.26	41.85	34.12
12	-45.28	37.29	29.47
13	-36.59	33.95	18.62
14	-47.77	29.98	24.54
15	-30.16	40.16	32.82

Participant	ThxYImp9iPreForCrunch	ThxYImp9iPostForCrunch	ThxXAdd9iPre	ThxXAdd9iPost
1	-27.58	-17.75	39.88	31.65
2	-17.41	-19.01	32.29	28.98
3	-19.83	-15.85	27.64	25.61
4	-10.73	-13.91	22.90	19.37
5	-4.32	-9.25	39.85	39.07
6	-21.51	-18.04	48.40	44.01
7	-24.52	-23.10	39.16	33.41
8	-26.82	-20.62	34.05	30.75
9	-21.36	-22.97	34.77	21.60
10	-24.02	-19.70	28.60	35.69
11	-23.16	-23.30	43.98	34.04
12	-21.98	-16.79	39.66	32.62
13	-12.68	-11.73	45.45	28.74
14	-16.73	-19.09	39.56	31.46
15	-12.91	-16.88	37.73	33.79

Participant	CrunchPre9	CrunchPost9	ThxZAdd6iPre	ThxZAdd6iPost	ThxYTop6iPre
1	52.50	37.08	8.30	-10.05	23.67
2	48.10	36.19	5.24	-17.59	31.24
3	48.36	38.48	9.91	-22.45	25.97
4	36.43	30.65	13.57	-4.83	24.30
5	32.79	34.68	-3.90	-12.57	26.86
6	60.86	46.54	9.04	-20.19	39.49
7	63.76	46.26	7.03	-29.25	39.21
8	60.84	48.14	1.16	-18.00	30.27
9	53.71	41.20	6.18	-18.50	31.10
10	56.61	51.28	0.77	-19.56	31.36
11	65.02	57.43	7.26	-12.80	40.45
12	59.28	46.27	2.54	-36.47	35.56
13	46.63	30.36	6.11	-24.77	30.21
14	46.70	43.64	-0.45	-19.04	31.68
15	53.07	49.69	4.34	-16.87	39.51

Participant	ThxYTop6iPost	ThxZImp6iPre	ThxZImp6iPost	ThxYImp6iPre	ThxYImp6iPost
1	19.47	26.89	8.47	-28.13	-19.00
2	15.75	11.31	0.93	-18.63	-19.91
3	21.41	3.56	-6.44	-21.52	-17.15
4	18.10	3.94	-10.44	-10.72	-11.57
5	22.50	-6.43	-11.81	-4.86	-9.70
6	25.84	19.96	-9.45	-22.02	-16.36
7	20.07	17.86	-3.27	-26.50	-22.29
8	25.25	20.44	1.90	-30.24	-21.46
9	18.87	6.85	4.44	-21.99	-23.46
10	32.05	16.04	8.69	-23.32	-22.39
11	31.64	18.76	8.12	-24.13	-23.89
12	26.42	7.81	-13.38	-22.41	-17.95
13	21.46	-0.38	-20.14	-14.88	-10.67
14	22.43	-1.88	-3.92	-15.79	-18.11
15	33.10	12.01	9.06	-16.01	-17.46

Participant	ClubSpeed6iPre	ClubSpeed6iPost	ClubAngle6iPre	ClubAngle6iPost	ClubPath6iPre
1	25.72	26.24	3.17	0.77	1.54
2	33.19	30.99	3.93	-0.33	-3.48
3	31.09	28.84	3.12	-1.25	4.70
4	26.06	26.88	4.21	-0.05	-2.07
5	32.61	27.96	6.90	5.65	-4.95
6	33.61	28.53	7.51	6.32	-9.90
7	33.93	29.67	2.28	-0.92	5.49
8	27.75	24.96	6.81	3.43	6.07
9	34.56	30.09	3.65	1.37	2.19
10	38.23	38.13	7.65	5.23	0.78
11	36.36	34.45	5.41	3.53	2.58
12	38.94	34.99	2.19	2.71	-0.38
13	25.71	23.94	3.75	2.23	-3.28
14	33.06	32.12	3.68	3.21	-0.96
15	34.67	34.08	5.06	3.96	1.95

Participant	ClubPath6iPost	ThxZTop6iPreForXFactor	ThxZTop6iPostForXFactor
1	2.25	-70.81	-78.92
2	-5.62	-63.31	-61.86
3	8.29	-106.10	-94.73
4	5.27	-65.76	-68.32
5	-2.96	-100.22	-66.07
6	-1.49	-49.77	-54.15
7	6.47	-65.30	-60.47
8	10.28	-115.02	-88.11
9	7.05	-108.33	-78.50
10	4.86	-87.07	-88.40
11	5.29	-81.80	-80.43
12	6.24	-85.64	-88.88
13	-1.43	-103.92	-86.13
14	1.48	-93.01	-82.49
15	3.83	-88.09	-73.17

Participant	PelZTop6iPreForXFactor	PelZTop6iPostForXFactor	ThxYTop6iPreForCrunch
1	-41.13	-45.29	23.67
2	-32.66	-34.48	31.24
3	-51.40	-47.22	25.97
4	-42.73	-39.85	24.30
5	-42.12	-28.75	26.86
6	-25.02	-33.99	39.49
7	-34.75	-33.15	39.21
8	-56.09	-42.62	30.27
9	-36.70	-38.11	31.10
10	-34.56	-35.80	31.36
11	-40.77	-48.08	40.45
12	-35.73	-44.53	35.56
13	-45.38	-40.75	30.21
14	-42.02	-47.59	31.68
15	-32.76	-31.16	39.51

Participant	ThxYTop6iPostForCrunch	ThxYImp6iPreForCrunch	ThxYImp6iPostForCrunch
1	19.47	-28.13	-19.00
2	15.75	-18.63	-19.91
3	21.41	-21.52	-17.15
4	18.10	-10.72	-11.57
5	22.50	-4.86	-9.70
6	25.84	-22.02	-16.36
7	20.07	-26.50	-22.29
8	25.25	-30.24	-21.46
9	18.87	-21.99	-23.46
10	32.05	-23.32	-22.39
11	31.64	-24.13	-23.89
12	26.42	-22.41	-17.95
13	21.46	-14.88	-10.67
14	22.43	-15.79	-18.11
15	33.10	-16.01	-17.46

Participant	ThxXAdd6iPre	ThxXAdd6iPost	CrunchPre6	CrunchPost6	ClubSpeedSD9iPre
1	38.50	30.88	51.80	38.47	1.03
2	30.47	28.99	49.87	35.65	0.56
3	26.43	22.85	47.49	38.56	0.26
4	20.53	18.50	35.03	29.67	0.47
5	38.65	37.27	31.72	32.19	0.73
6	44.91	42.21	61.51	42.20	0.47
7	35.91	31.86	65.70	42.37	0.91
8	32.37	26.27	60.52	46.71	0.81
9	35.51	20.89	53.09	42.33	0.35
10	24.83	30.65	54.67	54.44	0.45
11	39.87	31.46	64.58	55.53	0.58
12	36.29	27.78	57.97	44.36	0.30
13	46.23	32.82	45.09	32.13	0.65
14	38.80	28.06	47.47	40.54	0.75
15	37.15	32.84	55.52	50.56	0.17

Participant	ClubSpeedSD9iPost	ClubAngleSD9iPre	ClubAngleSD9iPost	ClubPathSD9iPre
1	0.23	0.49	0.81	1.33
2	0.28	0.66	1.74	2.25
3	0.18	1.01	1.01	0.60
4	0.42	0.90	1.58	1.65
5	0.77	0.57	1.43	1.47
6	0.32	0.72	0.82	0.87
7	0.55	1.47	0.38	1.73
8	0.47	1.01	1.73	1.26
9	0.68	1.10	0.98	1.12
10	0.49	1.36	1.03	1.13
11	0.77	1.92	1.09	0.70
12	0.48	1.82	1.71	0.50
13	0.38	0.56	1.02	1.55
14	0.24	1.11	1.32	0.96
15	0.10	1.19	1.27	1.39

Participant	ClubPathSD9iPost	ClubSpeedSD6iPre	ClubSpeedSD6iPost	ClubAngleSD6iPre
1	0.88	0.75	0.75	2.14
2	1.77	0.35	0.32	1.13
3	1.31	0.10	0.38	0.20
4	2.11	0.27	0.41	0.44
5	1.19	1.03	0.68	0.19
6	1.56	0.48	0.44	0.78
7	1.58	1.03	0.89	1.28
8	1.14	0.82	0.77	0.87
9	1.39	0.22	0.44	1.14
10	0.91	0.66	0.20	0.69
11	0.93	0.88	0.51	1.49
12	1.46	0.32	0.31	1.22
13	1.12	0.84	0.87	2.81
14	0.93	0.46	0.31	2.72
15	1.36	0.40	0.81	1.43

Participant	ClubAngleSD6iPost	ClubPathSD6iPre	ClubPathSD6iPost
1	1.86	0.25	0.84
2	1.37	1.29	1.73
3	0.93	0.77	0.58
4	1.53	1.47	1.57
5	0.51	1.08	2.23
6	0.85	1.02	1.98
7	1.28	1.13	0.95
8	1.08	0.63	1.14
9	1.25	1.15	0.78
10	2.13	0.68	0.89
11	0.98	1.14	0.98
12	1.97	1.31	1.80
13	1.16	1.34	1.34
14	1.96	1.33	0.89
15	2.01	1.61	0.42