2016

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This article was originally published as:
Joyce, C., Burnett, A., Cochrane, J., & Reyes, A. (2016). A preliminary investigation of trunk and wrist kinematics when using drivers with different shaft properties. *Sports Biomechanics, 15* (1), 61-75.

Original article available here:
http://www.tandfonline.com/doi/pdf/10.1080/14763141.2015.1123764

This is an Accepted Manuscript of an article published in *Sports Biomechanics* on 14 April 2016, available online:

http://www.tandfonline.com/doi/pdf/10.1080/14763141.2015.1123764

A preliminary investigation of trunk and wrist kinematics when using drivers with different shaft properties

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Running Title: Between-driver differences in golf swing kinematics

Key Words: golf, 3D, kinematics, kick point, clubhead speed

Word Count: 4,603 (not including references)

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Funding: No funding or grants were obtained for this study

ABSTRACT

It is unknown whether skilled golfers will modify their kinematics when using drivers of different shaft properties. This study aimed to firstly, determine if golf swing kinematics and swing parameters and related launch conditions differed when using modified drivers, then secondly, determine which kinematics were associated with clubhead speed. Twenty high level amateur male golfers (Mean ± SD: handicap = 1.9 ± 1.9 score) had their three-dimensional trunk and wrist kinematics collected for two driver trials. Swing parameters and related launch conditions were collected using a launch monitor. A one-way repeated measures ANOVA revealed significant ($p \leq 0.003$) between-driver differences; specifically, faster trunk axial rotation velocity and an early wrist release for the low kick point driver. Launch angle was shown to be 2° lower for the high kick point driver. Regression models for both drivers explained a significant amount of variance (60 – 67%) in clubhead speed. Wrist kinematics were most associated with clubhead speed, indicating the importance of the wrists in producing clubhead speed regardless of driver shaft properties.

INTRODUCTION

A golfer who is able to generate faster clubhead speeds can increase hitting distance off the tee (Fletcher & Hartwell, 2004) and this may help reduce the number of shots per round if driving accuracy can be maintained (Wiseman & Chatterjee, 2006). Factors relating to an individual's technique as well as equipment factors (the club they hit with) can be modified in an attempt to improve driving distance. In an attempt to understand driving outcome measures of the ball, previous investigations have modified properties of the driver's shaft such as, shaft length (Lacy, Yu, Axe, & Luczak, 2012), shaft mass (Haeufle, Worobets, Wright, Haeufle, & Stefanyshyn, 2012) and shaft stiffness (Betzler, 2010).

Shaft stiffness has typically been graded using a qualitative rating such as ladies, regular, stiff and extra-stiff (Betzler, 2010). However, shaft stiffness can be more precisely defined using flexural rigidity (EI) testing. This approach gives a quantitative grading of stiffness by examining the 'bending stiffness' at multiple locations along the shaft, rather than its general shape of the shaft under static load (Figure 1) (Brouillette, 2002; Joyce, Burnett, & Matthews, 2013b). This gives a more precise estimate of a shaft's complete bending profile from the bottom of the grip to the shaft's tip. Experimentally, swing kinematics of highly skilled golfers do not differ when hitting with drivers fitted with shafts of modifiable stiffness (Betzler, 2010; Betzler et al., 2011). This may possibly be due to the amount of movement variability in kinematics, which have shown to be highly variable between highly skilled golfers when optimising ball velocity (Tucker, Anderson, & Kenny, 2013).

INSERT FIGURE 1 ABOUT HERE

Another modifiable shaft property, the kick point, is usually determined in a static manner and is considered to be the maximum bend point from a line joining the two ends of a loaded shaft (Wishon, 2011). A shaft with a high kick point will have a maximum bend point closer to the grip, while a shaft with a low kick point will have its point of maximum bend closer to the clubhead. Recent research has found that kick point location can affect swing parameters and related launch conditions (Joyce, Burnett, Reyes, & Herbert, 2014), specifically, with a high kick point shaft providing a lower launch angle of the ball and more spin than a low kick point shaft (Cheong, Kang, & Jeong, 2006; Joyce et al., 2014).

Modifiable shaft properties are available to assist in producing desired swing parameters and related launch conditions for golfers of varied skill levels (Worobets & Stefanyshyn, 2007; Cheong et al., 2006; Wishon, 2011; Haeufle et al., 2012). Research undertaken to understand how highly skilled golfers influence swing parameters and related launch conditions such as clubhead speed, and the effect this has on shaft performance has largely been inconclusive. However, it is thought to be related to manipulations of upper body kinematics (Betzler, 2010; MacKenzie & Sprigings, 2009; Suzuki, Hoshino, & Kobayashi, 2009; Worobets & Stefanyshyn, 2007). Previous experimental studies have examined trunk kinematics of low handicap golfers and their effect on clubhead speed (Chu, Sell, & Lephart, 2010; Joyce, Burnett, Cochrane, & Ball, 2013a). Maximising angular displacement between the pelvis and shoulders at the top of the backswing (X-factor), and the associated countermovement of the pelvis at the start of the downswing (X-factor stretch) for example, has been shown to contribute to greater clubhead speed (Cheetham, Martin, & Mottram, 2001; Chu et al., 2010). Further three-dimensional methods used to analyse

X-factor have allowed the trunk to be modelled as multiple segments (Joyce, Burnett, & Ball, 2010), revealing significant associations between the lower trunk relative to pelvis angular displacement with clubhead speed in homogenous cohorts (Joyce et al., 2013a).

In addition to the trunk kinematics, the involvement of the 'leading' arm (i.e. the left arm for right handed golfers) has also been shown to be an important factor in influencing clubhead speed (Sprigings & Neal, 2000; Teu, Kim, Fuss, & Tan, 2006). Highly skilled golfers are known to exhibit a relatively late release of the wrists (i.e. a more delayed movement of the wrists from a radially deviated wrist position) in an attempt to maximise clubhead speed at ball impact (Betzler, 2010; Sprigings & Neal, 2000). In fact a delayed wrist release may result in increases in clubhead speed of between 9-46% (Milburn, 1982; Sprigings & Neal, 2000). Given the importance of wrist kinematics in contributing to the generation of high clubhead speeds, it would be of value to golfers and golf coaches to investigate upper body kinematics when using drivers with differing kick points. Although previous research has identified between-club differences in body kinematics, and their association with fast clubhead speeds, this has yet to be examined when using the same club (driver) fitted with shafts of differing kick point locations.

Based on the investigations that describe the interaction between golfer and club, it was hypothesised that a difference in golf swing kinematics would be seen for highly skilled golfers hitting with drivers of modifiable shaft properties. Therefore, the first aim of the study was to determine whether trunk and wrist kinematics, and swing parameters and related launch conditions differed when using drivers fitted with shafts of differing properties, i.e. kick point location (low and high), flexural rigidity profile and mass (56 g and 78 g). The second aim of the study was to determine if trunk and wrist kinematics were associated with clubhead speed for each of these drivers.

METHODS

PARTICIPANTS

Participants recruited for this study included 20 right handed, high level amateur male golfers (Mean ± SD: age = 24.6 ± 5.6 years, registered golfing handicap = 1.9 ± 1.9 score). At the time of testing, participants had a registered golfing handicap of 5 or lower, were aged between 18 and 35 years, and had no back pain in the previous 12 months prior to testing (as assessed by a modified Nordic Low Back Pain questionnaire). Ethical approval to conduct the study was provided by the Edith Cowan University Institutional Human Research Ethics Committee.

EXPERIMENTAL PROTOCOL

A repeated-measures design was utilised for this study, with each participant hitting five shots each with two drivers (i.e. 10 shots). The two drivers were fitted with shafts with differing kick point location and flexural rigidity profile (Figure 2). A 56 g 'stiff' shaft known to have a low kick point, and a 78 g 'stiff' shaft known to have a high kick point (Joyce et al., 2013b) were used in this study. This between-shaft approach to investigate differences in golf swing kinematics and swing parameters and related launch conditions has been used in previous research studies (Betzler, 2010). Isolating the effect of a single club parameter can have its difficulties in golf research (Haeufle et al., 2012) and in this study it was not feasible to change kick point location without having the shaft mass also modified. The driver lengths, grips and clubhead were identical.

The decision of what driver clubhead and shaft selection was made in consultation with an AAA-rated Australian Professional Golfers Association teaching professional, who determined which drivers were typically used by elite level male golfers. The properties of each driver are shown in Table 1, with the flexural rigidity (quantitative stiffness) of each driver shown in Figure 2. The procedures relating to the collation of these driver properties are reported elsewhere (Joyce et al., 2014). All properties in Table 1 were considered when explaining the between-club differences in golf swing kinematics and regression equations in the discussion.

INSERT TABLE 1 ABOUT HERE

INSERT FIGURE 2 ABOUT HERE

Testing for each participant was conducted on two days with players using a different driver on each day. The order of testing for each driver was randomised and the two sessions were separated by 24-48 hours. It has been suggested that experienced golfers need time to familiarise themselves with a new club (Kenny, Wallace, & Otto, 2008). Therefore, prior to testing on each day, participants completed two familiarisation sessions, i.e. an outdoor session and then an indoor session prior to the actual laboratory testing session. These sessions were always completed in this order and they were conducted within one hour of each other. The outdoor session was conducted at a driving range located at a golf course located nearby to the Biomechanics laboratory where testing took place. This session was performed first so each participant had the opportunity to receive visual feedback via the ball’s trajectory and its final landing position. Participants then completed the indoor familiarisation session at the laboratory prior to data collection. The familiarisation protocol was the same for each session with all participants hitting 10-20 shots each time. The exact number of shots was determined by the participant deciding when they felt sufficiently familiar with the driver. Total time required for the indoor familiarisation and testing was approximately 90 minutes on each day.

DATA COLLECTION

A 10-camera MX-F20 Vicon-Peak Motion Analysis system (Oxford Metrics, Oxford, UK) operating at 500 Hz was used to capture all 3D kinematics. During testing, participants wore bicycle shorts and golf shoes only and a total of twenty one retro-reflective markers were attached to them during static trials. The six lower arm and hand ‘anatomical’ markers were then removed for dynamic trials. A further two markers were attached to the shaft of the driver during the dynamic trials to identify top of the backswing, and a piece of retro-reflective tape was attached to the ball to identify ball impact (Table 2). These markers were used to provide 3D golf swing kinematics of the body, create a multi-segment trunk model (Joyce et al., 2010) as well as a model of the leading arm that being; the left arm for right-handed golfers (Betzler, 2010; Sweeney, Mills, Mankad, Elliott, & Alderson, 2012). These models were developed using Vicon BodyBuilder V.3.6.1 and the complete model was then used in Vicon Nexus V.1.7.1 (Oxford, UK) to obtain all kinematic variables (as described below).

INSERT TABLE 2 ABOUT HERE

The multi-segment trunk model consisted of three segments: trunk, lower trunk and pelvis. Table 2 shows the markers which define each reference frame from which each segment was created. Cardan angles were reported for the trunk (shoulders – pelvis reference frames) and lower trunk (lower trunk – pelvis reference frames) were reported using a ZYX (lateral bending, flexion/extension and axial rotation respectively) order of rotation (Joyce et al., 2010). Positive values indicated trunk extension, right lateral bending and left axial rotation and negative values indicating trunk flexion, left lateral bending and right axial rotation.

The wrist joint was modeled using three-marker clusters placed on the forearm and the hand and these were positioned along with the six anatomical markers on the forearm and hand during the static calibration trials. The anatomical markers were removed and produced virtual anatomical markers for dynamic trials, as not to impede the natural movement of the wrist in each participant's golf swing (Cappozzo, Catani, Leardini, Benedetti, & Croce, 1996). Cardan angles for the wrist were also reported using a XYZ order of rotation (Betzler, 2010). With previous investigations suggesting ulnar/radial deviation at the wrist joint is important for increasing clubhead speed (Sprigings & Neal., 2000; Teu et al., 2006), it was the wrist movement which was of interest for this study. Positive values indicated radial deviation and negative values indicated ulnar deviation.

DATA ANALYSIS

Two critical events in the golf swing were used in this study; top of backswing and ball impact. Top of the backswing was identified as the frame where the two club markers changed direction to initiate the downswing (Joyce et al., 2013a; Myers et al., 2008). Ball impact was defined as the frame immediately before when the ball (fitted with a piece of retro-reflective tape) was first seen to move after contact (Joyce et al., 2013b). Maximal trunk and lower trunk rotation was determined to be the peak value shortly after the top of the backswing. This variable (also known as 'x-factor stretch') was obtained due to the pelvis counter-rotating to commence the downswing while the shoulders remained relatively still which increases the separation angle (Cheetham et al., 2001). Wrist release was defined as a rate of change threshold point of greater than 5%, from that of the previous data point for wrist angular displacement. The point of wrist release was defined as a percentage value during the downswing from top of the backswing (0 %) to ball impact (100 %)

Initially, 28 variables relating to trunk and wrist kinematics were collected however, after examination of correlation matrices, a high degree of multicollinearity was seen to exist between some of these variables. Consequently, a reduced total of 20 variables were included in the final analysis (see Table 3). A further four variables were quantified relating to swing parameters and related launch conditions (see Table 4).

From the five trials recorded for each driver, three were chosen for analysis based on maximal clubhead speed, the ball landing within a predicted 37 m wide fairway (from the launch monitor described below), and had minimal marker drop out. All trials were smoothed using a Woltring filter with a mean square error of $20mm^2$ (Woltring, 1986). Ensemble averages for the trunk and lower trunk angular displacement data, as well as wrist ulnar/radial deviation between top of backswing and ball impact were created. In preparation for the ensemble average process, all data were time normalised (0-100%) using cubic spine interpolation

A real-time launch monitor (PureLaunch™, Zelocity, USA) was used to measure four swing parameters (clubhead speed at ball impact and attack angle of the clubface) and their related launch conditions (ball velocity and launch angle).

STATISTICAL ANALYSIS

For the first aim of the study, i.e. to determine whether between-driver differences existed for all trunk and wrist kinematics examined in this study, a one-way repeated measures ANOVA was used. Data from each of the three trials per driver was used. For the trunk and wrist kinematic variables there were 20 between-club comparisons conducted so a Bonferroni adjustment of the p-value ($p \leq 0.003$) was made to correct the family wise error rate. For the four swing parameters and their related launch conditions, the critical p-value value was adjusted to $p \leq 0.013$. Intra-class correlation coefficient (ICC) and standard error of mean (SEM) statistics were used to determine the within-trial reliability of all variables listed in Table 3. According to Fleiss (1986), ICC values greater than 0.75 were considered as excellent, ICC values between 0.40 and 0.75 were considered as fair to good, and ICC values less than 0.4 were considered as poor. As Fleiss' fair to good values spanned a large range, reliability for the purposes of this study was considered to be good when ICC values ranged from 0.60 to 0.74 (Gstoettner et al., 2007).

Relating to the second aim of the study, stepwise linear regression models were generated for each driver, in which swing kinematics were the independent variables, and the clubhead speed of each driver was the dependent variable. Again, all three trials per driver were used in each of these models. All assumptions relating to these models were met. All statistical analyses were undertaken using STATA V9.1 (Stata Corp. Texas, USA).

RESULTS

Ensemble average data of the angular displacement and velocity of the trunk, lower trunk and wrist for the two drivers from the top of the backswing (0 %) to ball impact (100 %) are shown in Figures

3 and 4 respectively. While the descriptive data relating to trunk and wrist kinematics for both drivers are reported in Table 3. There was excellent reliability for kinematic variables for both drivers (ICC = 0.859 – 0.996, SEM = 0.4 – 44.7) (Table 3). Results from the one-way repeated measures ANOVA revealed that there were four significant ($p \leq 0.003$) between-driver differences. With respect to the trunk, a larger amount of left lateral bending was reported at the top of the backswing, as well as there being faster axial rotation velocity being evident at ball impact for the driver fitted with the low kick point shaft. Further, the lower trunk segment showed a larger amount of maximum axial rotation for the driver fitted with the high kick point shaft. Finally, the wrists were released 4.3 % later (which translates to 0.044 s) in the downswing, for the driver fitted with the high kick point shaft when compared to the driver fitted with the low kick point shaft. Prior to the 5% rate of change threshold point, the percentage change was less than 4% for all data, and a minimum of 20% thereafter. Analysis of the swing parameters and their related launch conditions revealed a significantly lower launch angle for the high kick point driver (Table 4).

INSERT FIGURE 3-4 ABOUT HERE

INSERT TABLES 3-4 ABOUT HERE

The results from the regression analyses are shown in Table 5. The regression models for each driver were able to explain a significant amount of variance in clubhead speed. Specifically, 60% of variance was explained for the driver fitted with the shaft containing the low kick point and 67% of variance was explained for the driver fitted with the shaft containing the high kick point. For each model, the two variables most strongly associated with clubhead speed were related to the wrist. For the driver with the high kick point shaft wrist release point in the downswing ($\beta = 0.415$)

and radial deviation of the wrist at the top of the backswing ($\beta = 0.380$) were two variables most associated with clubhead speed. The two other variables included in this model were slower lower trunk axial rotation velocity at ball impact ($\beta = -0.249$) and radial deviation of the wrist at ball impact ($\beta = 0.176$). For the low kick point shaft, radial deviation of the wrist at the top of the backswing ($\beta = 0.775$) and radial deviation of the wrist at ball impact ($\beta = 0.568$) were the two variables most associated with clubhead speed. The other two variables in the model were, a reduced amount of trunk lateral bending at ball impact ($\beta = -0.486$) and greater lower trunk maximum axial rotation ($\beta = -0.438$).

INSERT TABLE 5 ABOUT HERE

DISCUSSION AND IMPLICATIONS

This study hypothesised that there would be a difference in golf swing kinematics for highly skilled golfers hitting with drivers fitted with shafts of modifiable properties. There were two aims of this study: (a) determine whether trunk and wrist kinematics, and swing parameters and related launch conditions would differ when using drivers fitted with shafts of different kick point location; and (b) determine what trunk and wrist kinematics were most strongly associated with clubhead speed for each of the drivers. While four between-driver differences in swing kinematics were found (Table 3), it could be reasonably argued that only two of these four variables (trunk axial rotation velocity at ball impact and the point of wrist release in the downswing) would seem to be meaningful in a practical sense. This is due to the small magnitude of differences being evident between-drivers for the other two variables. A discussion of the two findings with practical application follows.

Slower trunk axial rotation velocity at ball impact was reported for the driver fitted with the high kick point shaft. This may be related to the fact that the high kick point shaft condition in this study was created by using a heavier (78 g) shaft when compared to the low kick point shaft condition (56 g). No differences in clubhead speed and ball velocity were observed in the two drivers. The experimental findings of Haeufle et al. (2012) also revealed no differences in clubhead speed for two drivers with the same 22 g difference in shaft mass and they speculated that the increase in shaft mass may cause muscles related to the trunk to contract more slowly. The second between-driver difference of a later wrist release for the driver fitted with the high kick point shaft may be related to the slower trunk axial rotation velocity. Wrist release was shown to have occurred 4.3 % later in the downswing. A delayed wrist release has been shown to increase clubhead speed (Sprigings & Neal, 2000; Teu et al., 2006). As no between-driver difference in clubhead speed was seen, it could be assumed that clubhead speed was generated by more involvement of the wrist than the trunk for the driver fitted with the high kick point shaft. Alternatively, the early wrist release for the driver fitted with the low kick point shaft may explain that the faster trunk axial rotation velocity helped to achieve a similar clubhead speed to the driver fitted with the high kick point shaft.

The delayed wrist release for the driver fitted with the high kick point shaft may be explained by the interaction of the wrist and the heavier, high kick point shaft. White (2006) explained that wrist release elicits changes in the performance of the shaft during the downswing. It was reported that shaft properties such as moment of inertia are affected by wrist release. A higher moment of inertia, increased tip stiffness (Figure 2), as well as an increased amount of bending in the latter stages of the downswing have been previously reported for the high kick point shaft when compared to the low kick point shaft (Joyce et al., 2014). The between-driver difference in wrist release may be due to participants attempting to optimise the un-loading of the shaft through these properties in the downswing for optimal swing and related launch parameters. One such difference in launch parameters seen in this study was that of a lower launch angle for the driver fitted with the high kick point shaft (Table 4). As implied above, clubhead presentation may be influenced by the bending of the shaft in the downswing, as well as stiffer shafts (Figure 2) being less lofted at ball impact (Wishon, 2011; Haeufle et al., 2012; Joyce et al., 2014).

The regression models generated for each driver resulted in similar (and high) amounts of variance being explained in clubhead speed (Table 5). Importantly, the most strongly associated variables with clubhead speed for both models were variables related with the wrist, which is consistent with previous research (Milburn, 1982; Osis & Stefanyshyn, 2012; Sprigings & Neal, 2000). These variables were specifically; the release point of the wrists in the downswing, as well as the radial / ulnar deviation of the wrist at the top of the backswing and at ball impact. Firstly, participants who displayed greater radial deviation of the wrist joint (or wrist cocking) at the top of backswing had greater clubhead speed and this has been supported in previous research (Chu et al., 2010). Previous studies have shown an increased wrist cock angle at the top of the swing is essential for accelerating the club in the early stages of the downswing (Chu et al., 2010; Sprigings & Neal, 2000). Shortly after the point of wrist release, wrist velocity rapidly decreases at approximately 90% of downswing (see Figure 4). It has been suggested that wrist torque increases at this point (reducing wrist velocity), so that the club can release through ball impact and maximise clubhead speed (Kaneo & Sato, 2000; Osis & Stefanyshyn, 2012). The finding of a small amount of wrist cock maintained at ball impact being related to increased clubhead speed is in agreement with previous studies (Chu et al., 2010; Pickering & Vickers, 1999).

Variables of lower associations with clubhead speed (Table 5), firstly for the driver fitted with the high kick point shaft, were lower trunk axial rotational velocity at ball impact. This finding was previously discussed when a more delayed wrist release was seen for the driver fitted with the high kick point shaft, as well as slower trunk rotational velocity at ball impact. From what also can be seen in the regression model for the driver fitted with the high kick point shaft, the delayed release of the wrists was most likely the cause of clubhead speed, and involvement of the trunk and lower trunk not as important. Secondly, for the driver fitted with the low kick point shaft, lower associations with clubhead were seen by reduced right lateral bending and increased lower trunk maximum axial rotation. Previous recommendations report increasing right lateral bending of the trunk to facilitate higher launch angles (Gluck, Bendo, & Spivak, 2007) so it is unclear why this was reported for this study. Increasing lower trunk maximum axial rotation has been previously reported as being highly associated with clubhead speed (Joyce et al., 2013a). However, for both regression models, wrist segment variables were the most highly associated with clubhead speed which conforms to other investigations into the importance of the wrist at producing clubhead speed (Sprigings & Neal, 2000; Teu et al., 2006).

There were some limitations of this study. Firstly, isolating the single shaft modification of kick point was not permitted without other observed differences in mass, swing weighting and flexural rigidity (Joyce et al., 2014). Although this suggests that other shaft factors may have influenced differences in swing parameters and related launch conditions than kick point alone, it has previously been shown that modifying swingweight has no effect on swing and launch conditions (Haeufle et al., 2012; Wallace & Hubbell, 2001; Wallace, Otto, & Nevill, 2007). Secondly, there may have been more practically applicable differences in swing kinematics observed and possibly different associations with clubhead speed if participants were able to perceive shot outcome during indoor testing as in the outdoor familiarisation. In staging these limitations however, the bending, and flexural rigidity profiles of each shaft were known (Joyce et al., 2014). This type of detail has not been described in previous research examining wrist release and shaft stiffness (Betzler, 2010; Osis & Stefanyshyn, 2012).

CONCLUSION

Slower trunk axial rotation velocity and a greater delayed release of the wrist were seen when using the driver fitted with the high kick point shaft. With no between-driver difference in clubhead speed, the delayed wrist release may have helped attain a similar clubhead speed to that of the driver fitted with the low kick point shaft, which showed a faster trunk axial rotation velocity, and an earlier wrist release. A similar amount of variance was explained for both drivers and similar variables were shown to be associated with clubhead speed. The results from this study may assist teaching professionals and club fitters in understanding the interaction between the golfer, and the club that they are hitting with to maximise golfing performance. Future research which examines shaft bending profiles during the downswing and player interaction for modifiable driver properties will also be important for biomechanists and teaching professionals.

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