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DYNAMICS OF CLUB HEAD VELOCITY DURING GOLF SWING

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The purpose of this study was to identify the dynamics of club head velocity during a golf swing. Three professional golf players hit a golf ball to the net placed on a hit ball direction. Three dimensional kinematic data of swing motions were collected using motion capture system (VICON NEXUS). Dynamic equations were derived to determine the contributions of the torque and force acted on the grip, motion-dependent and gravity element to the club head velocity. The results were summarized as follows. The elements of the force acted on the grip and the centripetal acceleration were the main causes of the club head speed at the impact. The torque element acted on the grip contributed to the club head speed at the beginning of the swing.

KEY WORDS: golf, dynamics, club head velocity.

INTRODUCTION:

Golfers are required to hit a golf ball with a consistent accuracy so that they can finish games with lower score. However, many players have difficulties to hit the ball long distance, and to hit the ball strait or to the intended direction. The determinant factors of the initial hit ball velocity are the club head velocity, the club face angle, and the ball impact position on the club face at impact. Furthermore, the kinetic factors such as force and torque acting on the grip become the main causes of the club kinematics. Therefore, it is important to clarify the kinetic factors acting on the club. In previous studies, the causes of the club head velocity (Miura, 2006), and the kinematics of golf swing motion (Teua et al, 2001; Vena et al, 2011) have been researched. However, there are very few researches which investigated the dynamic elements that contribute to the club head velocity. The purpose of this study was to investigate the dynamic elements contributing to the club head velocity during golf swings.

METHODS:

Three male professional golfers (height: 1.76 ±0.03m, weight: 76.0 ±3.0kg) participated in the experiment. Subjects hit a golf ball to the net placed on the hit ball direction. Subjects repeated 15-20 trials with each driver and iron. Three dimensional kinematic data of the club were collected using motion capture system (VICON, 500 Hz). Global coordinate system was defined as follows. Vertical axis was defined as the Z axis, the hit ball direction in the horizontal plane was defined as the Y axis, the orthogonal axis to Z and Y axes was defined as the X axis. In order to measure the club angular velocity, an inertial sensor equipped with gyroscope (range: ±6000dps, weight: 35g, sampling frequency: 1000 Hz) was attached to the club shaft (under the grip). Club coordinate system (CCS) was defined as shown in Figure 1. The coordinate data of the markers attached to the club head were not smoothed because these markers were affected by the impact largely. The coordinate data except the club head and the sensor data were smoothed with a Butterworth low-pass digital filter of optimal cut-off frequencies which were determined by the residual error method (Winter, 1990), and ranged 5-30 Hz(coordinate data), and 30-40 Hz(sensor data). The coordinate data and the sensor data were interpolated to 2000 Hz by cubic spline function. The axes of the sensor were conformed to CCS.

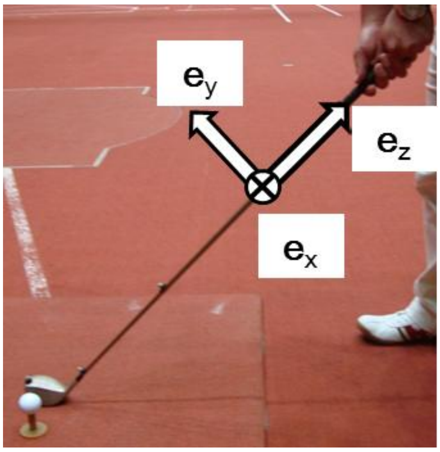

Figure 1: Definition of the club coordinate system.

The club shaft was assumed as a rigid body. The force and the torque were assumed to be acted on a particle on the grip. The fundamental equations of the motion of the club are

$$\mathbf{F} - \mathrm{m}_{\mathbf{cg}}\mathbf{g} = \mathrm{m}_{\mathbf{cg}}\mathbf{a}_{\mathbf{cg}} \qquad \cdots(1)$$

$$\mathbf{T} + \mathbf{r}_{\mathrm{cgp}} \times \mathbf{F} = \mathbf{R}(\hat{\mathbf{I}}\dot{\boldsymbol{\omega}}' + \boldsymbol{\omega}' \times \hat{\mathbf{I}}\boldsymbol{\omega}') \qquad \cdots(2)$$

where, **F**: the force acted on the grip, m_{cg}: the mass of the club, **g**: the gravity, $\mathbf{a}_{cg}$: the acceleration of the CG of the club, **T**: the torque acted on the grip, $\mathbf{r}_{cgp}$: the position vector from the CG of the club to the point where the force and the torque acted on, **R**: the rotational transformation matrix, $\hat{\mathbf{I}}$: the principal moment of inertia of the club, $\dot{\boldsymbol{\omega}}'$: the angular acceleration of the club in CCS, $\boldsymbol{\omega}'$: the angular velocity of the club in CCS. The equation of the acceleration of the club head are

$$\mathbf{a}_{\mathrm{ch}} = \mathbf{a}_{\mathrm{cg}} + \mathbf{R}(\dot{\boldsymbol{\omega}}' \times \mathbf{l}'_{\mathrm{ch}}) + \boldsymbol{\omega} \times (\boldsymbol{\omega} \times \mathbf{r}_{\mathrm{cgp}}) \qquad \cdots(3)$$

where, $\mathbf{a}_{ch}$: the acceleration of the club head, $\mathbf{l}'_{ch}$: the position vector from CG of the club to the club head in CCS. The equation for the CG of the club was derived from the equation (3), substituted to the equation (1). The equation for the angular acceleration of the club in CCS was derived from the equation (2). The simultaneous equation was derived from these equations. Finally, the equation (4) was derived as follows,

$$\mathbf{a}_{\mathrm{ch}} = \underbrace{\mathbf{AT}}_{\text{TORQUE}} + \underbrace{\mathbf{A}[\mathrm{r}_{\mathrm{cgp}} \times]\mathbf{F} + \frac{\mathbf{F}}{\mathrm{m}}}_{\text{FORCE}} - \underbrace{\mathbf{AR}(\boldsymbol{\omega}' \times \hat{\mathbf{I}}\boldsymbol{\omega}')}_{\text{GYRO}} + \underbrace{\boldsymbol{\omega} \times (\boldsymbol{\omega} \times \mathbf{l}_{\mathrm{ch}})}_{\text{CENT. ACC.}} - \underbrace{\mathbf{g}}_{\text{GRAVITY}} \qquad \cdots(4)$$

where, $\mathbf{A} = \mathbf{R}[\times \mathbf{l}'_{\mathrm{ch}}]\,\mathbf{R}^{-1}\,\hat{\mathbf{I}}^{-1}$

In order to assess the equation (4), the norm of the club head acceleration derived from the equation (4) was compared with that of the acceleration derived from second order differential of the club head coordinate data. Dynamic elements of the club head velocity were calculated by integrating each terms of the equation (4). Then, these dynamic elemants were projected to the club head velocity to clarify the dynamic components contributing to the club head speed.

RESULTS AND DISCUSSION:

1. Assessment of the calculated dynamic elements

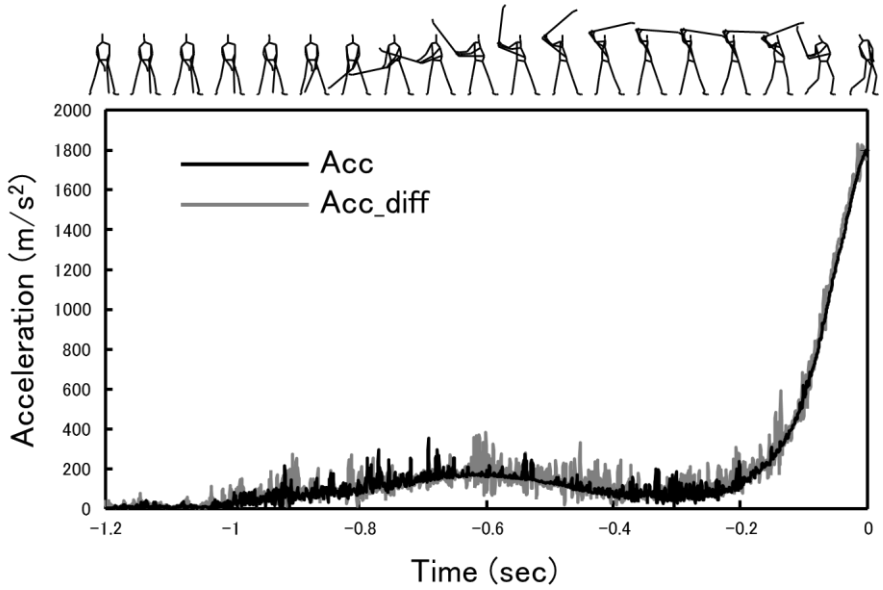

Figure 2: Assessment of the calculated club head acceleration (Driver)
Acc: The norm of the acceleration derived from the equation (4).
Acc_diff: The norm of the acceleration derived from second order differential of the club head coordinate data.

Figure 2 shows the comparison of the norm of the acceleration derived from the equation (4) with the norm of the acceleration derived from second order differential of the club head coordinate data during a typical driver swing. Regardless of the club (driver and iron), the other trial data also had the same patterns. The norm of the acceleration derived from the equation (4) was coincident with the norm of the acceleration derived from second order differential of the club head coordinate data. The club head velocity derived by integrating the equation (4) was also coincident with first order differential of the club head coordinate data・

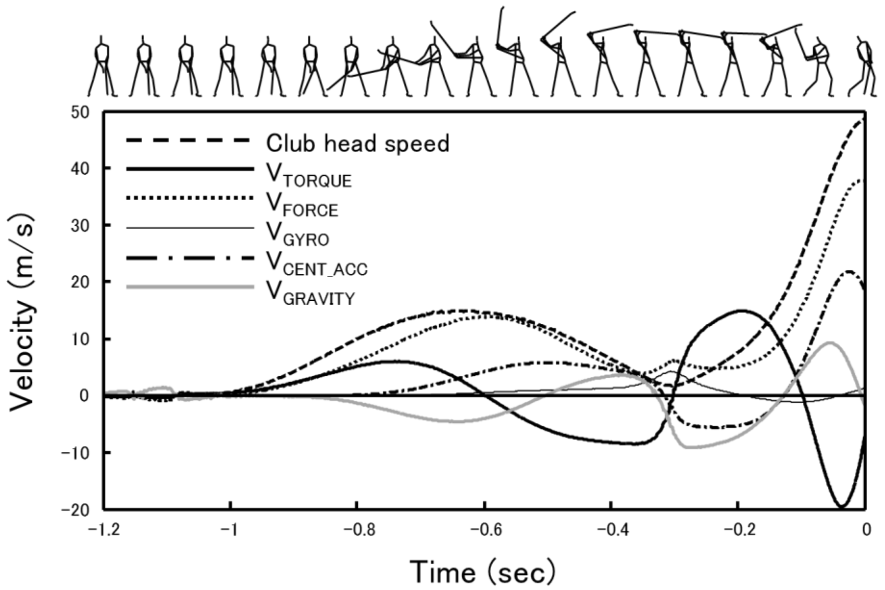

Figure 3: Dynamic components contributing to the club head speed (Driver).
V_{TORQUE}, V_{FORCE}, V_{GYRO}, V_{CENT_ACC}, $V_{GRAVITY}$ shows the dynamic components contributing to the club head speed.

2. Dynamic components contributing to the club head speed

Figure 3 shows the dynamic components contributing to the club head speed during a typical driver swing. Regardless of the club (driver and iron), the other trial data also had the same patterns. V_{TORQUE} contributed the most to the club head speed at the beginning of the swing (around -0.2s). Then, V_{FORCE}, V_{CENT_ACC} increased to be the main causes of the club head speed at the impact. The torque acted on the grip was the main cause of the club angular velocity (no figure). Therefore, it was thought that the torque acted on the grip contributed to the club head speed indirectly as the component of V_{CENT_ACC}.

CONCLUSION:

The dynamic elements of the club head velocity were calculated. The most contributing components to the club head speed were V_{TORQUE} at the beginning of the swing, and V_{FORCE} at the impact. The torque acted on the grip was thought to contribute to the club head speed indirectly as the component of V_{CENT_ACC}.

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