

KINEMATIC ANALYSIS OF SPORTS MOVEMENTS: GOLF SWING PLANE ANALYSIS

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The swing plane is one of the most controversial and misleading concepts in modern golf vocabulary. Several popular swing theories in regards to the swing plane have emerged in the popular literature by golf professionals, while the majority of the biomechanical studies have been conducted based on the planar double- and triple-pendulum swing models. The purpose of this paper is to provide a comprehensive review of both the scientific and popular golf literature on golf swing mechanics in regards to the concept of swing plane.

KEY WORDS: golf swing mechanics, on-plane swing, one-plane swing, double-pendulum

INTRODUCTION: Kinematics is an area of biomechanics dealing with measurement and description of the human body motion. Quantitative measurement of the motion of interest and subsequent analysis based on the computed kinematic quantities allow investigators an in-depth understanding of the motion itself and the common motion patterns. The human body is a mechanical system with a large number of degrees of freedom and isolating a set of key performance characteristics/components is of crucial importance for effective performance enhancement in complex 3-dimensional (3-D) body motions such as the golf swing.

Golf is one of the most popular sports in the modern world with 35 million participants worldwide (Geisler, 2001; Theriault & Lachance, 1998). The sole objective in a golf competition is to minimize the total number of shots taken to finish an 18-hole course using a variety of clubs and shots. The two most important elements of the performance in golf are accuracy (direction and distance) and consistency and one must develop a consistent fundamental swing pattern to secure these qualities. The direction of a shot and the ball carry distance are essentially determined by the clubhead trajectory around the impact position and the impact conditions such as the clubhead velocity, clubface orientation, impact location on the clubface, coefficient of restitution, and the effective mass involved in the impact.

The 'swing plane', which affects the impact conditions directly, is one of the most frequently used terms in golf coaching lately and is also one of the most controversial and misleading concepts. Since Hogan and Wind (1957) used this term in their book titled "Ben Hogan's five lessons: the modern fundamentals of golf", different swing theories have emerged in the popular literature (e.g. Haney & Huggan, 1999; Hardy & Andrisani, 2005). None of these, however, has truly grasped the essence of the swing plane due to the lack of understanding of the complex nature of the actual 3-D swing motion. Moreover, for last four decades, the majority of biomechanical studies on swing mechanics have been conducted based on the planar double-pendulum model (e.g. Budney & Bellow, 1979; Milburn, 1982; Milne & Davis, 1992; Pickering & Vickers, 1999; Sanders & Owens, 1992), originally proposed by Cochran and Stobbs (1968), or the triple-pendulum model (Sprigings & Mackenzie, 2002; Sprigings & Neal, 2000), a variation of the double-pendulum model. Although Vaughan (1981) and Neal and Wilson (1985) pointed out that the swing plane was not planar, it is only recently that scientists have critically investigated the swing plane (Coleman & Anderson, 2007; Coleman & Rankin, 2005; Nesbit, 2005; Shin, Casebolt, Lambert, Kim, & Kwon, 2008). The purpose of this paper is to provide a comprehensive review of both the scientific and the popular golf literature on golf swing mechanics in regards to the concept of swing plane.

MULTIPLE PENDULUM MODELS: Since Cochran and Stobbs (1968) proposed the planar double-pendulum model, it has been used as the fundamental swing model in numerous biomechanical studies (e.g. Budney & Bellow, 1979; Milburn, 1982; Milne & Davis, 1992; Pickering & Vickers, 1999; Sanders & Owens, 1992; Sprigings & Mackenzie, 2002; Sprigings

& Neal, 2000). The key concepts of the model include: (a) the golfer is considered as a system of two levers hinged in the middle; (b) the upper lever corresponds to the golfer's shoulders and the arms and the club forms the lower lever; (c) the levers are hinged at the wrists/hands; (d) the system is swung around a fixed point (hub) in a single inclined plane. The model has been particularly popular in the modelling and simulation studies due to its simplicity in deriving the equations of motion.

Although some modifications have been introduced, such as flexible clubshaft (Milne & Davis, 1992), triple pendulum (Campbell & Reid, 1985; Sprigings & Mackenzie, 2002; Sprigings & Neal, 2000), and moving hub (Jorgensen, 1994), the essence of the model, planar swing, has been remained intact. The assumption of planar swing, however, has never been substantiated in these studies other than subjective observations. In fact, a 3-D analysis of a golf swing at any skill level, regardless of the club used, readily reveals that the downswing is not planar (Figure 1). Trajectories of the major moving parts exhibit complex movement patterns and, in particular, the shoulders show motions on completely different planes and a significant amount of off-plane shoulder girdle motion is observed as a result. A single planar swing plane simply does not exist and the assumption of planar swing is not valid.

SWING PLANE STUDIES: A detailed, systematic analysis of the swing plane is possible only in a 3-D study. Vaughan (1981) was the first investigator who reported that the motion plane of the club was not planar. Using the unit vector normal to the clubshaft plane, he visualized the continuous motion of the clubshaft plane during the downswing. Neal and Wilson (1985) also concluded that the motion of the club was not planar for any substantial period of time during the downswing but no quantitative analysis result of the club motion was provided.

Coleman and Rankin (2005) systematically evaluated the assumption of planar downswing by quantifying the orientation (inclination and direction) of the instantaneous left arm plane, formed by the left arm and the shoulder, and the deviation of the clubhead from the arm plane. It was shown that the left arm plane continuously changed its orientation during the downswing and the deviation of the clubhead from the left arm plane was inconsistent. Coleman and Anderson (2007) further investigated the validity of the assumption of planar swing by finding a single swing plane that best fitted to the clubshaft motion and the instantaneous clubshaft planes. The reported mean goodness of fit values (RMS residuals) of the single swing plane were fairly large (> 8 cm) for all clubs used (driver, 5-iron, and pitching wedge), suggesting the shaft motion was in fact not planar. The driver showed flatter swing plane orientation than the 5-iron and the pitching wedge.

Although it has been clearly shown in these 3-D studies that the downswing plane is not planar, further studies were necessary to understand the swing mechanics in depth. In a study utilizing a full-body multi-link 3-D model of golfer's body, Nesbit (2005) showed that the downswing did not take place in a fixed plane and there was significant pitch motion of the club during the downswing. He also quantified the angle between the planes traced out by the clubhead and the hands (9 to 12°). Further more, in a study using several different phases of the downswing/follow-through (top of the backswing to mid follow-through, vertical shaft to mid follow-through, and horizontal shaft to mid follow-through), Shin et al. (2008) demonstrated that a well-defined "clubhead" swing plane could be obtained from the impact portion of the downswing (horizontal shaft to mid follow-through; mean RMS residual < 1.0 cm) and the swing plane changed continuously during the early phase of the downswing (top

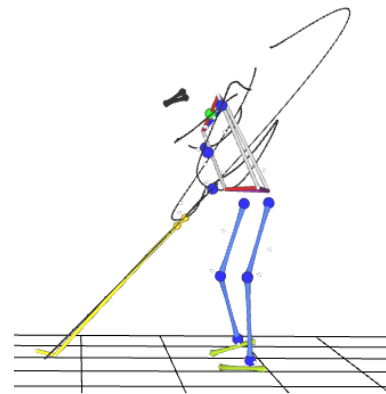


Figure 1: Trajectories (thin black lines) of the clubhead, left hand, left shoulder, right elbow and right shoulder of a scratch golfer during the downswing (driver shot). The body shows the impact position.

of the backswing to horizontal shaft). The slope and the direction angles of the driver, 5-iron, and pitching wedge shots were reported.

POPULAR SWING PLANE THEORIES: Hogan and Wind (1957) defined the backswing plane as “an angle of inclination running from the ball to the shoulders determined by the height of the golfer and the distance he stands from the ball at address” and visualized it as a large pane of glass that rests on the shoulders and inclines upward from the ball with the golfer’s head sticking out through a hole. It was also noted that the downswing plane is less steeply inclined than the backswing plane and the swing plane points slightly to the right of the golfer’s target as the body moves toward the target. In spite of the superb, detailed description of the downswing mechanics, Hogan’s visualization of the swing plane often has caused misconceptions due to the image of the glass pane connecting the ball and the shoulder line and has been subject to criticism.

More recent swing theories that have gained popularity include Hank Haney’s ‘on-plane’ swing and Jim Hardy’s ‘one-plane’ swing (Haney & Huggan, 1999; Hardy & Andrisani, 2005). Maintaining the clubshaft parallel to the original shaft plane, formed by the shaft at the address position, throughout the entire backswing and downswing is the key concept of the on-plane swing. The one-plane swing theory, on the other hand, views the shoulder plane as the swing plane and emphasizes the importance of aligning the shoulder plane perpendicular to the spine while keeping the ball within the shoulder plane. Both theories are flawed mechanically and anatomically in several aspects: (a) the club motion during the downswing occurs in less than 250 ms and bringing the club back to the address position for impact by rotating the club on the shaft plane while translating it in the normal direction simultaneously is a poor conceptualization at best (on-plane swing); (b) the trunk shows a lateral flexion toward the target during the early phase of the downswing (Nesbit, 2005) and maintaining the shaft plane parallel to the original shaft plane regardless of the trunk motion means that the club and the arms move independently from the trunk motion during this phase (on-plane swing); (c) the shoulders exhibit complex 3-D motions during the downswing and a postural plane like the shoulder plane at the top of the backswing is meaningless in regards to the actual motion of the club and the arms during the downswing (one-plane swing); (d) the shoulder girdles provide additional mobility in the trunk and a pure rotation of the trunk and the shoulder about the spine axis without shoulder girdle motion substantially limits the mobility of the trunk (one-plane swing). These recent popular swing theories are in fact a setback from Hogan’s original swing model and neither one has truly grasped the essence of the swing plane and mechanics during the downswing.

SUMMARY AND CONCLUSION: From the findings of the recent 3-D studies (Coleman & Anderson, 2007; Coleman & Rankin, 2005; Nesbit, 2005; Shin et al., 2008), it is evident that the downswing does not occur in a single plane and the major moving parts (the hands, elbows, shoulders, and the clubhead) exhibit complex movement patterns (Figure 1). In particular, the findings of Shin et al. (2008) provide several important implications: (a) since the impact portion (horizontal shaft to mid follow-through) is the most important component of the downswing as the motion of the clubhead during this phase directly affects the outcome (direction and distance), it is the swing plane obtained from this phase that truly characterizes a golfer’s downswing; (b) as long as the impact portion of the downswing forms a well-defined single plane, it may not be so critical for the entire downswing to be planar; (c) it is of crucial importance to understand how the golfer’s body and club move during the early phase of the downswing to secure a well-defined swing plane around the impact position.

In a recent review paper, Farrally et al. (2003) stated “although biomechanical analysis of the swing has attracted considerable research, it has yet to produce a convincing explanation of the physics involved that makes a significant advance on the landmark work of Cochran and Stobbs (1968)”. It could be the simple nature of the planar double-pendulum model proposed by Cochran and Stobbs (1968) which actually hindered scientists to produce a “convincing explanation of the swing mechanics”. Future studies on golf swing mechanics must be based

on a 3-D swing model incorporating full-body, multi-link 3-D representation of golfer's body (Nesbit, 2005). The cocking/uncocking motion, the key wrist motion in the double- and triple-pendulum swing models, must be replaced with the anatomically correct wrist deviation (ulnar/radial) and forearm pronation/supination. The in-plane motion of the club during the impact portion of the downswing and the off-plane motion during the early downswing phase must also be incorporated into the 3-D swing model for an in-depth understanding of the swing mechanics.

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