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2016

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

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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>

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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>

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

3  
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13  
14 *Running Title: Between-driver differences in golf swing kinematics*

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

16 *Word Count: 4,603 (not including references)*

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18 *Funding: No funding or grants were obtained for this study*

19

20

21 **ABSTRACT**

22 It is unknown whether skilled golfers will modify their kinematics when using drivers of different  
23 shaft properties. This study aimed to firstly, determine if golf swing kinematics and swing  
24 parameters and related launch conditions differed when using modified drivers, then secondly,  
25 determine which kinematics were associated with clubhead speed. Twenty high level amateur male  
26 golfers (Mean  $\pm$  SD: handicap =  $1.9 \pm 1.9$  score) had their three-dimensional trunk and wrist  
27 kinematics collected for two driver trials. Swing parameters and related launch conditions were  
28 collected using a launch monitor. A one-way repeated measures ANOVA revealed significant ( $p$   
29  $\leq 0.003$ ) between-driver differences; specifically, faster trunk axial rotation velocity and an early  
30 wrist release for the low kick point driver. Launch angle was shown to be  $2^\circ$  lower for the high  
31 kick point driver. Regression models for both drivers explained a significant amount of variance  
32 (60 – 67%) in clubhead speed. Wrist kinematics were most associated with clubhead speed,  
33 indicating the importance of the wrists in producing clubhead speed regardless of driver shaft  
34 properties.

35 **INTRODUCTION**

36 A golfer who is able to generate faster clubhead speeds can increase hitting distance off the tee  
37 (Fletcher & Hartwell, 2004) and this may help reduce the number of shots per round if driving  
38 accuracy can be maintained (Wiseman & Chatterjee, 2006). Factors relating to an individual's  
39 technique as well as equipment factors (the club they hit with) can be modified in an attempt to  
40 improve driving distance. In an attempt to understand driving outcome measures of the ball,  
41 previous investigations have modified properties of the driver's shaft such as, shaft length (Lacy,  
42 Yu, Axe, & Luczak, 2012), shaft mass (Haeufle, Worobets, Wright, Haeufle, & Stefanyshyn,  
43 2012) and shaft stiffness (Betzler, 2010).

44

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

56

57 INSERT FIGURE 1 ABOUT HERE

58

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

67

68 Modifiable shaft properties are available to assist in producing desired swing parameters and  
69 related launch conditions for golfers of varied skill levels (Worobets & Stefanyshyn, 2007; Cheong  
70 et al., 2006; Wishon, 2011; Haeufle et al., 2012). Research undertaken to understand how highly  
71 skilled golfers influence swing parameters and related launch conditions such as clubhead speed,  
72 and the effect this has on shaft performance has largely been inconclusive. However, it is thought  
73 to be related to manipulations of upper body kinematics (Betzler, 2010; MacKenzie & Sprigings,  
74 2009; Suzuki, Hoshino, & Kobayashi, 2009; Worobets & Stefanyshyn, 2007). Previous  
75 experimental studies have examined trunk kinematics of low handicap golfers and their effect on  
76 clubhead speed (Chu, Sell, & Lephart, 2010; Joyce, Burnett, Cochrane, & Ball, 2013a).  
77 Maximising angular displacement between the pelvis and shoulders at the top of the backswing  
78 (X-factor), and the associated countermovement of the pelvis at the start of the downswing (X-  
79 factor stretch) for example, has been shown to contribute to greater clubhead speed (Cheetham,  
80 Martin, & Mottram, 2001; Chu et al., 2010). Further three-dimensional methods used to analyse

81 X-factor have allowed the trunk to be modelled as multiple segments (Joyce, Burnett, & Ball,  
82 2010), revealing significant associations between the lower trunk relative to pelvis angular  
83 displacement with clubhead speed in homogenous cohorts (Joyce et al., 2013a).

84

85 In addition to the trunk kinematics, the involvement of the ‘leading’ arm (i.e. the left arm for right  
86 handed golfers) has also been shown to be an important factor in influencing clubhead speed  
87 (Sprigings & Neal, 2000; Teu, Kim, Fuss, & Tan, 2006). Highly skilled golfers are known to  
88 exhibit a relatively late release of the wrists (i.e. a more delayed movement of the wrists from a  
89 radially deviated wrist position) in an attempt to maximise clubhead speed at ball impact (Betzler,  
90 2010; Sprigings & Neal, 2000). In fact a delayed wrist release may result in increases in clubhead  
91 speed of between 9-46% (Milburn, 1982; Sprigings & Neal, 2000). Given the importance of wrist  
92 kinematics in contributing to the generation of high clubhead speeds, it would be of value to golfers  
93 and golf coaches to investigate upper body kinematics when using drivers with differing kick  
94 points. Although previous research has identified between-club differences in body kinematics,  
95 and their association with fast clubhead speeds, this has yet to be examined when using the same  
96 club (driver) fitted with shafts of differing kick point locations.

97

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

104 determine if trunk and wrist kinematics were associated with clubhead speed for each of these  
105 drivers.

106

107

## 108 **METHODS**

### 109 **PARTICIPANTS**

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

116

### 117 **EXPERIMENTAL PROTOCOL**

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



127 The decision of what driver clubhead and shaft selection was made in consultation with an AAA-  
128 rated Australian Professional Golfers Association teaching professional, who determined which  
129 drivers were typically used by elite level male golfers. The properties of each driver are shown in  
130 Table 1, with the flexural rigidity (quantitative stiffness) of each driver shown in Figure 2. The  
131 procedures relating to the collation of these driver properties are reported elsewhere (Joyce et al.,  
132 2014). All properties in Table 1 were considered when explaining the between-club differences in  
133 golf swing kinematics and regression equations in the discussion.

134

135 INSERT TABLE 1 ABOUT HERE

136 INSERT FIGURE 2 ABOUT HERE

137

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

150 time. The exact number of shots was determined by the participant deciding when they felt  
151 sufficiently familiar with the driver. Total time required for the indoor familiarisation and testing  
152 was approximately 90 minutes on each day.

153

#### 154 DATA COLLECTION

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

167

168 INSERT TABLE 2 ABOUT HERE

169

170 The multi-segment trunk model consisted of three segments: trunk, lower trunk and pelvis. Table  
171 2 shows the markers which define each reference frame from which each segment was created.  
172 Cardan angles were reported for the trunk (shoulders – pelvis reference frames) and lower trunk

173 (lower trunk – pelvis reference frames) were reported using a ZYX (lateral bending,  
174 flexion/extension and axial rotation respectively) order of rotation (Joyce et al., 2010). Positive  
175 values indicated trunk extension, right lateral bending and left axial rotation and negative values  
176 indicating trunk flexion, left lateral bending and right axial rotation.

177  
178 The wrist joint was modeled using three-marker clusters placed on the forearm and the hand and  
179 these were positioned along with the six anatomical markers on the forearm and hand during the  
180 static calibration trials. The anatomical markers were removed and produced virtual anatomical  
181 markers for dynamic trials, as not to impede the natural movement of the wrist in each participant's  
182 golf swing (Cappozzo, Catani, Leardini, Benedetti, & Croce, 1996). Cardan angles for the wrist  
183 were also reported using a XYZ order of rotation (Betzler, 2010). With previous investigations  
184 suggesting ulnar/radial deviation at the wrist joint is important for increasing clubhead speed  
185 (Sprigings & Neal., 2000; Teu et al., 2006), it was the wrist movement which was of interest for  
186 this study. Positive values indicated radial deviation and negative values indicated ulnar deviation.

187  
188 **DATA ANALYSIS**

189 Two critical events in the golf swing were used in this study; top of backswing and ball impact.  
190 Top of the backswing was identified as the frame where the two club markers changed direction  
191 to initiate the downswing (Joyce et al., 2013a; Myers et al., 2008). Ball impact was defined as the  
192 frame immediately before when the ball (fitted with a piece of retro-reflective tape) was first seen  
193 to move after contact (Joyce et al., 2013b). Maximal trunk and lower trunk rotation was determined  
194 to be the peak value shortly after the top of the backswing. This variable (also known as 'x-factor  
195 stretch') was obtained due to the pelvis counter-rotating to commence the downswing while the

196 shoulders remained relatively still which increases the separation angle (Cheetham et al., 2001).  
197 Wrist release was defined as a rate of change threshold point of greater than 5%, from that of the  
198 previous data point for wrist angular displacement. The point of wrist release was defined as a  
199 percentage value during the downswing from top of the backswing (0 %) to ball impact (100 %)

200

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

206

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

214

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

218

## 219 STATISTICAL ANALYSIS

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

232

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

238

## 239 **RESULTS**

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

242 3 and 4 respectively. While the descriptive data relating to trunk and wrist kinematics for both  
243 drivers are reported in Table 3. There was excellent reliability for kinematic variables for both  
244 drivers (ICC = 0.859 – 0.996, SEM = 0.4 – 44.7) (Table 3). Results from the one-way repeated  
245 measures ANOVA revealed that there were four significant ( $p \leq 0.003$ ) between-driver differences.  
246 With respect to the trunk, a larger amount of left lateral bending was reported at the top of the  
247 backswing, as well as there being faster axial rotation velocity being evident at ball impact for the  
248 driver fitted with the low kick point shaft. Further, the lower trunk segment showed a larger amount  
249 of maximum axial rotation for the driver fitted with the high kick point shaft. Finally, the wrists  
250 were released 4.3 % later (which translates to 0.044 s) in the downswing, for the driver fitted with  
251 the high kick point shaft when compared to the driver fitted with the low kick point shaft. **Prior to**  
252 **the 5% rate of change threshold point, the percentage change was less than 4% for all data, and a**  
253 **minimum of 20% thereafter.** Analysis of the swing parameters and their related launch conditions  
254 revealed a significantly lower launch angle for the high kick point driver (Table 4).

255

256 INSERT FIGURE 3-4 ABOUT HERE

257 INSERT TABLES 3-4 ABOUT HERE

258

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

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

273

274 INSERT TABLE 5 ABOUT HERE

275

## 276 **DISCUSSION AND IMPLICATIONS**

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

288

289 Slower trunk axial rotation velocity at ball impact was reported for the driver fitted with the high  
290 kick point shaft. This may be related to the fact that the high kick point shaft condition in this study  
291 was created by using a heavier (78 g) shaft when compared to the low kick point shaft condition  
292 (56 g). No differences in clubhead speed and ball velocity were observed in the two drivers. The  
293 experimental findings of Haeufle et al. (2012) also revealed no differences in clubhead speed for  
294 two drivers with the same 22 g difference in shaft mass and they speculated that the increase in  
295 shaft mass may cause muscles related to the trunk to contract more slowly. The second between-  
296 driver difference of a later wrist release for the driver fitted with the high kick point shaft may be  
297 related to the slower trunk axial rotation velocity. Wrist release was shown to have occurred 4.3  
298 % later in the downswing. A delayed wrist release has been shown to increase clubhead speed  
299 (Sprigings & Neal, 2000; Teu et al., 2006). As no between-driver difference in clubhead speed was  
300 seen, it could be assumed that clubhead speed was generated by more involvement of the wrist  
301 than the trunk for the driver fitted with the high kick point shaft. Alternatively, the early wrist  
302 release for the driver fitted with the low kick point shaft may explain that the faster trunk axial  
303 rotation velocity helped to achieve a similar clubhead speed to the driver fitted with the high kick  
304 point shaft.

305

306 The delayed wrist release for the driver fitted with the high kick point shaft may be explained by  
307 the interaction of the wrist and the heavier, high kick point shaft. White (2006) explained that wrist  
308 release elicits changes in the performance of the shaft during the downswing. It was reported that  
309 shaft properties such as moment of inertia are affected by wrist release. A higher moment of inertia,  
310 increased tip stiffness (Figure 2), as well as an increased amount of bending in the latter stages of



311 the downswing have been previously reported for the high kick point shaft when compared to the  
312 low kick point shaft (Joyce et al., 2014). The between-driver difference in wrist release may be  
313 due to participants attempting to optimise the un-loading of the shaft through these properties in  
314 the downswing for optimal swing and related launch parameters. One such difference in launch  
315 parameters seen in this study was that of a lower launch angle for the driver fitted with the high  
316 kick point shaft (Table 4). As implied above, clubhead presentation may be influenced by the  
317 bending of the shaft in the downswing, as well as stiffer shafts (Figure 2) being less lofted at ball  
318 impact (Wishon, 2011; Haeufle et al., 2012; Joyce et al., 2014).

319  
320 The regression models generated for each driver resulted in similar (and high) amounts of variance  
321 being explained in clubhead speed (Table 5). Importantly, the most strongly associated variables  
322 with clubhead speed for both models were variables related with the wrist, which is consistent with  
323 previous research (Milburn, 1982; Osis & Stefanyshyn, 2012; Sprigings & Neal, 2000). These  
324 variables were specifically; the release point of the wrists in the downswing, as well as the radial  
325 / ulnar deviation of the wrist at the top of the backswing and at ball impact. Firstly, participants  
326 who displayed greater radial deviation of the wrist joint (or wrist cocking) at the top of backswing  
327 had greater clubhead speed and this has been supported in previous research (Chu et al., 2010).  
328 Previous studies have shown an increased wrist cock angle at the top of the swing is essential for  
329 accelerating the club in the early stages of the downswing (Chu et al., 2010; Sprigings & Neal,  
330 2000). Shortly after the point of wrist release, wrist velocity rapidly decreases at approximately  
331 90% of downswing (see Figure 4). It has been suggested that wrist torque increases at this point  
332 (reducing wrist velocity), so that the club can release through ball impact and maximise clubhead  
333 speed (Kaneo & Sato, 2000; Osis & Stefanyshyn, 2012). The finding of a small amount of wrist

334 cock maintained at ball impact being related to increased clubhead speed is in agreement with  
335 previous studies (Chu et al., 2010; Pickering & Vickers, 1999).

336

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

352

353 There were some limitations of this study. Firstly, isolating the single shaft modification of kick  
354 point was not permitted without other observed differences in mass, swing weighting and flexural  
355 rigidity (Joyce et al., 2014). Although this suggests that other shaft factors may have influenced  
356 differences in swing parameters and related launch conditions than kick point alone, it has

357 previously been shown that modifying swingweight has no effect on swing and launch conditions  
358 (Haeufle et al., 2012; Wallace & Hubbell, 2001; Wallace, Otto, & Nevill, 2007). Secondly, there  
359 may have been more practically applicable differences in swing kinematics observed and possibly  
360 different associations with clubhead speed if participants were able to perceive shot outcome  
361 during indoor testing as in the outdoor familiarisation. In staging these limitations however, the  
362 bending, and flexural rigidity profiles of each shaft were known (Joyce et al., 2014). This type of  
363 detail has not been described in previous research examining wrist release and shaft stiffness  
364 (Betzler, 2010; Osis & Stefanyshyn, 2012).

365

## 366 **CONCLUSION**

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

377

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