WORK AND POWER ANALYSIS OF THE GOLF SWING

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ABSTRACT

A work and power (energy) analysis of the golf swing was performed using a full-body computer model. Four amateur subjects of various skill levels were analyzed and compared. The analysis determined the values and curve profiles of work and power transferred from the golfer to the club during the downswing. The balance of linear/angular work and power was also determined. These energy values and curve profiles are discussed in relation to swing forces/torques, club velocity, swing timing, and skill level.

PURPOSE AND BACKGROUND

Traditional kinetic analyses of the golfer focused on determining the forces and torques generated during the downswing (Dillman and Lange, 1994). Much useful information has been obtained concerning force and torque profiles and their relation to skill level (Nesbit, et al, 2001). However, this information provides insight to instantaneous accelerations, not overall changes in velocity thus yielding a snapshot image of the swing dynamics. An energy analysis has the following advantages: Only the forces/torques that change the velocity of the club are taken into account, i.e., forces/torques that do no work are ignored; The cumulative effects of forces/torques applied over a distance are determinable which introduces factors such as range of motion, timing, and sustainability of forces/torques; The collective effect of various body motions can be summarized by looking at the output i.e., the energy transferred to the club and the resulting club velocity.

METHODS

The study was performed using a full-body computer model of a human coupled to a parametric model of a golf club (Fig. 1). A detailed description of the model development, verification, and application can be found in Nesbit, et al (1994, 1996, 2001). The human (android) model consists of fifteen rigid segments interconnected with spherical joints. The segment size, mass, and inertia properties are determined from population parameters. The golf club is modeled as a stepped flexible shaft connected to a rigid club head. The shaft and club head properties are determined using a variety of analytical, modeling, and experimental methods. The club model is attached with spherical joints. All joints are driven kinematically using spline data functions generated from subject swing data. Swing data are recorded using a passive five camera motion analysis system. Reflective markers are placed at strategic locations on the golfer and club. The paths of the markers are recorded, processed, and analyzed to determine the joint 1-2-3 Euler angle motions. Four amateur subjects of various skill levels were selected for analysis and comparison. Each subject used the same club (1-iron). Several swings from each subject were recorded and analyzed using the computer model.

Figure 1 – Computer Model of Golf Swing

RESULTS AND DISCUSION

The quantities of interest were the forces/torques applied to the club, the hand displacement and velocity, and the club head velocity. Each quantity was resolved into its linear and rotational DOF's (X, Y, Z, swing, pitch, roll). From this information, the 3-D work and power were determined using traditional methods of mechanics. Work and power components were summed to yield the rotational work/power, linear work/power, and total work/power. Table 1 gives the work and power (total, angular, and linear), forces, torques, and club head velocities for the subjects. The work and power output of the subjects is plotted from the top of the backswing through follow-through (Figs. 2 and 3 respectively). Impact is at time zero.

Table 1 – Subject Work, Power, Kinetic, and Velocity Data

Sub	Handi-cap Gender	Work Total Ang / Lin	Power Total Ang / Lin	Peak Force/ Torque	Peak Vel
		N-M	**N-M/sec**	**N/N-M**	**M/sec**
1	0 male	355 146 / 206	3875 1150 / 2775	512 42.1	52.0
2	5 male	289 134 / 155	3005 890 / 2316	453 36.8	49.7
3	13 male	288 148 / 140	2310 1078 / 1402	390 24.6	46.3
4	18 fem	235 121 / 114	1720 698 / 1188	304 24.0	42.1

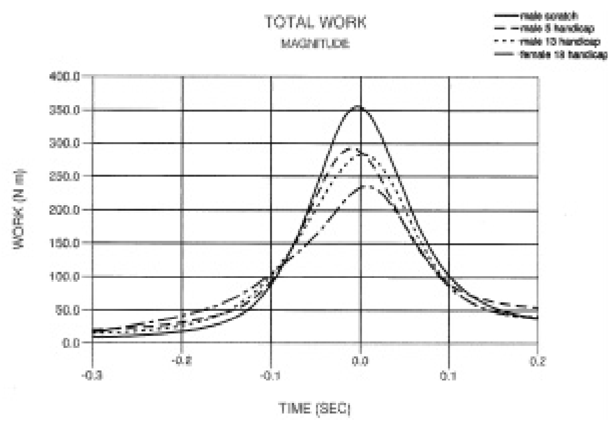

Figure 2 – Total Work During Downswing

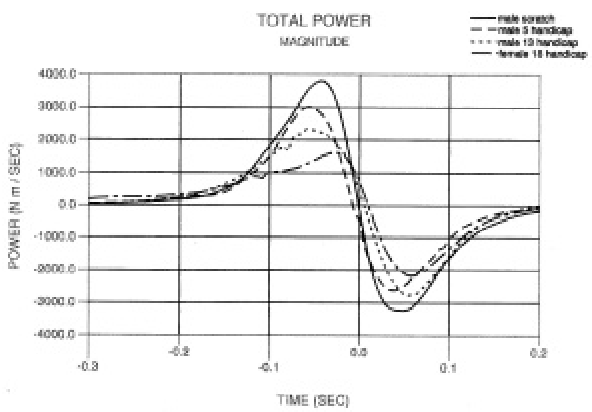

Figure 3 – Total Power During Downswing

The force, linear work, and linear power are primarily transferred from the golfer to the club via pulling on the club by and through the arms. The torque, angular work, and angular power are transferred by and through the wrists. The ability to develop high peak forces and torques reflects the strength of the arms and wrists respectively. Table 1 shows a large range in values for both quantities among the subjects. The ability to apply forces and torques in the direction of motion during the downswing is indicated by the total work, and the ability to apply forces and torques as the swing increases in velocity is indicated by the total power. The total work is the primary factor in generating club head velocity and the relationship is apparent from the data. Referring to Fig. 2, the total work profiles can be seen and reveal differences among the subjects in magnitude, shape, and timing. It is interesting that all subjects had the same total work at time –0.085 seconds which corresponds to the club position shown in Fig.1 for all subjects. The better golfers initially do work at a slower rate until –0.085 seconds, then do work more rapidly through impact. The better golfers also had higher club head velocities, higher peak torques and forces, higher total work done, and were able to peak total work closer to impact. An analysis of the ratio of linear work to angular work seems to indicate that the arms are more essential in doing work than the wrists during the downswing.

A further analysis was done on subject one's ability to peak his total work output just before impact. Plots (not shown) of the linear and rotational components of work, and the force/torque component profiles were analyzed. It was seen that by impact the linear force was perpendicular to the direction of motion. The force was reacting to the centrifugal loading of the club thus doing no more work. Just before impact, the wrists began to apply a retarding torque which reduced the rotational work. The negative torque caused the club shaft to straighten thus releasing its strain energy. (Club shaft deflection can be seen in Fig. 1 as the gap between the shaft and club head.) The club shaft deflection passed through zero at impact and resulted in the club head velocity peaking exactly at impact.

Fig. 3 reveals differences among the subjects in the magnitude, shape, and timing of the total power profiles. Total power is approximately the same until –0.12 seconds which roughly corresponds to the vertical position of the club. The power then peaks at different times prior to impact for each subject. More importantly, the zero handicap golfer was able to zero his power output at impact resulting in maximum work output. The differences in total power are quite significant as is the balance between angular and linear power components. The arms are more important for generating power than the wrists. The angular power peaks prior to the linear power for each subject. In the author's opinion, power is based not only on strength, but also on the ability of the muscles to keep up with the swing while still positively applying forces and torques to the club.

This analysis revealed large differences in work, power, forces, and torques among the subjects. These differences do translate to differences in club velocity, however not to the degree one would expect. Factor in the higher losses associated with impact and aerodynamic drag at higher club speeds and the results are driving distances that are not that different. This observation is especially important for the individual golfer to realize as swinging the club "harder" may do little to improve driving distance. In fact, it may be more difficult to do useful work with tight muscles, and the cost associated with increased effort is often a reduction in accuracy.

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