

A Review of Biomechanical Differences Between Golfers of Varied Skill Levels

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ABSTRACT

The purpose of this article was to review and summarize the biomechanical research literature comparing golfers of different skill levels. A golfer's skill will influence their success in being able to consistently and predictably hit the ball in the desired direction for the proper distance. By scientifically investigating the differences in swing technique between players of different abilities, golfers and golf educators should gain a better understanding of how to improve performance. Analyses of the kinetic forces, kinematic timing and sequence of the various body segments, as well as the muscle activity patterns that generate movements revealed that skilled players exhibit increased force production, efficiency and consistency relative to less skilled players. However, the variability in assorted measures even amongst skilled players, raises the question of whether there is only one ideal swing method for all individuals.

Key words: Golf Biomechanics, Electromyography, Kinematics, Kinetic Analysis, Motor Skill, Muscle Activity

INTRODUCTION

Golf is a very popular sport, with approximately 30,000 golf courses and 55 million participants worldwide. [1] In Canada alone, the number of adult golfers who play at least eight games per year has increased from 1.8 million in 1996 to 2.7 million in 2006. [2] This segment of core golfers represents over 10% of the eligible population. The increased participation rate in golf has coincided with an increase in the amount

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of scientific literature associated with the sport. In 1996, the World Scientific Congress of Golf Trust was formed for the purpose of promoting and stimulating golf-related scientific research by staging a world scientific congress of golf every four years. [1] The increased level of scientific scrutiny has resulted in a better understanding of the golf swing.

The full golf swing is regarded as one of the most difficult biomechanical motions in sport to execute, given the challenging performance requirement to swing a relatively long club at a relatively small ball with maximal velocity. [3] As a result, most golfers struggle to achieve satisfactory levels of performance and often turn to golf instructors and coaches in order to improve. Despite technological advances such as video or motion analysis and launch monitor recording, many golf educators still rely heavily on empirical judgments during the instructional process. It is likely these empirical judgments would be enhanced if the golf educator had a better understanding of golf biomechanics.

Golf biomechanics applies the principles and technique of mechanics to the structure and function of the golfer. [4] Specifically, golf biomechanics examines movement characteristics of the swing as well as the resultant joint forces and patterns of muscle activity; thus biomechanical analysis of an elite player's swing should allow a better understanding of optimal swing mechanics. However, also knowing the biomechanical tendencies of less-skilled recreational players would enable coaches to correct inappropriate swing patterns in a more informed and objective manner. Furthermore, since swing mechanics may contribute to injury susceptibility [5], correcting the biomechanical deficiencies should assist in the prevention of golf injuries. Therefore, the purpose of this article is to review and summarize the biomechanical research literature comparing golfers of different skill levels. A particular focus is placed on the full swing, typically with the driver, where the emphasis is placed on maximizing club head speed at impact, yet still achieving a ball strike location near the centre of the clubface.

GOLF BIOMECHANICS

The goal of the golf swing has been described as hitting the ball in the desired direction for the proper distance and with the most efficient motion. [6] The term 'efficiency' is commonly used when describing the golf swing, but its definition is often left to the reader's interpretation. For the purposes of this review, efficiency refers to a full swing that is able to consistently and predictably hit the ball in the desired direction for the proper distance.

While the goal of the golf swing may be consistent across different skill levels, the methods used to execute the swing will obviously vary. These variations in method can be quantified through biomechanical study. Literature dealing with golf biomechanics has focused on three types of swing analyses; kinetics, kinematics and muscle activity. Kinetics describes the resultant joint forces and torques that occur during the golf swing and are typically measured via force transducers or force plates, or estimated from computer models. Analysis of movement associated with the golf swing is termed kinematics and is most often assessed with high-speed cameras and three-dimensional imaging. Muscle activity throughout the swing can be recorded using electromyography (EMG).

KINETIC ANALYSES

The interaction between the shoe and the ground has been recognized as a vital link in a golfer's ability to perform the body movements necessary for efficient impact between the club head and ball. [7] The musculoskeletal forces created by the body during the golf swing are exerted through the soles of the feet to the ground. This interaction is termed ground reaction force and the measurement of these forces provides insight into how the body creates movement of the club head towards the ball. [8]

Richards et al. [9] conducted one of the earliest studies comparing ground reaction force between golfers of different abilities. The authors specifically measured the center of vertical force distribution pattern under each foot during the downswing of shots taken with a 5-iron. Ten low-handicap (< 10) and 10 high-handicap (> 20) golfers participated in the study. Results from the study showed that higher skilled players tended to produce a greater weight shift onto the front foot on the downswing, but kept the center of vertical force closer to their heels at impact. The authors attributed the increased weight on the anterior portion of the front foot in the less skilled golfers to a reduced amount of body rotation on the downswing.

Barrentine et al. [10] examined ground reaction forces in golfers categorized into one of three different skill level groups, with each group having 20 subjects. The three groups included professional golfers (tour and teaching professionals), low-handicap recreational players (0 – 15) and high-handicap (> 15) recreational golfers. The following is a brief summary of the forces reported by the authors' analysis when the driver golf club was used.

The initiation of the backswing corresponded with a shift of the golfer's weight onto the trail or rear foot. Vertical force, which was defined as the force exerted by the golfer's shoe in a downward direction, peaked at 700 N and occurred 0.27 seconds before the golfer's club reached the top of the backswing. Approximately 0.1 seconds before the completion of the backswing, the trail foot applied a 22 N-m clockwise torque (for a right-handed player when viewed from above). The high frictional load between the golfer's shoe and the ground results in this torque producing a counter-clockwise rotation of the golfer's body towards the target (i.e., left). In addition to the vertical and rotational forces exerted by the trail foot, a lateral force directed away from the target was also observed. This lateral force peaked at 130 N and occurred approximately 0.05 seconds after the golf club started on the downswing. This lateral force shifts the momentum of the body laterally towards the target (left).

As the downswing progressed, significant anterior and posterior shear forces were noted under the lead and trail feet respectively. A peak anteriorly directed force of 186 N occurred under the lead foot (i.e., the foot is attempting to push forward) while the posterior force under the trail foot peaked at 145 N. These forces produce a counter clockwise rotational force couple. As the downswing continued, the golfer's weight was further shifted onto the lead foot resulting in a peak immediately prior to impact of 950 N of vertical force. Also prior to ball contact, the lead foot applied a peak lateral force of 133 N directed towards the target to help control and stabilize this forward shift of weight onto the front foot. Deceleration of the body after impact was achieved by an outward or counter-clockwise torque applied by the lead foot that peaks at 23 N-m.

In terms of differences between groups, Barrentine et al. [10] found that higher-skilled golfers developed more acceleration on the downswing and were shown to achieve greater club head velocities at the time of impact. It was also noted that higher skilled players produced a larger and earlier anterior (lead foot) and posterior (trail foot) shear force that would contribute to an increased rotational force couple during the acceleration phase of the swing.

Koenig et al. [11] also compared ground reaction forces and centers of pressure among golfers of different ability levels. Subjects ranged in skill from low handicap (0 – 7), mid handicap (8 – 14) and high handicap (> 14). An optical motion-capture system was used to monitor the positions of different body segments as well as the golf club, and a force plate was used to investigate the shoe-ground interaction. Results indicated that less-skilled players demonstrated excessive shoe movement and greater lateral forces on both feet during the backswing which reduced the rotation of the pelvis away from the target as well as the transfer of weight onto the trail (right) foot. Skilled players demonstrated less shoe movement, kept their centers of pressure more towards the medial portion of their heels and displayed a larger and more consistent weight shift to the right foot on the backswing and to the left foot on the downswing. These results suggest that better players employ more weight shift involving rotation of their body during the backswing and downswing compared to lateral movement for the less-skilled individuals.

Kawashima et al. [8] examined the forces exerted at three different plantar areas of each foot during the golf swings of seven skilled (mean handicap 5.5 ± 1.8) and seven unskilled (mean handicap 28.0 ± 4.0) players. Results showed that highly skilled golfers exerted greater force on all of the front (i.e., left) foot pressure points through impact whereas the less-skilled golfers showed high forces remaining on the right foot. Therefore, it was concluded that less-skilled golfers do not complete the weight transfer through impact compared to skilled golfers. The authors also noted the importance of a firm and steady stance, with sole pressure kept within the inner (i.e., medial) edges of the feet, to allow the golfer to effectively transfer rotary power from the hips, trunk, shoulders, and arms to the club head prior to impact with the ball.

It may be concluded from these kinetic studies that sole-to-ground interactions vary in some meaningful ways between skilled and less-skilled players. To summarize, less-skilled golfers were found to have: greater lateral forces on the feet during the backswings and downswings, decreased and delayed weight shift on the downswing, and more movement of weight onto the anterior or toe portion of the feet through impact. These differences may lead to a reduction in club head speed from: a decreased transfer of energy, a decrease in stability (an increase in movement of the centre of gravity away from the midline of the body), and a delay in the timing of essential joint actions. In comparison, highly skilled golfers demonstrated: a greater weight shift to the left foot on the downswing, increased transfer of force at impact, a more medial center of pressure allowing for greater stability and less lateral movement, thus creating a more stable base to rotate about during the swing.

KINEMATIC ANALYSES

Coordination of the various body segments during the golf swing can be evidenced

using kinematic analysis that examines the swing motion from both a spatial and temporal perspective without any reference to the forces causing the observed motion. [12,13] Unlike the left arm and clubface, it may be observed that the lower body and pelvis of a skilled golfer are already rotated past the starting position and toward target (i.e., “cleared”) late into the downswing while the upper body and arms lag behind the hips. This sequencing and coordination of motion between different body segments not only gives the golf swing its unique appearance, but likely is essential for developing maximum club head speed at impact.

Burden et al. [14] investigated the segmental body motions of skilled golfers; specifically, whether these players utilized the summation of segment speed principle. This principle implies that to maximize the speed of the distal end of the system (i.e., the club head), the swing must start with movements at the more proximal segments and progress sequentially to faster movements of the more distal segments. The authors reported on the pattern of hip and shoulder rotation in eight skilled golfers (handicap < 10). Rotation referred to the turning of an imaginary line bisecting the bilateral hip and shoulder joints. The study also examined the movement of the centre of mass. Results demonstrated that subjects turned their pelvis during the backswing 37 ± 9 degrees away from the target. It was also noted that the maximum amount of pelvic rotation occurred before the club head reached the end of the backswing. Results also indicated that the line bisecting both shoulder joints turned 109 ± 12 degrees away from the target during the backswing. Trunk rotation, which was represented by the mean differential between the pelvic and shoulder turns on the back swing, was 70 ± 20 degrees. Centre of mass data revealed a mean displacement of 8.2 ± 3.2 cm to the right (away from the target) during the backswing and a mean displacement of 12.3 ± 3.7 cm to the left (toward the flag) at impact. It was concluded that the observed sequential pattern of trunk rotation indicated, at least in this part of the body, that subjects adhered to the summation of segment speed principle. This pattern results in the hips and shoulders rotating in opposite directions immediately prior to the golf club starting in the downswing direction. The eccentric – concentric sequence affecting the trunk rotators would theoretically lead to a greater torque being applied to the club.

McTeigue et al. [15] sought to determine the key differences between torso motions of fifty-one PGA Tour Players, forty-six Senior PGA Tour Players and thirty-four recreational players (mean handicap 17.5). Angular displacements of the thoraco-lumbar spine were measured using a tri-planar motional analysis device. Results indicated that recreational golfers demonstrated greater left lateral bending at the top of the backswing, resulting from sliding of the hips away from the target and dropping the left (lead) shoulder toward the ground. At impact, recreational players showed significantly less right lateral bending, which may be related to the reduced weight shift observed in other studies. [8, 9] In terms of rotation, professional golfers used more spinal rotation range of motion (ROM) and velocity during their backswing and downswing compared to the recreational players.

The spinal rotation ROM reported by McTeigue et al. [15] has often been referred to as the “X-factor” due to the fact that when viewed from above, imaginary lines drawn through the hips and shoulders would have the appearance of an “X” as the trunk or spine rotates. McTeigue et al. [15] did report that the longer hitters in their

study tended to use more trunk rotation (larger X-factor) at the top of the backswing. The authors also reported that approximately 70% of the professional tour players rotated their hips first on the downswing. As described by Burden et al. [14], this pattern results in the hips and shoulders rotating in opposite directions immediately prior to the golf club starting in the downswing direction and would further increase the amount of trunk rotation stretch at the start of the downswing. Cheetham et al. [16] attempted to quantify the amount of trunk rotation increase by comparing the “X-factor stretch” between 10 highly-skilled golfers and 9 less-skilled players (handicap > 14). The authors used the term “X-factor stretch” to describe this increase in trunk rotation during the early downswing phase. Results showed that the higher skilled players increased the X-factor stretch by 19% during the early part of the downswing. This compared with 13% for the less-skilled players. The authors went on to state that the extra stretch on the trunk rotation muscles, along with the active resistance to that stretch, can increase muscular contraction forces leading to more force production on the downswing and a resultant higher club head speed through impact.

McLaughlin and Best [17] used three-dimensional motion analysis techniques to investigate differences in kinematic parameters between highly-skilled (handicap < 4), moderately-skilled (handicap 9 – 18) and lower skilled (handicap 19 – 27) players. A total of 30 players were equally divided into the three handicap groups. The main findings of this study demonstrated that low-handicap golfers incorporated a greater degree of wrist joint radial deviation (wrist cock) at the mid-point of the downswing compared to all other groups. Low-handicap golfers also demonstrated greater rotation of the lines bisecting the bilateral hip and knee joints towards the target at the middle of the downswing. In golf instruction terminology, this rotation of the lower body is referred to as “clearing the hips”. The angular velocity of ulnar deviation, as well as the amount of knee and hip turn at the mid-point of the downswing, were highly correlated with club head velocity (0.869 and 0.854 respectively). The authors concluded that the rotational position of the lower body as well as the speed and delay of ulnar deviation on the downswing were very important for increasing club head velocity through impact.

Yahara et al. [18] examined the differences in golf swing spinal biomechanics between touring professionals and recreational golfers (31 males and 17 females). It was found that recreational golfers demonstrated significantly more lateral flexion and less spinal rotation at the top of the backswing. It was also reported that recreational players displayed significantly more flexion and less rotation at ball impact. It was concluded that less-skilled golfers do not harness the rotational power from the spine as well as professionals resulting in less efficient swing kinematics and subsequent decreased club head speed.

Lephart et al. [19] compared the acceleration and velocity of the upper torso (shoulder and thorax) and lower torso (pelvis) of nine professional and nine amateur golfers (mean handicap 7.9 ± 3.8) using a three-dimensional motion analysis system. Results indicated that at club takeaway, both upper and lower torso angular velocities were significantly slower for the professional golfers. It was also reported that amateur players decelerated their upper torso at follow through, while professionals continued to accelerate after ball impact. It was concluded that the slow deliberate

backswing speed used by professional golfers helped facilitate proper mechanics and correct swing plane during the rest of the swing. Furthermore, the enhanced upper torso acceleration beyond impact demonstrated by the professional athletes may contribute to increased clubhead speed and facilitate the squaring of the clubface at impact.

In a related study, Zheng et al. [20] calculated and compared upper-body kinematics during the golf swing of 72 healthy, male golfers of varied skill levels. Subjects were divided into four equal sized groups; professional, low handicap (0 – 7), mid handicap (8 – 14) and high handicap (> 14). A six-camera motion analysis system was used to calculate angular displacement and velocity parameters of the wrists, elbows, shoulders and trunk. Results indicated that professional golfers displayed the largest angular displacements at the peak of the backswing for left shoulder horizontal adduction, right shoulder external rotation, and trunk rotation. These findings suggest the higher skilled golfer produced a greater coiling of their trunk and shoulders at the top of the backswing which would contribute to increased power generation on the downswing. On the downswing, elite players followed a summation of speed pattern similar to that described by Burden et al. [14] where proximal body segments preceded distal segments. At ball contact, the higher-skilled players demonstrated less uncoiling of the trunk and a straighter left elbow than the lower-skilled players.

The high-handicap golfers in Zheng et al.'s [20] study produced approximately 40% less right shoulder internal rotation angular velocity and bilateral wrist release speed than the professional golfers. Furthermore, the peak trunk and shoulder velocities for the less-skilled players occurred later in the downswing while the left wrist release occurred earlier, resulting in the more proximal shoulder segment reaching its maximum velocity after the more distal wrist segment. These factors likely contributed to the high-handicap group having a much slower club shaft angular velocity than the professional players (1756 ± 320 versus 2413 ± 442 degrees per second, respectively). This altered sequencing amongst the less-skilled players would decrease the efficiency of the swing and may predispose the less-skilled player to a greater risk of injury.

To summarize these kinematic studies, elite golfers employ a slow and deliberate backswing concentrating on a full turn of the shoulders away from the target while at the same time minimizing any side-bend or lateral motion of the trunk. Elite golfers utilize summation of speed principles by initiating the downswing with the lower limbs resulting in an increased X-factor stretch as well as an increase in the amount of left shoulder adduction and right shoulder external rotation. Furthermore, these highly skilled players maintain an increased radial deviation of both wrists (wrist cock) until late in the downswing. The increased ROM of the various body segments in combination with an appropriate sequence of motion, delayed wrist release and straight left elbow allow the skilled player to generate increased clubhead speed through impact.

MUSCLE ACTIVITY ANALYSES

By examining the muscle activity differences in professional and recreational golfers, further insight can be gained into how skilled movement is initiated and controlled.

For example, Abernethy et al. [21] examined differences between five expert and five novice golfers with respect to muscle recruitment during the golf swing. Handicap measures for the expert and novice golfers were not disclosed. Electromyography (EMG) and high-speed video analysis were used to assess the swing in four different randomly assigned ball hitting conditions (20, 40, 60 m and full shot), and three different randomly assigned club conditions (pitching wedge, 9-iron, and 7-iron). EMG activity was only recorded from the left side of the following upper-body muscles; wrist flexors, wrist extensors, biceps brachii, triceps brachii, anterior deltoid and posterior deltoid. Results indicated that novice golfers demonstrated more variable patterns of muscle activity which was exacerbated when they were required to hit “touch” shots to the 20, 40, and 60 m targets. Expert golfers tended to show considerable inter-subject variation, but their individual muscle activation patterns were remarkably consistent across trials. This finding led the investigators to suggest that there may be many variations of muscle activity that can produce the same kinematic task or goal.

Barclay and McIlroy [23] investigated differences in forearm and neck muscle activity amongst eight subjects of varying handicap (<3 – 20). The authors were unable to establish differences in mean activity levels in the left and right forearm (flexor carpi radialis) or neck (upper trapezius) muscles in any of the subjects. However, the higher-skilled golfers did demonstrate less overall variability in muscle activity and swing time compared to the less-skilled players. The authors also attempted to examine the effect of increased anxiety level on two of the lesser-skilled players by introducing an unexpected audience to those subjects. Results showed a 25% increase in the tonic upper trapezius muscle activity of one player and a significantly shorter swing time in the second player.

Hosea et al. [24] compared trunk muscle activity during full swings with a 5-iron in four professional and four recreational (handicap = 16) golfers. The rectus abdominus, external obliques, and paraspinal muscles were investigated. Results showed higher EMG activity expressed as a percentage of maximum voluntary contraction for all of the tested muscles for the recreational players compared to the professionals. Considering the slower trunk rotation velocities typically generated by less-skilled players [15, 20], these findings are interesting and suggest that these players are not as efficient in using this region during the swing. Furthermore, Hosea et al. [24] reported that amateur golfers created increased kinetic loads on their spine which may increase injury susceptibility. It was concluded that a professional golfer is able to strike the golf ball with greater clubhead speed while generating lower spinal loads compared to amateurs.

Computer modeling is another viable way in which biomechanical characteristics of golfers can be studied. Nesbit and Serrano [3] examined differences in golfers of varying skill levels through a work and power analysis of the golf swing. Two computer-based models were used to study the energy production, conversions and transfers during the golf swing. Four amateur golfers including three male golfers (handicaps of 0, 5 and 13) and one female golfer (handicap 18) participated in the study. Results indicated that work comes primarily from the back and hip joints, generating 71.8, 72, 70 and 68.7 percent of the total body work for the four subjects, respectively. Better golfers were also found to have higher clubhead velocities, higher

total work done, and were able to peak total work done closer to impact. Results also showed that total work done was the primary factor in generating clubhead velocity. The results from the study suggest that the trunk and hips (i.e., “core”) generate the most amount of work in the golf swing, and that highly skilled golfers demonstrate better function in this region.

Reviewing the findings of these muscle activation studies reveals some interesting results consistent with the other biomechanical studies. Highly-skilled golfers appear to generate a large amount of the force needed to create high clubhead speed from the hip and trunk regions without creating excessive loads on the spinal joints. As expected, less-skilled golfers were more inconsistent in their muscle activation patterning and would appear to be more susceptible to performance deterioration associated with increased anxiety or stress.

CONCLUSION

A number of studies were found in the scientific literature investigating biomechanical differences among golfers of varying abilities, from which certain key factors were identified. For example, a well-executed golf swing that maximizes distance via high clubhead speed combined with optimal ball contact appears to reflect the summation of segmental speed principle. In other words, highly skilled players initiate the downswing from the lower limbs (proximal segment) and follow this motion with progressively faster angular velocities from the more distal segments (i.e. trunk, upper limbs and club). It would also appear from a number of studies that less-skilled golfers do not harness the rotational power from the spine as effectively as professionals. Elite players demonstrate a larger amount of trunk rotation ROM at the end of the backswing followed by increased trunk rotation velocity during the downswing. These players also tend to continue to accelerate their torso through and past impact, whereas lesser-skilled players tend to decelerate their trunk immediately after impact. Elite players would appear to set the golf club at the top of the backswing with a greater stretch of the shoulder joints as well as more radial deviation of the wrists. Furthermore, the release of this increased wrist angle was delayed much later on the downswing among skilled golfers resulting in increased club head speed at impact. Distinct differences in the pattern and magnitude of weight shifts were also observed between skill levels. Less-skilled players tended to use more lateral rather than rotational ground reaction force on the downswing and did not shift as much weight forward onto the front foot through impact as the better players.

While the information derived from the studies reviewed in this article are useful, certain limitations exist in their interpretation. This review focused on the full swing, but it is also likely that additional biomechanical differences occur in short-game performances between players of varied skill level. When examining the studies that were reviewed, most incorporated small numbers of subjects. This fact, combined with the variability in assorted measures even among skilled players, makes it difficult to ascertain whether the differences observed were truly representative of the larger population of golfers and raises the question whether there is only one ideal swing method for all individuals. The fact that not all the world’s best golfers use exactly the same swing technique suggests that there is more than one model swing

for optimal performance.

Despite the above limitations, however, these biomechanical studies do shed light upon areas that golfers and golf educators can use to improve performance through proper technique. For example, performance enhancement may be derived from increased force production, increased efficiency and increased consistency. In addition to golfers and their coaches, exercise physiologists and healthcare providers may also benefit from an enhanced understanding of the biomechanics of the golf swing to help create innovative and individualized golf-specific fitness, rehabilitation and prevention programs.

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