AN ANALYSIS OF THE KINETICS AND KINEMATICS OF THE GOLF SWING

G. Koenig, M. Tamres, R. W. Mann

Newman Laboratory for Biomechanics
Massachusetts Institute of Technology
Cambridge, Massachusetts, USA

INTRODUCTION

In recent years, a growing number of sports and sports-related activities have incorporated biomechanics in order to understand the motions of the athlete. Among the goals of such efforts are applying the new knowledge to enhance performance, as well as to identify how to reduce or prevent injury. Over this same period golf has continued to expand in popularity and become more thoroughly researched. Cochran and Stobbs (1968) were the first to perform an extensive study of golf incorporating scientific principles to explain the golfer's actions and outcomes. Further work was performed in modeling the swing of the golfer (Williams, 1967; Jorgensen, 1970; Vaughan, 1981; Milburn, 1982; Neal and Wilson, 1985), and in studying the mechanics of the foot-ground interaction (Cooper et al., 1973; Williams and Cavanagh, 1983; and Richards et al., 1985). The study reported here sought to determine the kinematics and kinetics of the golf swing as an integrated whole by examining the shoe-ground interaction and the upper body swing motion.

METHODS

Data acquisition was centered around the MIT TRACK system in the Newman Laboratory for Biomechanics and Human Rehabilitation. This is an active marker system incorporating two Selspot II cameras with software, designed to measure six degree of freedom kinematics using a stereophotogrammetric technique. The markers, infra-red Light Emitting Diodes (LEDs), are multiplexed so as to flash sequentially at a rate of 215 Hz (23 LEDs). Three or more markers are assembled in non-colinear groups (arrays) which are mounted on body segments, the clubs and the shoes. A single Kistler force plate was used in conjunction with the TRACK system, to quantify the kinetics of the shoe-ground interaction.

Fourteen golfers were tested and organized into three handicap groups (low: 0-7, mid: 8-14, high: 15+). Each golfer hit golf balls off an artificial turf surface into a golf cage using three different golf clubs (driver, 3-iron, 7-iron). The force plate was covered with artificial turf, along with the surrounding laboratory floor. Seven trials for each foot were conducted for each club, with all subjects fitted with the same type of golf shoes and all using the same three clubs. Each subject was instrumented with arrays on the following body segment locations: head, shoulders, wrists, knees, and ankles. In addition, the shoes and club were instrumented with arrays.

A seven degree of freedom, double pendulum model was used to represent the golfer's swing motion and simplify the segmental kinematics. The upper lever corresponded to the golfer's shoulder and arms, while the lower lever corresponded to the golf club. The shoulder pivot, or distal end of the upper lever, was free to translate in three coordinate directions.

An algorithm was developed to analyze the ground reaction data in the continuously moving local reference frame of the shoe, as opposed to the conventional initial stance reference frame. The shoe position and movement during the swing were measured using two arrays mounted directly on the shoe. Previous work by Williams and Cavanagh (1983) was limited to displaying the data in an initial fixed stance reference frame. The moving frame approach is more representative of what the shoe actually experiences during the swing.

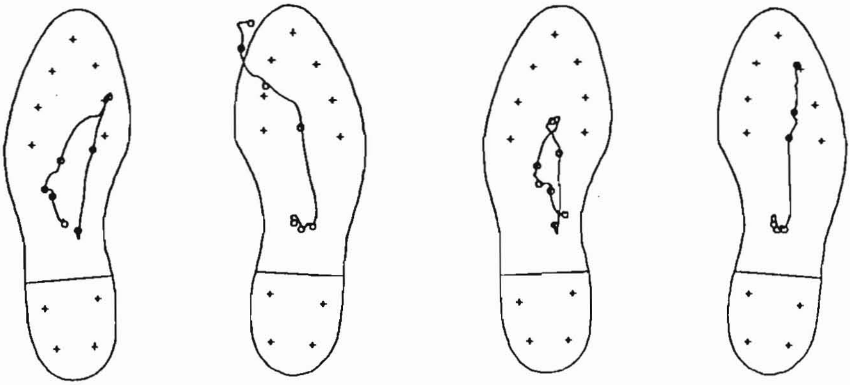
An inter-subject and inter-group normalization routine was also developed. The normalized data elucidated the overall trends for the entire subject pool, as well as for the handicap groups. This routine accounted for temporal effects, as well as the net magnitudes of each data parameter generated. This was achieved by identifying seven distinct kinematic locations of the swing as reference points (initiation IN, mid backswing MB, top of backswing TB, mid downswing MD, impact IM, mid follow-through MF, and top of follow-through TF). Data corresponding to each period of time, defined by these key points, compared each individual trial to the overall average time for each of these periods. Data defining each individual period were then scaled to fit the averaged time period with inherent subject characteristics, such as body segment lengths and weight, incorporated within the data. The data were then averaged across the given data sets.

RESULTS and DISCUSSION

The measurement of shoe movement permitted representation of the ground reaction forces and moments, and center of pressure migration in the moving shoe reference frame. In general, the shoes exhibited significant movement, with the high handicappers having the greatest total amount of movement.

The moving reference frame representation of the center of pressure migration revealed a more centralized migration pattern with respect to the shoe (Figure 1). The more skilled players demonstrated a pattern free of a loop occurring at the top of the backswing for the lead shoe (left shoe for right-handed golfers), implying a more efficient movement. The moving reference frame representation also showed that the center of pressure migration followed a closed circuit pattern for the lead shoe for all skill levels, which was apparent only in the fixed stance reference frame representation for the low handicap players. The back shoe had a migration pattern that progressed straight up the shoe in the moving frame representation. The fixed frame showed that the migration pattern arched after the mid downswing. Overall the low handicap group had migration patterns for both shoes that were further back on the heels and towards the medial edges.

The couple, also referred to as the free moment, demonstrated the trends more clearly than the net moments since the couple is independent of the reference frame used. The net moment is the sum of the couple (free moment) and the moment porduced from the vector product (r X F) of the resultant shear force acting at the center of pressure. The study of the net moment in the fixed and moving reference frames results in two net moments. Study of the couple demonstrated that the low handicap players generated greater couple on the back leg at the critical top of backswing phase. Essentially, they wound themselves up as a tighter spring. The couple on the lead leg was significantly less in magnitude than that of the back leg, indicating that the back leg produces the major rotational drive in the golf swing. However, the lead leg was critical after impact in the latter stages of the swing, generating a large couple as the golfer counteracted the angular momentum of the body in order to arrest movement.



(a) (b)

Figure 1. Center of pressure migration pattern of the averaged golfer in the (a) initial stance reference frame, and (b) moving reference frame (center of pressure data for the back foot is only through mid follow-through). Circles represent kinematic reference points.

a)

b)

c)

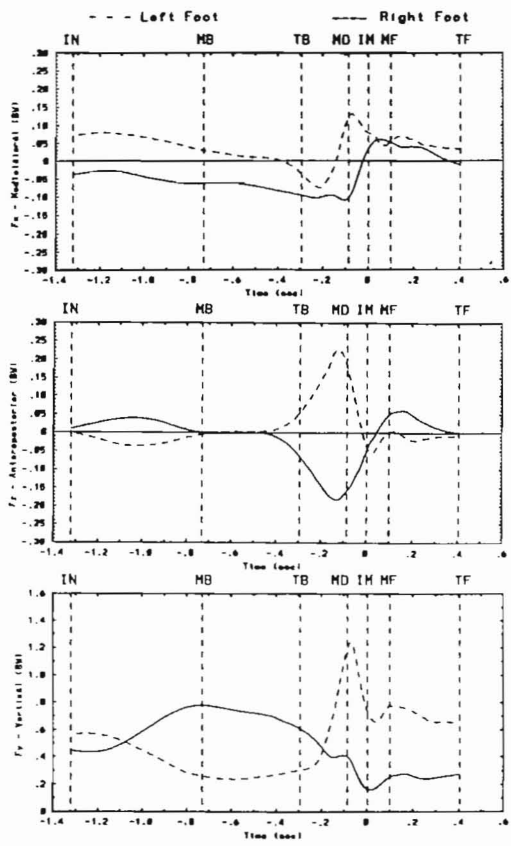
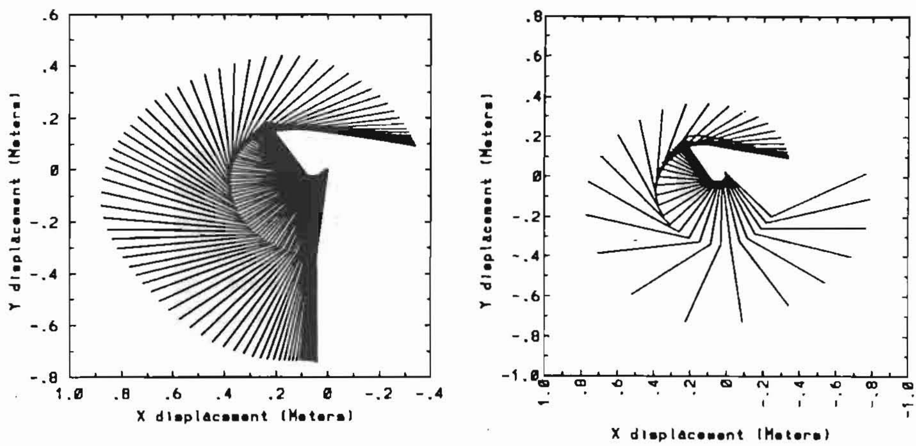


Figure 2. Normalized force-time curves of the left and right foot averaged for all subjects: a) mediolateral (Fx); b) anteroposterior (Fz); c) vertical (Fy).

Forces were analyzed in terms of the reactions to the forces imposed by the golfer on the ground, i.e. the ground reaction forces. These forces are presented as components with respect to the laboratory reference frame. The mediolateral forces (Fx) define the lateral or side-to-side foot action of the golfer in producing and stabilizing the swing motion (see Figure 2a). From initiation to the top of the backswing, the forces are directed so as to produce a translational body shift away from the target (to the right) and a rotation of the hips. The force begins to redirect on the back foot shortly after the top of the backswing until the mid downswing which produces a lateral body motion towards the target. The golfer then acts to stabilize this lateral motion by reversing forces around the time of impact. The less skilled players tended to maintain a greater mediolateral force on both back and lead feet during the backswing, while the better skilled players produced a greater rate of decrease of force on their lead foot during the later phases of the downswing. However, the general trends are very similar among the various skill level groups.

The anteroposterior forces (Fz) define the front-to-back foot action producing the rotational motion of the golfer (see Figure 2b). Overall, the forces produced by both feet complement one another. In the initial backswing phase, the forces act to prevent the golfer from rotating as the clubhead is brought straight back. As the wrists cock and the clubhead is brought vertically upward, the golfer begins to push forward with the lead foot and backward with the back foot, resulting in a rotation about the torso. Near the midpoint of the downswing, the forces rapidly reduce and the upper torso and arms effectively transfer their angular momentum to the clubhead. After impact, the foot forces react to the angular momentum of the clubhead and stabilize the motion of the body. On average, higher forces are produced throughout the swing by both feet of the better skilled players, and they initiate their forces just prior to the top of the backswing earlier. However, as in the mediolateral forces, similar trends in the force-time curves are found among the skill level groups.



(a) Backswing

(b) Downswing

Figure 3. Normalized spatial representation of the (a) backswing, and (b) downswing using the double pendulum model.

The vertical force component (Fy) reports the weight distribution that takes place during the swing, and indicates the center of gravity shift signifying the translational movement of the body's torso (see Figure 2c). The golfers initially shift their weight away from the target and onto their back foot until the top of the backswing, where they rapidly shift their weight back over to their lead foot. Maximum vertical force on the left foot occurs at the mid downswing point and reaches a minimum shortly after impact for both feet. High handicappers tended to maintain more weight on their lead foot as compared to the other handicap groups, resulting in their weight being more evenly distributed. Low handicappers produced a greater maximum total vertical force at the mid downswing point of the swing.

A spatial depiction using the double pendulum representation of the averaged backswing and downswing of all subjects is shown in Figure 3. Wrist cocking and uncocking are evident during the swing, as well as the relative displacements of the arms segment and club segment. High handicappers were found to rotate the club segment through a greater angle in reaching the top of the backswing, while the better skilled players maintained a greater relative angle difference between the club and arms segment at the point of impact. Overall, swing motion was not confined to a common plane in either the backswing or downswing.

CONCLUSIONS

The following is a brief synopsis of the conclusions obtained from this investigation:

1. Expected differences were found between the two feet, showing that the two sides of the body behave differently in the execution of the swing.
2. The less skilled players have more shoe movement overall than the better players, implying inefficiency.
3. The better players have center of pressure migration patterns that are more circular, without loops, again believed to be representative of more efficient movement. In addition, the center of pressure migration pattern for the better players is further towards the heel and medial edge of both shoes. This pattern appears to relate to stability and performance.
4. The better players generated more couple on the back leg demonstrating the importance of body coiling.
5. General trends showed greatest activity in the ground reaction forces during the downswing, with the greatest rate changes occurring around the midpoint.
6. Mediolateral and anteroposterior forces, which provide information on body rotation, showed differences among the skill level groups.
7. Differences in the force-time profiles among the three clubs were largely due to club inertia and swing technique, with the driver generating greater forces during the downswing.
8. Force-time profiles and swing phase timing were similar within an individual, and no statistical correlations were found between the level of skill and the degree of consistency for both individual and group profiles.

REFERENCES

Cochran, A. J. and Stobbs, J. (1968). The Search for the Perfect Swing. New York, N.Y: J. B. Lippincott Company.

Cooper, J. M., Bates, B. T., Bedi, J., Scheuchenzuber, J. (1973). Kinematic and kinetic analysis of the golf swing. Biomechanics IV. pp. 298-305. University Park, Pennsylvania, University Park Press.

Jorgensen, T. J. (1970). On the dynamics of the golf swing. Am J Physics 38(5): 644-651.

Milburn, P. D. (1982). Summation of segmental velocities in the golf swing. Med Sci Sports Exer 14(1):60-64.

Neal, R. J. and Wilson, B. D. (1985). 3D kinematics and kinetics of the golf swing. Int J Sport Biomech 1:221-232.

Richards, J., Farrell, M., Kent, J., Kraft, R. (1985). Weight transfer patterns during the golf swing. Res Quart Exer Sport 56(4):361-365.

Vaughan, C. L. (1981). A three-dimensional analysis of the forces and torques applied by a golfer during the downswing. Biomechanics VII-B. pp. 325-331. Baltimore: University Park Press.

Williams, D. (1967). The dynamics of the golf swing. Quart J Mech App Math 20:247-264. Oxford: Clarendon Press.

Williams, K. R., and Cavanagh, P. R. (1983). The mechanics of foot action during the golf swing and implications for shoe design. Med Sci Sports Exer 15(3):247-255.