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Christopher Joyce
University of Notre Dame Australia, chris.joyce@nd.edu.au

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An examination of the correlation amongst trunk flexibility, x-factor, and clubhead speed in skilled golfers

Christopher Joyce [1]

[1] *School of Health Sciences, The University of Notre Dame Australia, Fremantle, Western Australia*

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Author Contact: chris.joyce@nd.edu.au [+61 (8) 94330224]

Abstract

Skilled golfers are reported to be more flexible than lesser able golfers, which may assist in increased x-factor (shoulder – pelvis separation) at the top of the backswing. However, it is unknown if increased flexibility produces faster clubhead speed. The aim of this study was to investigate the correlations amongst trunk flexibility and x-factor, as well as the association between flexibility and clubhead speed in low handicap golfers. Fifteen low handicap male golfers who displayed a modern swing, had their trunk static anatomical end-range of motion (ROM) (flexibility) and driver swing kinematics were measured. Although Pearson correlations revealed trunk extension and lateral bending were moderately related to x-factor, axial rotation flexibility was not. A generalised linear model (GLM) reported three axial rotation flexibility variables and six golf swing kinematic variables were associated with faster clubhead speed. The Pearson correlation results suggests that skilled golfers who have increased axial rotation flexibility do not necessarily utilise it to increase x-factor, and the GLM results support the importance of multi-segment flexibility, and interaction for improving golf performance with skilled golfers.

Introduction

The recent rise in the use of physical conditioning for golf at the elite level has seen a number of experimental studies aim to quantify its effect on golf performance (Fletcher & Hartwell, 2004; Keogh et al., 2009; Lephart, Smoliga, & Myers, 2007). The goal of most physical conditioning research is to increase performance through faster clubhead speed and reduced shot variability (Keogh et al., 2009; Meira & Brumitt, 2010; Thompson & Osness, 2004). The use of multi-factorial training interventions agree that joint flexibility is crucial to optimal swing mechanics, although joint flexibility has been shown to be negatively affected by the development of muscular hypertrophy (Gergley, 2009; Keogh et al., 2009).

One physical attribute which has been under-investigated individually, is the effect flexibility has on golf performance (Hume, Keogh, & Reid, 2005). Research agrees that flexibility is important for golfers for such reasons as; a decreased resistance to swing plane and a decreased stretch reflex (Chettle & Neal, 2001) which allows for a greater ROM in the backswing (Keogh et al., 2009; Meira & Brumitt, 2010), and injury reduction (Lindsay & Horton, 2006). Flexibility in more able, or lower handicap players, has been found to be significantly greater than their higher handicap counterparts (Sell, Tsai, Smoliga, Myers, & Lephart, 2007), and may possibly explain faster clubhead speed for lower handicap players (Fletcher & Hartwell, 2004; Fradkin, Sherman, & Finch, 2004; Wells, Elmi, & Thomas, 2009). One explanation for this may be that lower handicap players who exhibit greater flexibility throughout the golf swing are able to attain specific positions (i.e. top of backswing) with increased balance and control, to then deliver faster clubhead speed, with reduced shot variability (Sell et al., 2007; Smith, 2010).

A player who can attain increased ROM, measured by angular displacement between the shoulders and the pelvis at the top of the backswing, is said to have an increased ‘x-factor’ (Brown, Selbie, & Wallace, 2013; Myers et al., 2008). Golfers who are able to maximise their x-factor at the top of the backswing are said to increase clubhead speed, and or ball velocity at ball impact (Chu, Sell, & Lephart, 2010; Lephart et al., 2007; Myers et al., 2008). Further, at the commencement of the downswing, the pelvis generally rotates towards the target before the shoulders and produces ‘x-factor stretch’ (Burden, Grimshaw, & Wallace, 1998; Cheetham, Martin, & Mottram, 2001). Faster clubhead speeds are attained through skilled golfers who exhibit x-factor stretch at the commencement of the downswing through dynamic tension of the torso muscles that contract maximally during the downswing (Cheetham et al., 2001). These swing features are displayed in ‘modern’ swing golfers who utilise a greater shoulder turn, and keep the pelvis restricted throughout the backswing (Gluck, Bendo, & Spivak, 2007). However, recent evidence suggests that certain methods used to measure x-factor are questionable based on the motion analysis techniques used (Kwon, Han, Como, Lee, & Singhal, 2013). More anatomically valid x-factor can be obtained when modelling the thorax as multi-segments (upper and lower, relative to the pelvis) to suit the rotational characteristics of the spine, and using Cardan / Euler 3D methods as opposed to projected plane methods (Brown et al., 2013; Kwon et al., 2013).

Although it has been reported that lower handicap golfers (HC < 0) are more flexible than their higher handicap counterparts (HC 10-20) for shoulder and pelvis ROMs (including axial rotation for comparison to x-factor) (Sell et al., 2007), it is unknown how this directly relates to x-factor. It is also unknown if flexibility, reported as ‘static anatomical end-ROM’ is associated with faster clubhead speed when investigating x-factor variables (x-factor and x-factor stretch), with the trunk modelled as multiple segments. The first aim of this study was to investigate the correlation amongst flexibility variables of the trunk and lower trunk and x-factor variables. The second aim was to determine which x-factor related flexibility and golf swing kinematic variables were associated with clubhead speed. Both aims were investigated in a group of low handicap golfers using their own driver.

Methods

Participants & Experimental Protocol

Fifteen right handed low handicap male golfers (Mean ± SD: age = 22.7 ± 4.3 years, registered golfing handicap = 2.5 ± 1.9) were recruited for this study. A modified Nordic Low Back Pain questionnaire (Kuorinka et al., 1987) was completed by each participant to confirm the absence of back pain within the last 12 months, which may limit flexibility or swing kinematic variables (Lindsay & Horton, 2006). Participants were also undertaking no form conditioning, or resistance program where flexibility could have been compromised (Hume et al., 2005; Keogh et al., 2009). To assume similarity between participants golf swings, all participants were adjudged to have demonstrated a ‘modern’ golf swing when obtaining golf swing kinematics, rather than a ‘classic’ swing (Gluck et al., 2007). This was confirmed by two Australian Professional Golfers Association teaching professionals, independently verifying ‘modern’ golf swing traits via a qualitative video analysis of each participant’s golf swing. Those participants who exhibited golf swing traits associated with a classic golf swing, i.e. heel raise and pelvic movement, resulted in exclusion from the study. On the basis of these criteria, five of the originally screened 20 participants were excluded.

The experimental protocol of this study involved each participant firstly having their flexibility variables obtained, then to hit five shots with their own driver using the same leading brand of golf ball using a 3D motion analysis system. During testing, participants wore bicycle shorts, their own golf glove and golf shoes, and hit off a tee positioned on an artificial turf surface into a net positioned five metres in front of the hitting area. Participants were instructed to perform a warm up, which included practice swings and real swings, to familiarise themselves with hitting within the laboratory. This study was undertaken in an indoor biomechanics laboratory. Ethical approval to conduct the study was provided by the Institutional Human Research Ethics Committee at Edith Cowan University (6069 JOYCE).

INSERT FIGURE 1 ABOUT HERE

Data Collection

A 10-camera MX-F20 Vicon-Peak Motion Analysis system (Oxford Metrics, Oxford, UK) operating at 250 Hz was used to capture each participant’s flexibility variables and golf swing kinematics. A previously validated multi-segment trunk model (Joyce, Burnett, & Ball, 2010) was used to create three anatomical reference frames for the trunk, lower trunk and pelvis (Table 1). The top of the backswing was defined as the frame where the two club markers changed direction to initiate the downswing (Lephart et al., 2007). A small piece of retro-reflective tape attached to the golf ball was used to identify ball impact. Ball impact was defined as the frame immediately before the ball was first seen to move after contact with the driver (Joyce, Burnett, Ball, & Cochrane, 2013). A validated real-time launch monitor (PureLaunch™, Zelocity, USA) was positioned at a distance of 3m adjacent to the participant’s target line to determine clubhead speed at ball impact (Joyce, Burnett, Herbert, & Reyes, 2014).

To obtain flexibility values, participants were instructed to perform three end-ROM trials, in a standing, static anatomical position for; trunk flexion, extension, left and right lateral bending, and left and right axial rotation, with the maximum value from the three trials used for analysis.

Participants were instructed to stand in an upright starting position with arms held out to the side, and bend as far as possible forwards, then backwards. Again from the starting position, bend as far as possible to the left, then right. Finally, from the starting position, rotate as far left, then as far right as possible. All trunk movements were asked to be completed with a static pelvis position, and straight legs, specifically for trunk flexion and extension. All movements were practised so the investigators were confident the participants reached end ROM for each movement (Ranson, Burnett, King, Patel, & O'Sullivan, 2008).

INSERT TABLE 1 ABOUT HERE

Data Analysis

From the five trials recorded for each driver, the trials with the fastest and slowest clubhead velocity were removed, and the remaining three trials were averaged, assuming that there was; minimal retro-reflective marker drop out, the ball landed within a predicted 37 m wide fairway (from the launch monitor), and where the participant felt that improper contact had not been made were analysed. Flexibility and golf swing kinematic trials were smoothed using a Woltring filter with a mean square error of $20mm^2$ (Woltring, 1986).

The multi-segment model used in this study was developed using Vicon BodyBuilder V.3.6.1 (Oxford, UK) and used in Vicon Nexus V.1.7.1 (Oxford, UK), to obtain all kinematic variables. Cardan angles reported for the trunk were reduced from the joint coordinate system of the shoulders relative to the joint coordinate system of the pelvis, and lower trunk Cardan angles reduced from the joint coordinate system of the lower thorax relative to the joint coordinate system of the pelvis (i.e. 0,0,0 indicates the shoulder or lower thorax reference frame is relative to the pelvis reference frame). In order to calculate the rotations relative to the pelvis, cardan angles for each segment were reported using a ZYX (lateral bending, flexion / extension, axial rotation) order of rotation, followed by derivation of axial rotation velocity at ball impact, using finite difference calculations. For each segment, a total of six flexibility, and six golf swing kinematic variables were reported (Table 2). Values for trunk flexion, left lateral bending and right axial rotation were reported as negative.

Statistical Analysis

All statistical analyses were performed using SPSS V22.0 for Windows (IBM Co., NY, USA). All data were screened to assess normality. For the flexibility analysis, a Pearson Product-Moment Correlation matrix was constructed to explore correlations between flexibility variables of the trunk and lower trunk, and x-factor variables. For the clubhead speed analysis, a generalised linear model (GLM) was used to determine which x-factor related flexibility (right and left end-ROM axial rotation) and swing kinematic variables (axial rotation at top of backswing and ball impact, as well as maximum axial rotation at top of backswing, and axial rotation velocity at ball impact) were associated with clubhead speed. All twelve variables were entered into the GLM, then non-significant variables were removed one at a time until only significant ($p < .05$) variables remained in the final GLM.

Results

Flexibility and golf swing kinematic variables are described in Table 2, and swing kinematic / time data are presented in Figure 2. For the flexibility analysis, the Pearson correlation matrix revealed moderate correlations amongst flexibility variables and x-factor variables (axial rotation at the top of the backswing and maximum axial rotation) (Figure 3). Trunk extension flexibility revealed a negative correlation with lower trunk axial rotation at top of backswing (r = -0.519). Trunk left lateral bending flexibility revealed a positive correlation with both trunk axial rotation at top of backswing (*r* = 0.650), and trunk maximum axial rotation (*r* = 0.644). Trunk right lateral bending flexibility revealed a negative correlation with trunk maximum axial rotation (*r* = -0.583).

INSERT TABLE 2 ABOUT HERE

INSERT FIGURE 2 ABOUT HERE

INSERT FIGURE 3 ABOUT HERE

For the clubhead speed analysis, the GLM reported that nine of the original twelve x-factor related flexibility and golf swing kinematic variables were significantly ($p < .05$) associated with clubhead speed (Table 3). Of the nine selected variables, the four most strongly associated variables (b> .20) were; lower trunk maximum axial rotation ($b = -.52$, $t(15) = 26.23$, $p < .01$), lower trunk axial rotation at top of backswing ($b = .34$, $t(15) = 11.87$, $p < .01$), trunk axial rotation at the top of backswing ($b = .28$, $t(15) = 88.65$, $p < .01$) and lower trunk left axial rotation flexibility ($b = .23$, $t(15) = 65.64$, $p < .01$). Of those four selected variables, lower trunk maximum axial rotation was the only variable negatively associated with faster clubhead speed. Two other flexibility variables were selected in the GLM; trunk right axial rotation flexibility ($b = .07$, $t(15) = 3.83$, $p < .05$), and trunk left axial rotation flexibility ($b = -.10$, $t(15) = 35.80$, $p < .01$), which was negatively associated with faster clubhead speed.

Clubhead velocity (predicted) = intercept + Lower trunk maximum axial rotation $\bar{x}$ *(0.517) + Lower trunk axial rotation TOB* $\bar{x}$ *(-0.343) + Trunk axial rotation TOB* $\bar{x}$ *(-0.276) + Lower trunk left axial rotation flexibility* $\bar{x}$ *(0.229) + Trunk left axial rotation flexibility* $\bar{x}$ *(-0.096) + Trunk maximum axial rotation* $\bar{x}$ *(0.076) + Trunk right* *axial rotation flexibility* $\bar{x}$ *(-0.066) + Lower trunk axial rotation velocity BI* $\bar{x}$ *(-0.018) + Trunk axial rotation velocity BI* $\bar{x}$ *(0.012)*

Using the above predictive equation, if we substituted the minimum possible score for each independent variable, the predicted clubhead speed would be 45.7 m/s. Likewise, using the mean, clubhead speed would be 46.6 m/s, and using the maximum, clubhead speed would be 48.1 m/s.

INSERT TABLE 3 ABOUT HERE

Discussion

The aims of this study were to firstly, investigate the correlation amongst flexibility variables of the trunk and lower trunk and x-factor variables and secondly, identify which x-factor related flexibility and golf swing kinematic variables were associated with clubhead speed. This was undertaken using fifteen low handicap male golfers, using their own drivers. Firstly, Pearson correlations for the flexibility analysis reported positive correlations for flexibility variables; trunk and lower trunk left lateral bending, and negative correlations for flexibility variables; trunk extension and trunk right lateral bending, with x-factor related swing kinematics. Secondly, the GLM reported that nine of the original twelve x-factor related flexibility and golf swing kinematic variables were significantly ($p < .05$) associated with clubhead speed, with four variables having stronger associations than the others ($b > .20$).

The Pearson correlation matrix revealed a moderate positive correlation between trunk left lateral bending flexibility and trunk axial rotation at top of backswing, as well as trunk maximum axial rotation. Participants displayed a small amount of trunk left lateral bending at the top of the backswing (Table 2), similar to that reported by Chu et al (2010). Experimental evidence suggests that a more upright trunk position at the top of the backswing allows for greater stability by which to increase trunk axial rotation, and transfer potentially faster clubhead speed into a more efficient downswing (Chu et al., 2010; McHardy, Pollard, & Bayley, 2006). This can be seen in Table 2 and Figure 2 where, trunk maximum axial rotation in the golf swing exceeds right axial rotation flexibility by 5.3°. It was interesting to note that trunk axial rotation at the top of the backswing was moderately related to faster clubhead speeds ($r = 0.560$), as reported in other x-factor research (Myers et al., 2008). However, for the lower trunk the opposite is reported. Left lateral bending is close to end range flexibility, yet maximal axial rotation is exceeded by 9.4°. This can be explained by the counter-rotation of the hips at the start of the downswing (x-factor stretch), which facilitates dynamic tension of the torso muscles that contract maximally during the downswing (Cheetham et al., 2001), and allow the shoulders (trunk) to follow in sequence. This segment-coupling is critical for faster clubhead speed (Horan & Kavanagh, 2012). Another trait of skilled modern swing golfers is increasing lateral bending and axial rotation velocity throughout the downswing, which is referred to as 'crunch-factor'. Although crunch-factor increases the force behind the ball at impact, there are implications for lower back injury, possibly linked with excessive lateral bending in the participants of this study (Cole & Grimshaw, 2014; Gluck et al., 2007). The skilled golfers in this study have shown that although flexibility in the trunk segment is important, the need for a flexible lower trunk segment to commence the downswing is vital, and not previously investigated.

Negative moderate correlations between trunk extension flexibility and lower trunk axial rotation at the top of the backswing, as well as trunk right lateral bending flexibility and trunk maximum axial rotation were reported. Firstly, participants who exhibited greater trunk extension flexibility, displayed reduced lower trunk axial rotation at the top of the backswing.

As previously stated, modern swing kinematics display reduced pelvic rotation in the backswing (Gluck et al., 2007). As previously explained, trunk extension is not a trait of the modern swing, as some flexion of the trunk is required throughout the golf swing (Breed, 2008; Chu et al., 2010). Secondly, participants who exhibited greater trunk right lateral bending flexibility, displayed reduced trunk maximum axial rotation. Horan et al., (2010) reported similar findings, where skilled male golfers utilised an increased amount of trunk right lateral bending in the downswing, which reduced trunk axial rotation, but still produced clubhead speed through superior physical characteristics, when compared to skilled female golfers. It could also be suggested that, as explained earlier, the lower trunk was seen to be more active in lateral bending, which may have assisted the generation of faster clubhead speeds, without the need for the trunk to laterally bend and therefore axially rotate more (Gluck et al., 2007).

For the clubhead speed analysis, the GLM was able to identify flexibility variables important to golf performance, with clubhead speed as the dependent variable. This model contained both flexibility and golf swing kinematics variables. It reported that nine of the original twelve x-factor related flexibility and golf swing kinematic variables were significantly ($p< .05$) associated with clubhead speed. Three flexibility variables were selected as being associated with faster clubhead speed, they being, trunk and lower trunk left axial rotation, and importantly, trunk right axial rotation. This supports the importance of trunk right axial rotation flexibility in more able, lower handicap players that has been reported to be significantly greater than their higher handicap counterparts (Sell et al., 2007), and also supports the notion of faster clubhead speed for lower handicap players (Fletcher & Hartwell, 2004; Fradkin et al., 2004; Wells et al., 2009). Four of the nine selected variables had higher beta coefficients ($b> .20$) than the other five variables, showing stronger associations with clubhead speed. Trunk and lower trunk axial rotation at the top of the backswing were both associated with faster clubhead speed. This has been reported in previous literature investigating the x-factor and clubhead speed (Cheetham et al., 2001; Chu et al., 2010; Lephart et al., 2007), and also shows the importance of modelling the trunk as multiple segments to show segment interaction in the golf swing (Kwon et al., 2013). However, lower trunk maximum axial rotation was shown to be negatively associated with faster clubhead speed. This may suggest that too much involvement of the lower trunk is detrimental to modern golf swing kinematics (Gluck et al., 2007). The last of these four variables was lower trunk left axial rotation flexibility, which was shown to be associated with faster clubhead speed. Despite modern swing golf kinematics suggesting minimal pelvic movement in the backswing, a flexible, and active lower trunk rotating through ball impact would be more desirable. Previously reported pelvic movement through ball impact and follow-through, known as ‘hip clearance’, assists with shoulder movement at maximising clubhead speed through segment summation (Burden et al., 1998; McHardy & Pollard, 2005; Meister et al., 2011).

Despite no correlations being reported between trunk or lower trunk right axial rotation flexibility and x-factor variables using Pearson correlations, the four correlations reported (both positive and negative) are indicative of modern swing kinematics, from which faster clubhead speed has been reported (Gluck et al., 2007; McHardy et al., 2006). A limitation of this study was that it did not compare flexibility data to that of a higher handicap, or lesser able group of golfers, the results of the flexibility analysis can only support modern swing kinematics that aim to increase balance and control, to then deliver faster clubhead speeds, with reduced shot variability (Sell et al., 2007; Smith, 2010). A second limitation of this study was the relatively small, homogenous sample size used. Significant variables identified in the GLM were associated with faster clubhead speed for skilled golfers within this study, and results should not be taken as predictive inferences of similar skill level golfers (Shmueli, 2010).

As previously stated, the Pearson correlation matrix identified flexibility variables that were correlated with modern swing kinematics, although axial rotation flexibility of both segments reported no correlation with x-factor variables. This suggests that skilled golfers who have increased axial rotation flexibility do not necessarily utilise it to increase x-factor at the top of the backswing. Of interest was the interaction between lower trunk flexibility and modern swing kinematics, which has not previously been investigated. The GLM did report that axial rotation flexibility variables of the trunk and lower trunk were associated with clubhead speed, and therefore it can be implied that flexibility is important for improving golf performance with male skilled golfers. The findings of this study lend support to the notion that flexibility training may be an aid for generating faster clubhead speed.

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