KINETIC MECHANISMS OF THE PELVIS ROTATION ABOUT ITS LONGITUDINAL AXIS DURING THE GOLF SWING

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The purpose of this study was to clarify the dynamics of the pelvis axis rotation during the golf swing. Sixteen skilled golfers performed swings with the driver. The 3D kinematic data and ground reaction forces were collected using an optical motion analysis system and two force platforms. The dynamic components of the pelvis angular acceleration were calculated as a function of 1) joint torque, 2) gravity, 3) motion-dependent forces, and 4) inertia force parameters. The present study found that the joint torque was the largest component of the pelvis axis rotation. In the torque component, both hip joint torques about its extension/flexion and adduction/abduction axes most affect the pelvis axis rotation, but the role of the torques differs between the rear and target legs. The control strategy of the pelvis axis rotation during the golf swing was discussed.

KEY WORDS: ground reaction force, joint torque, joint force, motion-dependent force

INTRODUCTION: The torso rotation about its longitudinal axis (torso axis rotation) is the fundamental of the golf swing (Horan & Kavanagh, 2012; Hume et al., 2005; Joyce et al., 2013). Golfers generate large power from the torso rotation and translate it to the upper limbs (Hume et al., 2005). The direction of the torso rotation, or the trunk lateral bending also relates to the direction of the swing, resulting in the launch angle of the ball (Joyce et al., 2016). Therefore, the torso axis rotation relates to the clubhead speed and the swing direction. Torso rotational motion differs between the skill levels and genders (Tinmark et al., 2010), indicating that learning the 'good' torso rotation or proper training for the torso rotation are essential for the performance enhancement. Understanding of mechanics of the torso rotation during the golf swing is required to assess the torso rotation and the proper training. In the golf swing, pelvis rotates first, then the thorax rotates about its longitudinal axis (Horan & Kavanagh, 2012). During this sequence, torso twist motion is observed generating the large power (Hume et al., 2005). Therefore, the pelvis axis rotation might be the key motion as a starting point for generating large power. Large number of the researches have investigated the pelvis axis rotation during the golf swing (Horan & Kavanagh, 2012; Tinmark et al., 2010). Unfortunately, comparing to the kinematics, few studies have been investigated about the kinetics. So far, regurations of the ground reaction forces (McNitt-Gray et al., 2013), the angular impulse of the body (Peterson et al., 2016), and the spinal load of the lumbar (Lim, et al., 2012) have been investigated. However, in our knowledge, none of the researches reveal the kinetic mechanisms of how the pelvis rotate during the golf swing. Understanding of the dyanmics of the pelvis rotaion would be crucial for the training and coaching. The purpose of this study was to clarify the dynamic components of the pelvis axis rotation and investigate the kinetic mechanisms of the pelvis axis rotation during the golf swing.

METHODS: Sixteen right-handed golfers (eight men and eight women; handicap, 2.9 ± 1.8; age, 17.4 ± 2.6 years; height, 164.2 ± 8.0 cm; mass, 61.4 ± 7.2 kg) participated in the experiment. the participants hit four to seven shots into a net (placed approximately 7 m away) with their own driver. The marker trajectories were collected using a three-dimensional motion capture system (VICON MX; Vicon Motion Systems Ltd., Oxford, UK) consisting of 17 cameras operated at 500 Hz. The ground reaction forces on the both feet were measured using two force platforms (Kistler) operated at 1000 Hz. The shot where the participant felt best was analysed in each participant. The three-dimensional coordinate data of the club and the body markers from the start of the
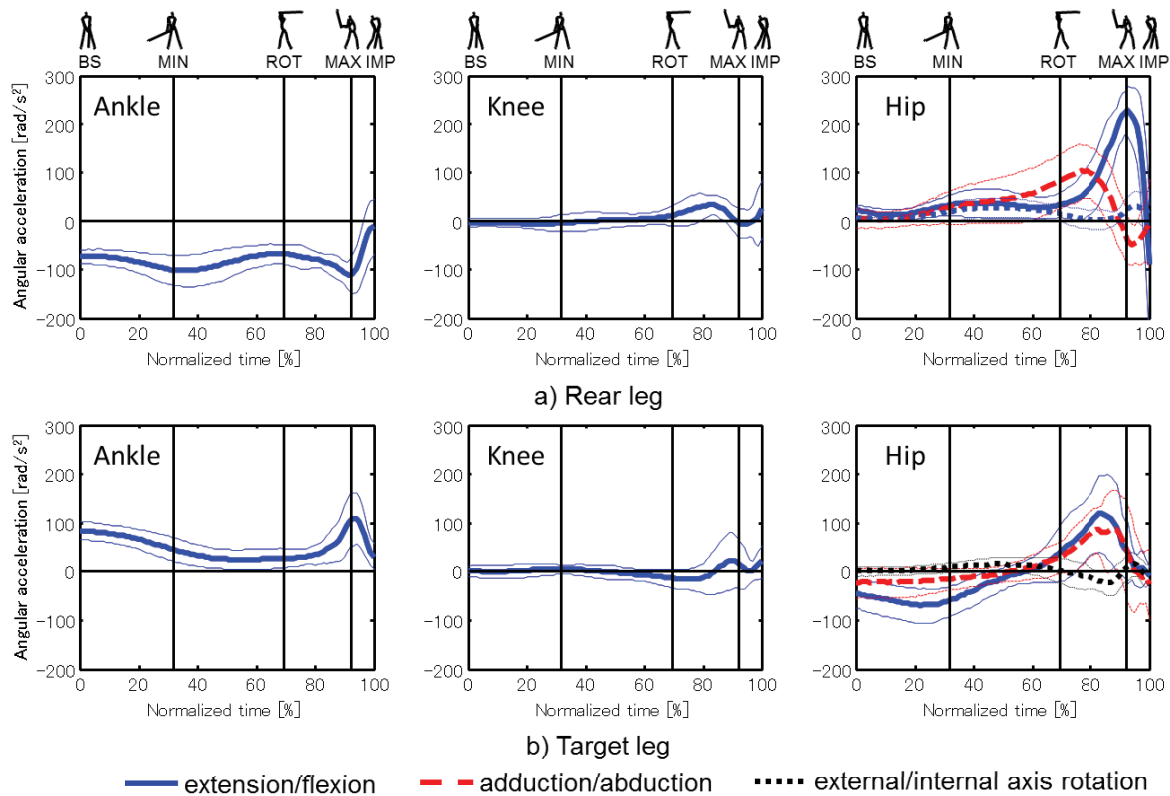

Figure 1: Attached marker-set

backswing to just before impact were smoothed using a zero-lag fourth-order low-pass Butterworth digital filter. The coordinate data were smoothed after padding processing (Derrick, 2004). The cut-off frequencies were determined through residual analysis (Winter, 1990). Torso and lower limbs model consisting of the seven segments (i.e., both thighs, shanks, feet, and pelvis) were used (Figure 1). The local coordinate systems of the segments were defined based on the ISB recommendation (Wu, et al., 2002). All segments were assumed to be the rigid body. The ankle and knee joints were assumed to be the hinge joints (i.e., the range of the motion was about the extension/flexion axis only). The dynamic components (c.f., torque, gravity, motion-dependent forces, and ground reaction forces) of each segment accelerations and angular accelerations were calculated by satisfying the following three equations simultaneously (Koike & Harada, 2014; Takagi, 2016); (1) Newton–Euler equations of the motion, (2) the kinematic constraint equation of the segments, which express the relationship between acceleration vectors of neighboring centers of mass (Fujii & Hubbard, 2002), and (3) the equation of the constraint axes of the joints (Fujii & Hubbard, 2002). Additionally, the the ground reaction forces were distributed to the other dynamic components such as torque (Koike et al., 2007). Finally, the accelerations and angular accelerations of the segments were described as a function of the 1) torque, 2) gravity, 3) motion dependent force, 4) inertia forces due to the accelerations of the lumbar joint and COPs, and 5) the error terms caused from the present assumptions (c.f., change of the segment lengh). The dynamic components of the pelvis angular acceleration were extracted, and projected to the pelvis longitudinal axis.

RESULTS: The torque component was the largest especially in the phase from the beginning of the pelvis axis rotation (ROT) to the time of the maximum pelvis angular velocity (MAX) (Figure 2). After MAX, the torque component affects negatively. The hip joint torque about its extension/flexion and adduction/abduction axes were the largest positive components to the pelvis axis rotation after ROT (Figure 3). The hip joint torque about its extension/flexion and adduction/abduction axes in the target leg increased simultaneously between ROT and MAX (Figure 3b). The rear hip joint torque increased from the time of the minimum pelvis angular velocity (MIN). In contrast to the target leg, sequencing pattern was observed in the rear hip joint torques, in other words, the hip joint torque about its adduction/abduction and extension/flexion axes reached its peak in order (Figure 3a). In the phase between ROT to MAX, the hip extension and abduction torques were generated in the rear leg while the hip flexion and adduction torques were generated in the target leg (no Figure), indicating that these torques affects positively to the pelvis axis rotation. In the phase from ROT to MAX when the torso twist motion was observed, the large negative torque was affected from the lumbar joints to the pelvis about its longitudinal axis (Figure 4).
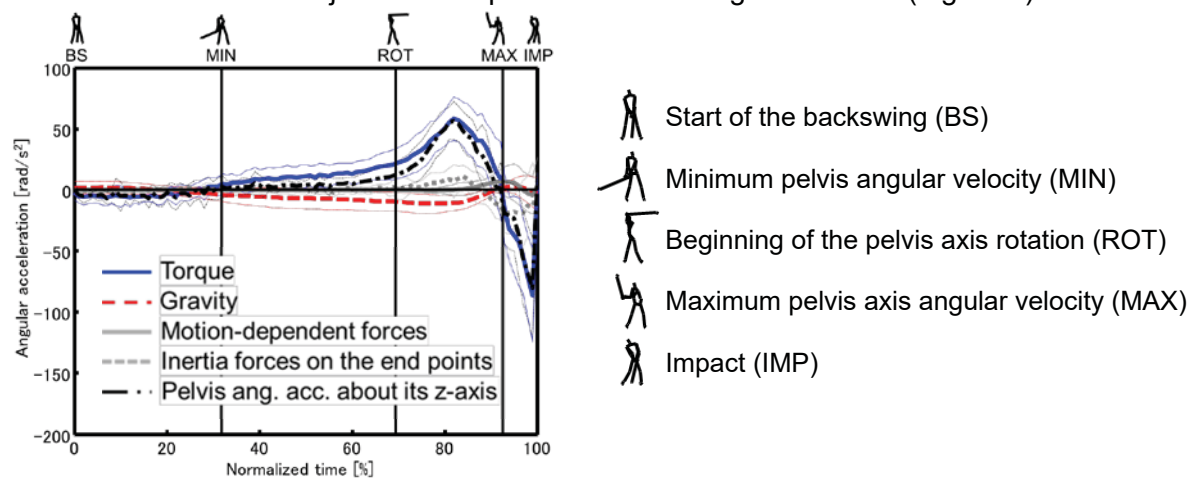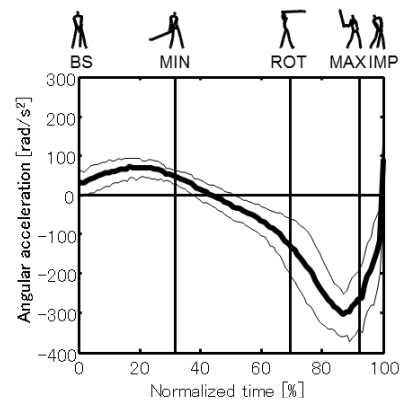

Figure 2: Dynamic components of the pelvis angular acceleration about its longitudinal axis. The thick and thin lines exhibit the means and standard deviations of the dynamic components between the participants, respectively. The inertia forces on the end points exhibit the forces due to the accelerations of the lumbar joint and COPs. The illustrations of the time events of the motion are defined in the right side.

a) Rear leg

b) Target leg

——— extension/flexion – – – adduction/abduction ······ external/internal axis rotation

Figure 3: Lower limbs joint torque components of the pelvis angular acceleration about its longitudinal axis. The thick and thin lines exhibit the means and standard deviations of each torque between the participants, respectively.

DISCUSSION: The present results indicate that both hip joint torques are the primary positive components of the pelvis axis rotation especially between ROT and MAX. On the other hand, the lumbar joint torque affects negatively to reduce the pelvis axis rotation after ROT through the torso twist motion. The difference of the patterns in the hip joint torque components between the rear and target legs indicate that the role of the hip joint torques for the pelvis axis rotation differs between the both legs. In the target leg, the hip joint flexion and adduction torques increased simultaneously accelerating the pelvis axis rotation between ROT and MAX phase. Golfers increase the angular impulse of the body and club system and shot distance by increasing the target leg angular impulse and the target leg peak resultant horizontal reaction force (Peterson et al., 2016; McNitt-

Figure 4: Lumbar joint torque component of the pelvis angular acceleration about its longitudinal axis.

Gray et al., 2013). Therefore, the hip flexion and adduction torques in the target leg rather than the rear leg may relate to the control of the pelvis axis angular speed. In the rear leg, the hip joint torques increased as early as MIN, remained to be positive even after MAX when the pelvis angular velocity began to decrease (Figure 3a). Not only increasing the pelvis axis angular velocity but also inhibiting the rapid reduction of the pelvis axis angular velocity after MAX would be important. The lumbar joint torque negatively affected to the pelvis axis rotation from ROT to the impact (Figure 4). Resisting the negative torque component is required for maintaining or increasing the thorax axis angular velocity (Otherwise, the pelvis axis rotation would decelerate rapidly, which results in the reduction of the thorax axis angular velocity). Therefore, the hip extension torque in the rear leg after MAX might have an important role for cancelling the negative torque component of the

lumbar joint. Based on the above, following could be suggested; (1) The training of the hip flexion and adduction torque in the target leg especially between ROT and MAX phase may be required to golfers who cannot increase the pelvis axis angular velocity sufficiently, (2) golfers, whose pelvis axis rotation decelerated excessively before impact, should learn the skill to keep the rear hip extension torque until the impact.

CONCLUSION: This study identified the dynamic components of the pelvis axis rotation during the golf swing. The torque component was the largest among the dynamic components of the pelvis axis rotation. The both hip joint torques most affect the pelvis axis rotation, but the role of the torques differs between the rear and target legs. The practical applications were suggested from the perspectives of the regulations of the joint torque patterns and activation timing.

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