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THE IMPORTANCE OF WRIST FLEXION AND X-FACTOR IN THE GOLF SWING: A FORWARD KINEMATIC APPROACH

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This study aimed to investigate the importance of wrist flexion and trunk rotation relative to the pelvis about a vertical axis (X-factor) in the golf swing, through the use of kinematic simulation. Empirical data of 5 highly skilled golfers were collected using a 3D opto-reflective system. A full body, 3D forward kinematic model was created that predicted the endpoint of the club to within 0.02 mm of the empirical data. X-factor rotation, then flexion of the wrist was locked at zero degrees throughout the downswing, with the effect on the kinematics of the club-head analysed. The results indicated that effective extension/ flexion at the wrist is of great importance to performance with an average reduction of club-head velocity at impact of 46%, when wrist flexion is restricted during the downswing. Effective rotation of the trunk was also important to performance variables.

KEY WORDS: Computer modelling, golf drive, performance.

INTRODUCTION: The velocity, orientation and path of the club-head when impacting the ball, will dictate the outcome of any golf drive (Hay, 1993). Optimising these variables is a result of the coordination of a great number of segments throughout the golfer's body. Understanding the influence of specific segmental kinematics in the swing, therefore, is vital for coaches in enabling golfers to achieve their optimal performance. To this end, previous research has identified some kinematic differences in the swings of golfers of different skill levels. For example, a number of papers have identified the magnitude and velocity of trunk rotation relative to the pelvis (or X-factor) as a key difference between high and low handicappers (Cheetham et al., 2000; Egret et al., 2004; Myers et al., 2008). Additionally the timing and velocity of rotation about the wrists has been highlighted to be different between players who are highly skilled, and those who are of poor skill (Nozawa & Kaneko, 2003; McLaughlin and Best, 1994).

While previous observational case-control and cross-sectional studies have provided an understanding of kinematic differences between golfers of varying skill levels they have limited potential for identifying and quantifying causal relationships between kinematics in the golf swing. Additionally correlational and regression based analyses are also inadequate in identifying causal relationships between kinematic variables, as they are based on assumptions of linearity between variables.

An alternative is to simulate a specific change to the swing using a forward dynamic approach. Research of this nature has revealed some important information regarding optimal performance of the swing (Chen et at., 2007; Sprigings & Neal, 2000). However, this approach has generally suffered from the limitations of operating in 2D, with a limited number of segments. Additionally there is paucity in understanding the role kinematics play,, as it is kinematics that coaches use most commonly (quantitatively and qualitatively) to assess a swing.

The aim of the current study is to assess the influence of restricting X-factor rotation and wrist flexion/extension, on the orientation and velocity of the club-head during the downswing phase of the golf drive.

METHODS: Five highly skilled male golfers were recruited for the study, possessing an average handicap, height and mass of 3.6 (±4.9), 1.77 m (±0.08) and 75.2kg (±9.7) respectively. After providing written consent and performing a 5 minute warm up, each participant hit 4 drives, into a net situated 5 m in front of them. Participants were asked to use their natural technique that they would employ for a straight drive on the golf course.

Each swing was recorded using a 12 camera Vicon (Oxford, UK) MX system operating at 400 Hz. Seventy-seven retro reflective markers, of 16 mm diameter, were affixed to the participant and club during the calibration procedure. Twenty eight of these markers identified key anatomical landmarks required for the definition of segment anatomical coordinate systems (ACSs). The rest of the markers, inclusive of 12 semi-rigid ‘T-bar’ clusters, were used to define technical coordinate systems (TCSs) that represented the movement of each segment. A pointer method (Cappozzo et al., 1995) was used to identify the 3D position of lateral and medial epicondyles for both elbows, as well lateral and medial femoral condyles at each knee. The locations of these landmarks were held in the TCSs from the upper arm and thigh respectively. The same method allowed the creation of a club-face ACS from three markers affixed to the top of the club-head (Sweeney et al., 2009).

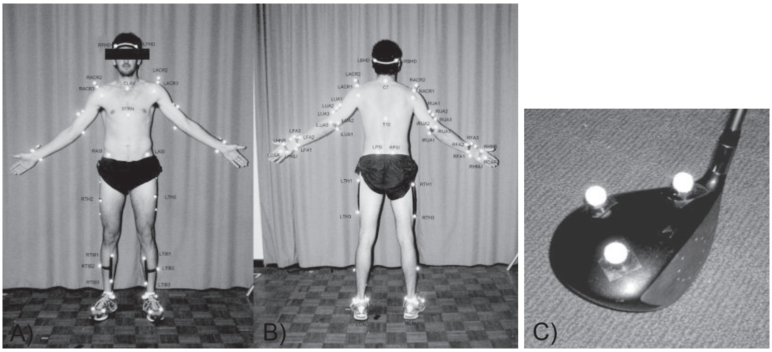

Figure 1: Full body retro-reflective marker set from A) anterior view, B) posterior view and of the C) golf club-head.

A Forward Kinematic Model (FKM) was developed to allow the calculation of club-head position and orientation, given the position and orientation of the initial segment, as well as the subsequent segment angles and joint positions (relative to ACSs) for the rest of the kinematic chain. The FKM consisted of 36 Degrees of Freedom (DOF), from the 11 segments defined as a part of the original kinematic data. The general equation was:

$$^{G}P_{CF} = {}^{G}P_{1} + \sum_{i=1}^{N} {}^{i}P_{i} \; {}^{G}_{i}R_{zyx}\left(\alpha, \beta, \chi\right)$$

Where $^{G}P_{CF}$ was the position of the centre of the club-face in the global coordinate system, $^{G}P_{1}$ was the position of the left foot (initial segment), $^{G}_{i}R_{zyx}$ (α,β,χ) was the rotation matrix defining the orientation of segment i, which was composed via sequential rotations about the z-, x- and y-axes of segment i by the angles α,β,χ (corresponding to the medio-lateral, anterior-posterior and vertical axis) and $^{i}P_{i}$ was the position of the endpoint of segment i defined within segment i’s ACS.

Validation of the FKM was performed by evaluating club-face position, orientation (club-head loft) and resultant velocity produced by the FKM in comparison to the empirical data. Using the FKM, two altered conditions were then imposed for each trial collected across all participants, to assess the effect of restricting X-factor rotation and wrist flexion/extension. The former was achieved by replacing the X-factor angle with a zero value for the entire downswing, whilst keeping the kinematics across the other 35 degrees of freedom the same as the empirical data. The same process was repeated for the second altered condition, this time with the flexion/extension of the wrist set to zero. Dependent samples t-tests ($p<.05$) were used to assess whether either experimental condition produced significantly different club-head loft angle and/or resultant velocity to the original FKM data at impact.

RESULTS: With respect to the predicting the club-face centre position in the global coordinate system, the maximum resultant error of the FKM was 0.02 mm across all time points of all trials analysed, with an average RMS Error of 0.0014 mm. In predicting club-head velocity and loft angle the average FKM also had an average RMS of under 0.001 ms^{-1} and 0.001º respectively.
Club-head resultant velocity and loft angle during the downswing from the empirical data, FKM and both altered conditions can be seen in Figure 2. Club-head velocity and orientation in both altered conditions were markedly different to the original FKM data, with the patterns seen in Figure 2 being consistent across all participants. Both restricting the X-factor rotation and the wrist flexion/extension resulted in slightly higher club-head velocities at different stages during the downswing, however both caused a significantly ($p<0.05$) decreased club-head velocity at impact (Table 1). Further, it was apparent that this decrease at impact was much greater in the condition restricting the wrist flexion/extension. A significantly more lofted angle of the club-head also resulted from both altered conditions, when compared with the empirical data.

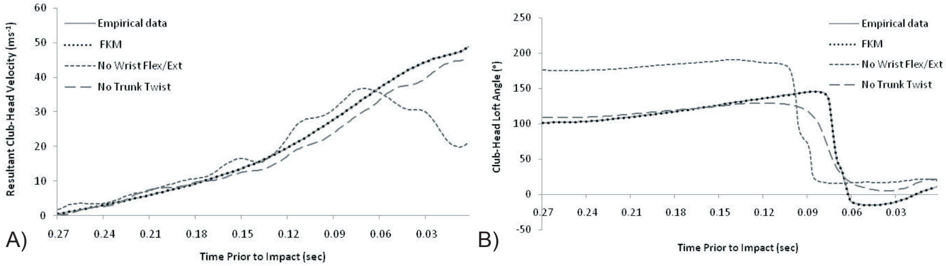

Figure 2: A representative trial showing A) resultant club-head velocity and B) club-head loft angle, for each condition, across four trials.

Table 1
Average club-head velocity (ms^{-1}) and loft angle (◦) across all three conditions

	Original FKM	No Trunk Twist	No Wrist Flex/Ext
Resultant Club-Head Velocity	47.7	43.6*	25.8**
Club-Head Loft Angle	6.8	17.6**	20.2**

** sig <0.05, ** sig <0.01*

DISCUSSION: The FKM predicted all kinematics of the club-head highly accurately and therefore can be considered a valid tool for simulating the endpoint of the chain based on the kinematics of the previous segments.
Resultant velocity of the club-head has often been used as an indicator of performance in the golf drive, as it plays a large role on allowing a player to achieve maximum distance (Hay, 1993). The results indicate that restricting movement at either the trunk or wrist will result in a significant decrease in club-head velocity late in the downswing, and therefore a diminished performance. While the decrease in club-head velocity observed with restricted rotation of the X-factor may be considered somewhat minor (9% of empirical club-head velocity), the decrease caused by restricting the flexion/extension of the wrist during the downswing (46% of empirical club-head velocity) suggests that movement in this single degree of freedom is responsible for generating a large portion of club-head velocity at impact. These findings would seems to support previous 2D simulation studies that have highlighted the effect that timing and magnitude of kinetics at the wrist joint can play in the golf swing (Chen et at., 2007; Sprigings & Neal, 2000). Furthermore the research indicates that players not achieving adequate ‘wrist cock angle’ or perhaps ‘releasing’ this angle too early will likely hit the ball dramatically shorter.

Whilst orientation of the club-head at impact has been reported as a key to performance in the swing (Hay, 1993), there has been a paucity of research linking it to any kinematics of the golfer. The results of this study would indicate that the kinematics at the trunk and wrist both play a role in dictating the orientation of the club at impact. Restriction of these two movements both resulted in the club-head having a significantly greater loft angle at impact. A loft angle too high at impact will logically result in an overly steep launch angle and/or too much backspin on the ball, leading to decreased distance and perhaps accuracy. It seems important for both distance and accuracy, therefore, that golfers are able to freely rotate their trunk and wrists during a high performance golf drive
While the results of the current study provide valuable information with regard to the role of two key kinematic variables in the swing, further research is needed encompassing a greater number of participants and a more diverse spread of skill levels.

CONCLUSION: A novel technique for simulating the kinematics of the swing has been presented in this study, highlighting the importance of both rotation of the trunk and the flexion/extension of the wrists in achieving optimal distance and accuracy. The results indicated that X-factor rotation of the trunk may play a significant but somewhat minor role in creating velocity of the club-head, as well as allowing the club-head to be orientated optimally at impact. However, extension then flexion at the wrists appears to play an even greater role in the creation of club-head velocity and optimal club-head orientation at impact. To maximise performance in the golf drive, therefore, coaches should ensure players get the most out of their shoulder turn and, in particular, the extension followed by flexion of their wrists.

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