JOINT MOTIONS AFFECTING THE ENERGY TRANSFER TO THE CLUB DURING THE GOLF SWING

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This study identified the effect of joint motions on the force power and segment torque power acting on the golf club, and investigated contributions of proximal joint motions to energy transfer to the club during the golf swing. Sixteen skilled golfers performed swings with the driver. Their 3D kinematic data were collected using an optical motion capture system. The wrist joint force power and club segment torque power were decomposed into powers relating to 1) velocity of the center of the gravity of pelvis, and angular velocities of 2) pelvis, 3) lumber joint, 4) shoulder joint, and 5) wrist joint. The powers associated with the pelvis angular velocity were the main components of the power generation at the wrist joint. The powers associated with the pelvis and proximal joint angular velocities reached their peak simultaneously. These findings indicate that synchronised timing of the peak powers might represent an efficient strategy to maximise the energy transfer to the club during the golf swing.

KEYWORDS: jont force power, joint torque, work.

INTRODUCTION:

Clubhead speed is an important element for performance enhancement in the golf swing. Golfers generate a large amount of power, especially by torso twisting motion, and transfer energy to the club (Nesbit et. al., 2003). Therefore, the skill in energy transfer in a proximal-to-distal sequential motion as well as the magnitude of power generation would be important for increasing clubhead speed. There have been studies investigating power and work generation and the energy transfer between adjacent segments during the golf swing (Nesbit et. al., 2003). However, it remains unknown how the proximal joint motions contribute to transfer energy to the club. Since a proximal-to-distal sequential motion is observed in skilled golfers, it might be related to effective energy transfer. Energy flow from the body to the club can be described as the integral of the joint force power and segment torque power acting on the club. Sprigings et al. (1994) described the velocity of the racket head speed as a function of its proximal joint angular velocities during the tennis serve. Applying this idea, the hand velocity and the club angular velocity, which are the components of the joint force power and segment torque power acting on the club, can be decomposed into the proximal joint angular velocities. Therefore, the joint force power and segment torque power acting on the club can be described as a function of the proximal joint motions. This new analyses can reveal the effect of joint motions, such as torso twisting motion, to the energy transfer to the club. Therefore, it might be useful to assess the skill levels and be helpful for technical instructions of the golf swing. The purpose of this study was to identify the affect of the proximal joint motions on the joint force power and segment torque power acting on the club, and to investigate the contributions of the proximal joint motioins to the energy transfer to the club during the golf swing.

METHODS: Sixteen right-handed skilled golfers (9 men and 7 women; handicap, 2.9 ± 1.9; age, 17.4 ± 2.6 years; 164.2 ± 8.0 cm; 61.4 ± 7.2 kg) participated in the experiment. After a sufficient warm-up period, the participants hit four to seven shots into a net (placed approximately 7 m away) with their own driver. The participants were asked to hit the balls straight into the target, which was represented by a vertical line attached to the net (approximately 50.0 cm in length and 7.0 cm in width). After each shot, the participants were asked to assess their own shot using a five-point scale (i.e., 5 is best, 1 is worst) (Lim, et al., 2012). Reflective markers were attached to each participant's body and driver. The ball was covered with reflective tape. The marker trajectories were collected using a three-dimensional motion capture system (VICON MX) consisting of 20 cameras operated at 500 Hz. The swing with the highest reported rating was analysed for each participant. Data analysis was restricted from the start of the backswing (i.e., takeaway) to just before impact. The time just before impact was identified by the ball movement. The three-dimensional coordinate data of the club and body markers were smoothed using a zero-lag fourth-order low-pass Butterworth digital filter. The coordinate data were smoothed after the padding processing (Derrick, 2004). The five time events were defined: (1) takeaway (TA); (2) the time point of the minimum (i.e., maximum clockwise) axial rotation velocity of the pelvis (MIR); (3) the transition point where the pelvis stops backward rotation and begins rotating toward the target (i.e., top of the backswing, TOB); (4) the time point of the maximum (i.e., maximum counter-clockwise) axial rotation velocity of the pelvis (MAR); (5) the time point just before impact (IM). Both hands, forearms, and upper arms were defined as the 'arm' segment. A torso and upper limbs model consisting of the club, arm, thorax, and pelvis segments was defined. Each segment was assumed to be a rigid body. The wrist, shoulder, and lumbar joints were defined as the midpoint between both hands, shoulders, and ribs, respectively. The swing planes (motion planes) of the club, left arm, and torso are not completely but approximately the same direction during the golf swing (i.e., there are no significant differences between the inclinations of the planes which are characterised by clubhead, left shoulder, and left hand trajectories (Kwon et. al., 2012)). Therefore, energy was assumed to be transferred mainly on the swing plane of the club, namely, the plane perpendicular to the clubshaft angular velocity excluding its longitudinal rotational axis component (Vaughan, 1981). The present calculation described below was on the swing plane. The first-order differential of the club energy on the club swing plane ($\dot{\mathbf{E}}$) can be written as follows:

$$\dot{\mathbf{E}} = \mathbf{F}_{\mathbf{plane}} \cdot \mathbf{V}_{\mathbf{hand}} + \mathbf{T}_{\mathbf{plane}} \cdot \boldsymbol{\omega}_{\mathbf{club}} \qquad (1)$$

Where $\mathbf{F}_{\mathbf{plane}}$ and $\mathbf{T}_{\mathbf{plane}}$ are the joint force and torque vector acting at the wrist joint on the swing plane. $\mathbf{V}_{\mathbf{hand}}$ is the wrist joint velocity. $\boldsymbol{\omega}_{\mathbf{club}}$ is the club angular velocity. Decomposing $\mathbf{V}_{\mathbf{hand}}$ and $\boldsymbol{\omega}_{\mathbf{club}}$ into the proximal joint angular velocities (Sprigings et al, 1994), equation (1) can be written as follows:

$$\begin{aligned}\dot{\mathbf{E}} = {} & \mathbf{F}_{\mathbf{plane}} \cdot \mathbf{V}_{\mathbf{pelvis}} \\ & + \mathbf{F}_{\mathbf{plane}} \cdot \{\boldsymbol{\omega}_{\mathbf{pelvis}} \times (\mathbf{r}_{\mathbf{lumbar}} + \mathbf{r}_{\mathbf{shoulder/lumbar}} + \mathbf{r}_{\mathbf{arm}})\} + \mathbf{T}_{\mathbf{plane}} \cdot \boldsymbol{\omega}_{\mathbf{pelvis}} \\ & + \mathbf{F}_{\mathbf{plane}} \cdot \{\boldsymbol{\omega}_{\mathbf{thorax/pelvis}} \times (\mathbf{r}_{\mathbf{shoulder/lumbar}} + \mathbf{r}_{\mathbf{arm}})\} + \mathbf{T}_{\mathbf{plane}} \cdot \boldsymbol{\omega}_{\mathbf{thorax/pelvis}} \\ & + \mathbf{F}_{\mathbf{plane}} \cdot (\boldsymbol{\omega}_{\mathbf{arm/thorax}} \times \mathbf{r}_{\mathbf{arm}}) + \mathbf{T}_{\mathbf{plane}} \cdot \boldsymbol{\omega}_{\mathbf{arm/thorax}} \\ & + \mathbf{T}_{\mathbf{plane}} \cdot \boldsymbol{\omega}_{\mathbf{club/arm}} \end{aligned} \qquad (2)$$

Where $\mathbf{V}_{\mathbf{pelvis}}$ and $\boldsymbol{\omega}_{\mathbf{pelvis}}$ are the velocity and angular velocity of the centre of gravity of the pelvis, $\boldsymbol{\omega}_{\mathbf{thorax/pelvis}}$, $\boldsymbol{\omega}_{\mathbf{arm/thorax}}$, $\boldsymbol{\omega}_{\mathbf{club/arm}}$ are the angular velocities of the lumbar, shoulder, and wrist joints, respectively. $\mathbf{r}_{\mathbf{lumbar}}$ is the position vector pointed from the centre of gravity of the pelvis to the lumbar joint, $\mathbf{r}_{\mathbf{shoulder/lumbar}}$ is the position vector pointed from the lumbar joint to the shoulder joint, and $\mathbf{r}_{\mathbf{arm}}$ is the position vector from the shoulder joint to the wrist joint. The first term is the power associated with the pelvis velocity, the second–fifth terms are the powers associated with the pelvis angular velocity, the sixth–eighth terms are the powers associated with the angular velocity of lumbar joint, the ninth–ten terms are the powers associated with the angular velocity of shoulder joint, and the eleventh term is the power associated with the angular velocity of wrist joint.

RESULTS and DISCUSSION:
The power calculated using the presented method (i.e., the right side of the equation (2)) was well matched with the first-order differential of the club energy (Figure 1), indicating that the present calculation procedure is valid.

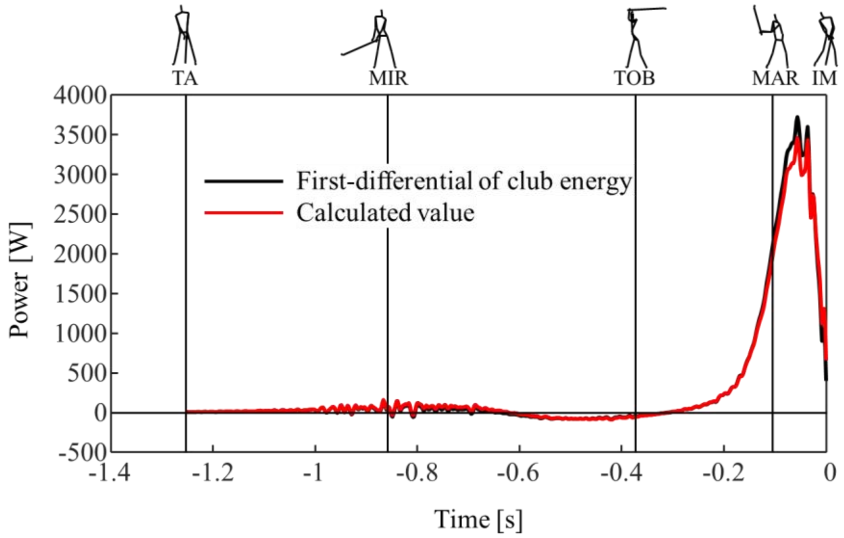

Figure 1: Validation of the presented method

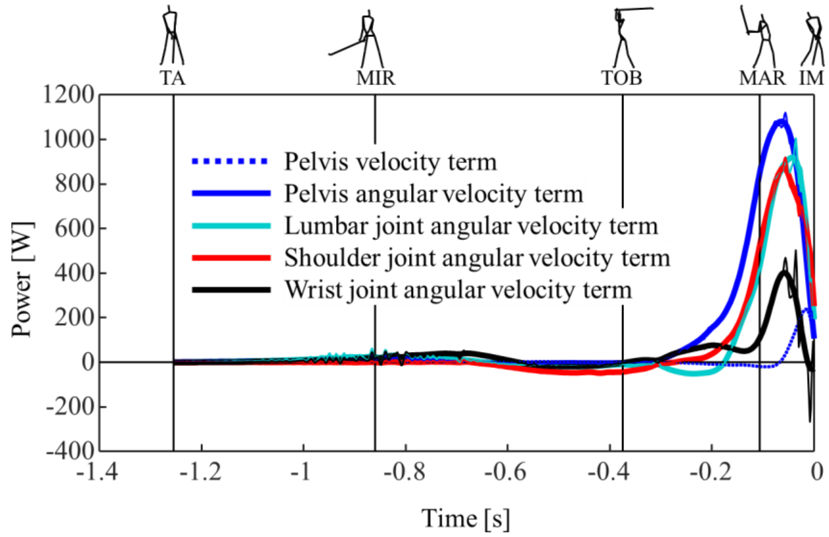

Figure 2: Power components generated at the wrist joint of a typical participant. Each component represents the power associated with the proximal joint angular velocity. Thick lines represent the smoothed values while the thin lines represent the raw values.

Power and work acting on the club was related mainly to the pelvis angular velocity, and subsequently lumbar and shoulder angular velocities (Figure 2, Table 1). These indicate that the pelvis rotation and torso twisting motion, contribute directly to the power generation acting on the club as a component of the hand velocity and club angular velocity. While the powers associated with the pelvis and the proximal joint angular velocities increased from the proximal to distal joint, the powers reached their peaks almost simultaneously (Figure 2). Horan and Kavanagh (2012) also reported that there is no difference of the peak timing between the thorax and pelvis angular velocities. Synchronising the peak velocities of the proximal joints might have an advantage of maximising the hand (distal end) joint and club angular velocities which can be expressed by the sum of the proximal joint angular velocities.

Because the golf swing conducted in a short period of time, it might be effective to synchronise the peak angular velocities of the pelvis and proximal joints rather than a proximal-to-distal sequential peak angular velocity patterns of the joints to increase the club energy. Considering the above, synchronised timing of the peak powers associated with joint angular velocities might represent an efficient strategy to maximise the energy transfer to the club during the golf swing.

Table 1: Work associated with each joint motion acting on the club (mean ± *SD*). Parentheses represents the ratio of the work associated with each joint motion to total work acting on the club.

	Work
Pelvis vel. term [J]	5.0 ± 2.6 (2%)
Pelvis ang. vel. term [J]	148.2 ± 25.6 (45%)
Lumber ang. vel. term [J]	78.4 ± 18.5 (24%)
Shoulder ang. vel. term [J]	71.3 ± 26.1 (22%)
Wrist ang. vel. term [J]	27.1 ± 11.8 (8%)

CONCLUSION:
The study identified the effect of the pelvis and proximal joint motions (i.e., lumber, shoulder, and wrist joints) on the joint force power and segment torque power acting on the club. The ratios of the work associated with the pelvis and joint motions acting on the club were 2% (pelvis velocity), 45% (pelvis angular velocity), 24% (lumber joint angular velocity), 22% (shoulder joint angular velocity), and 8% (wrist joint angular velocity) respectively. While the powers increased from the proximal to distal joint, the powers reached their peaks almost simultaneously. These findings indicate that synchronised timing of the peak powers associated with joint angular velocities might represent an efficient strategy to maximise the energy transfer to the club during the golf swing.

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