RELATIONSHIP BETWEEN JOINT ANGLES AND X-FACTOR IN GOLF SWING

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The X-Factor is the most commonly investigated performance parameter in the golf. Although there are several studies have reported the relationship between X-Factor and clubhead speed, ball velocity and golfing skills. However, the associated joint kinematics required to attain large X-Factor during the golf swing has received little attention. Therefore, the purpose of current study was to identify the key joint angles that are associated with X-Factor. Ten low handicap male golfers participated in this study. The motion capture system was used to record full body motion. The results indicate the key joints that associate with the X-factor during two phases of swing. This study provides fundamentals of the movement mechanisms of the major joints and their relationship with the X-Factor that can be integrated with coaches and players to improve the golfing skill.

KEYWORDS: golf swing, x-factor, joint angle, motion analysis.

INTRODUCTION: In golf, the most important determinants of swing performance are the driving distance and shot accuracy, where the driving distance is a direct result of the club head speed (Hume, Keogh & Reid, 2005). In order to increase the clubhead speed or ball velocity, a golfer increases the upper torso rotation at the top of the backswing (TB) while limiting the amount of pelvis rotation (Myers et al., 2008). This separation between upper torso and pelvis rotation often termed as “X-Factor” (Hume et al., 2005; Myers et al., 2008), which is the most commonly investigated performance parameter for golf performance (Joyce, 2017). Most studies have computed the X-Factor from the shoulder line from hip lines on the projected transverse plane (Myers et al., 2008; Cole & Grimshaw 2009; Chu, Sell & Lephart, 2010; Meister et al., 2011). Joyce (2010) directly computed the X-Factor using the relative orientation of the shoulder to the pelvis via three-dimensional (3D) approach. Kwon et al. (2013) projected the shoulder and hip lines onto the functional swing plane (FSP) to calculate the separation between two segments.
Due to the highly complex and multi-joint movements are involved in the golf swing, the previous studies focused on relationship between X-Factor and clubhead speed (Meister et al., 2011; Joyce, 2017), ball velocity (Myers et al., 2008; Chu et al., 2010) and golfing skills (Cole & Grimshaw 2009). However, the associated joint kinematics required to attain large X-Factor during the golf swing has received little attention. Therefore, the purpose of current study was to identify the key joint angles that are associated with the X-Factor.

METHODS: Ten right-handed low handicap male golfers (age, 23.2 ± 1.6 years; 175.7 ± 3.8 cm; 74.4 ± 10.4kg; handicap, 2.6 ± 1.3) participated in this study. All participants were recruited with informed consent form the Korean College Golf Federation and the Korean Professional Golf Association. This study was approved by our Institutional Review Board. The motion capture system (Motion capture system, Visol Inc, Kwangmyung, Korea), which consisted of six high-speed cameras, was used to record full body. The recorded motion data were exported as 3D positions of 46 anatomical landmarks, where the 43 and 3 reflective markers were attached to the body of the subject and driver, respectively. A previously developed model in Matlab (MathWorks, Natick, MA, USA) was used to calculate 3D kinematics of the full body (Khurelbaatar, K. Kim, Lee & Kim, 2015; Khuyagbaatar, Purevsuren, Park, K. Kim & Kim, 2017). The joint angles were calculated as the Euler angles of the distal segment reference frame relative to the proximal segment reference frame using inverse dynamic analysis based on the motion data. The X-Factor was calculated by projecting the shoulder and hip lines onto a global horizontal plane and then subtracted one angle from the other. (Myers et al., 2008; Chu et al., 2010; Cole & Grimshaw 2009; Meister et al., 2011; Brown, Selbie & Wallace, 2005). The shoulder and hip lines defined by 3D

position data of anatomical markers attached on the right and left anterior superior lilac spines for hip and the right and left acromion for shoulder (Figure 1).
A linear regression analysis was used to determine the significant predictors of X-Factor for the ball address (BA) to TB and the TB to end of follow-through (EFT) events (MathWorks, Natick, MA, USA). Data for the BA to TB and TB to EFT were normalized and averaged for all subjects, respectively. The regression model determines whether certain predictor variables (joint angles) are related to the dependent variables (X-Factor). First, all joint angles were entered into the regression model then non-significant joint angles were removed until only significant joint angles remained in the final regression model. Then, the joint angles with significant level ($p < 0.05$) were applied to each subject data. Finally, the averaged magnitudes of the X-Factor were compared with predicted data in terms of correlation coefficients (R^2) and root mean squared error (RMSE).

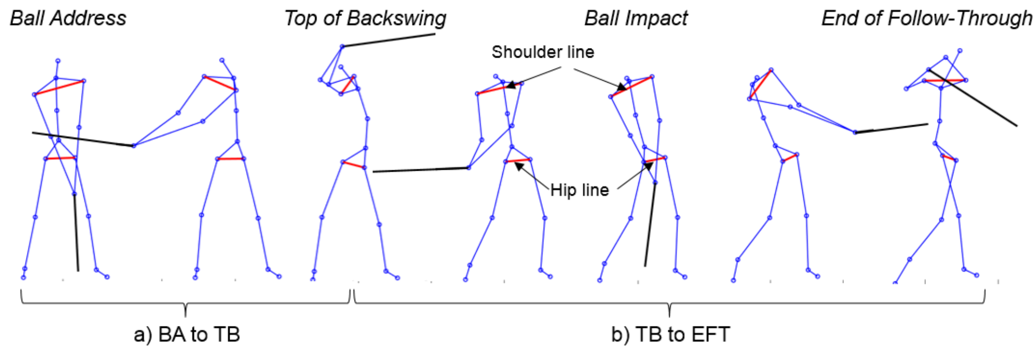

Figure 1: Schematic representation of the golf swing from BA to EFT. Red lines indicate the shoulder and hip lines.

RESULTS: The ensemble averages of the hip and knee angles during the golf swing are presented in Figure 2. All peak angles occurred during the transition from the TB to BI. For shoulder and elbow, peak angles were observed after the BI, except maximum flexion of right elbow at the TB (Figure 3). The lower and upper trunk angles showed similar patterns with left axial rotation (Figure 4).

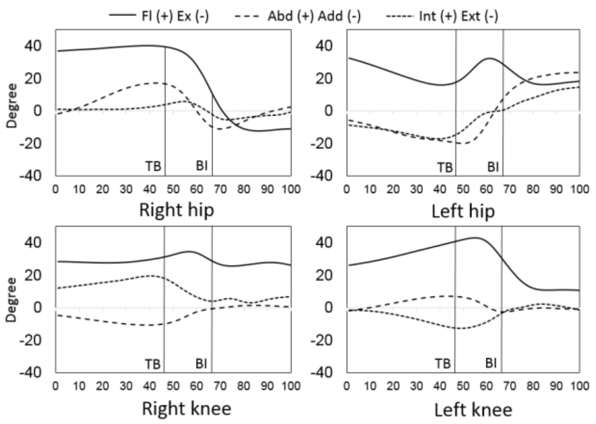

Figure 2: Hip and knee joint angles

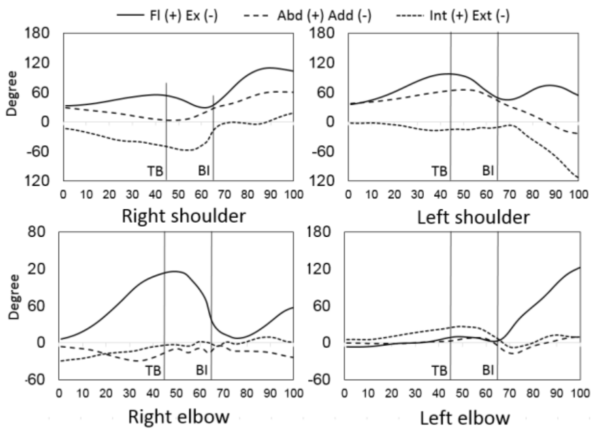

Figure 3: Shoulder and elbow joint angles

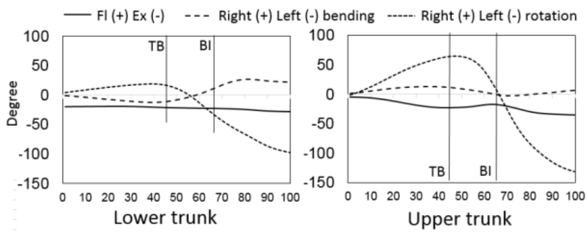

Figure 4: Lower and upper trunk joint angles

The linear regression model reported right knee adduction, right shoulder external rotation and left elbow extension in the BA to TB, and left knee adduction, lower trunk right bending and left rotation in the TB to EFT as the significantly associated variables with the X-Factor (Figure 5). The predicted X-Factor from the regression model showed a good agreement with the RMSE of 1.4° to 2.5° and strong correlations of R^2 = 0.99 as compared to the calculated data.

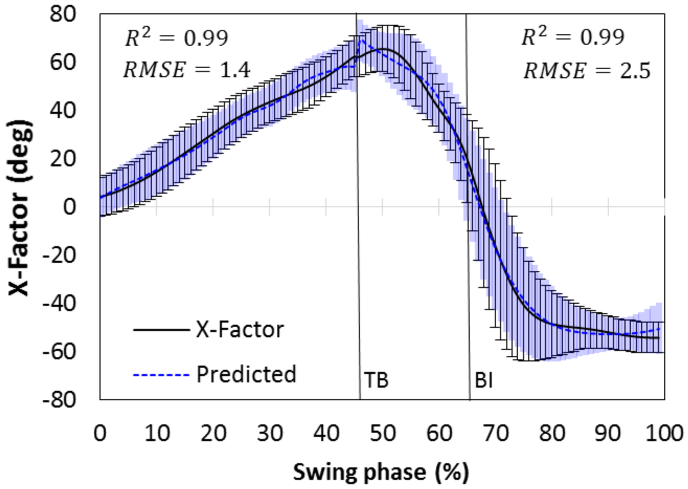

Figure 5: Ensemble averages and SDs of calculated (black) and predicted (red) X-factors

DISCUSSION: Our study investigated the relationship between joint kinematics and X-Factor. The regression model found that right shoulder external rotation increased as X-Factor increased while having a straight left elbow and adducted right knee during the backswing. These agree with previous studies that modern golf swing emphasizes a large shoulder turn with a restricted hip turn in order to maximize the hip-shoulder separation (Gluck, Bendo & Spivak 2008). Hume et al. (2005) reported that left elbow is extended during the backswing. From TB to EFT, right bending and left rotation of the lower trunk, as well as left knee adduction, were found to be significant predictors of the X-Factor. The product of lumbar lateral bending and axial rotation velocity is important to increase the force at the BI, but golfers should avoid the excessive trunk lateral bending because of it makes difficult to rotate the upper body which has the potential for injury to the vertebral body and facet joints of the lumbar spine (Gluck et al., 2008; Joyce, 2017). There are few studies have reported the importance of knee joint during the golf swing. Golfers tend to constrain the right knee while flexed their left knee during the backswing to create a large X-Factor (Hellström, 2009; Keogh & Hume, 2012). Hume et al. (2005) reported that players should produce large GRF on right (trailing foot) foot during the backswing and transfer these GRFs to left (leading) foot during the downswing. Although the knee adduction-abduction rotations were found as the predictor variables, the golf swing was considered a strenuous activity for the knee joint and the excessive training without enough rest is not recommended due to possible injury to the anterior cruciate ligament (ACL) by fatigue failure (Purevsuren et al., 2017). The results suggest that specific joint angles highly related to the X-factor during the golf swing, which can help to improve the golf swing performance and training efficiency.
There are some limitations in this study. The linear regression model included only major joint kinematics except for wrist, ankle, and neck joint. The inclusion of all joints in the human body may give a further explanation in maximizing the X-Factor. The conventional method was used to calculate the X-Factor based on projected separation angle on the horizontal plane. Finally, marker position and skin motion may lead to inaccurate measurements during the golf swing.

CONCLUSION: We investigated the relationship between joint kinematics and X-Factor during the golf swing. The results indicate the key joints that associate with the X-factor during two phases of swing such as BA to TB and TB to EFT. In order to maximize the X-

Factor at the TB, the players may need to extend the right shoulder external rotation while having the straight left elbow. The trunk plays important roles in the downswing and follow-through. This study provides fundamentals of the movement mechanisms of the major joints and their relationship with the performance parameter that can be integrated with coaches and players to improve the golfing skill and training efficiency.

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