JOURNAL OF SPORTS SCIENCES
https://doi.org/10.1080/02640414.2018.1479133

Routledge
Taylor & Francis Group

The influence of golf shaft torque on clubhead kinematics and ball flight

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ABSTRACT

The purpose of this study was to investigate the influence of shaft torque (torsional rigidity) on clubhead kinematics and the resulting flight of the ball. Two driver shafts with disparate levels of torque, but otherwise very similar properties, were tested by 40 right-handed golfers representing a range of abilities. Shaft deflection data as well as grip and clubhead kinematics were collected from 14 swings, with each shaft, for each golfer using an optical motion capture system. Ball flight and additional clubhead kinematics were collected using a Doppler radar launch monitor. At impact, the high torque shaft (HT) was associated with increased delivered loft ($P = .028$) and a more open face ($P < .001$) relative to the low torque shaft (LT). This resulted in the HT shaft being associated with a ball finishing position that was further right ($P = .002$). At the individual level, the change in face angle due solely to shaft deformation was significantly higher for the HT shaft for 25/40 participants. Although shaft twist was not directly measured, it was logically deduced using the collected data that these outcomes were the result of the HT being twisted more open relative to the LT shaft at impact.

ARTICLE HISTORY
Accepted 17 March 2018

KEYWORDS
Golf; club; torsional stiffness; motion capture; shaft torque

1. Introduction

Modifying shaft parameters is a primary method used to customize a driver to a particular golfer's swing in order to optimize performance. This practice is supported by research that demonstrates that the shaft of a golf club can have a meaningful influence on how the clubhead is delivered at impact and consequently on the resulting flight of the ball (MacKenzie & Boucher, 2017; MacKenzie & Sprigings, 2009). For example, increasing shaft length will result in an increase in the maximum clubhead speed (Wallace, Otto, & Nevill, 2007), although most likely at the expense of centeredness of ball contact on the face (Werner & Greig, 2000). Unless other club properties – such as shaft mass – are modified, increases in shaft length will have diminishing returns with respect to clubhead speed due to an increase in the overall inertia of the club (MacKenzie, Ryan, & Rice, 2016). Arguably, of all the shaft parameters that can be fine-tuned, shaft stiffness has received the most attention. Manufacturers tend to provide options, within and across shaft models, based on the flexural rigidity profile of the shaft, and as a result, it is relatively easy for club fitters to test the influence of stiffness on ball flight. A shaft's stiffness, or flex, represents the resistance to bending about an axis perpendicular to the shaft and typically varies along the length of the shaft. Systematic changes in delivered loft, due to a change in shaft stiffness, can be as high as 6° for an individual golfer, which will have a marked influence on driving distance (MacKenzie & Boucher, 2015). Golf shafts can be designed to not only have different bending properties, but also different torsional properties. In the golf industry, a shaft's resistance to twisting about its long axis (torsional rigidity) is referred to as torque (Summit, 2000). Unlike shaft stiffness, virtually no published scientific research is available on the influence of shaft torque on golf performance; yet, it is frequently discussed by clubfitters and in the popular golf literature (Saternus, 2013; Tursky, 2016; Wishon, 2012).

Although there is no industry standard, shaft torque is typically measured by determining how much the shaft twists, in degrees, when the butt is fixed and 1 ft-pound (1.36 Nm) of torque is applied to the tip (Summit, 2000). Generally speaking, while in this set-up, a driver shaft that twists ≤ 3° would be considered to have "low torque", while a shaft that twists ≥ 6° would be considered a "high torque" shaft. Although it is somewhat possible to manipulate shaft torque independently of shaft stiffness, it is typical to see more flexible shafts with a higher torque rating and stiffer shafts with a lower torque rating. All else equal, a flexible and light weight shaft with a low torque rating will be more expensive to manufacture (Summit, 2000).

If shaft torque has a meaningful influence on ball flight, then it would most likely be due to its influence on clubhead orientation at impact. Based on recent findings for shaft stiffness (MacKenzie & Boucher, 2017), it is less likely that shaft torque would have a meaningful systematic influence on either clubhead speed or variability in any of the clubhead impact kinematics. With respect to clubhead orientation, consider a right-handed driver at address with the shaft at 58° above the horizontal, 10° of loft, and with the vector normal to the center of the face projecting directly above the target line. If the shaft is twisted 3° Counter-clockwise (as viewed from the butt of the grip and looking down the shaft), then the face will close 2.5° and deloft 1.6°. These amounts will have a meaningful influence on the trajectory of a drive. The converse is true if the shaft is twisted 3° Clockwise. The tendency of shaft torque to influence the direction and magnitude of shaft twist at impact has not been well established and there is

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conflicting conjecture in the popular golfing literature. According to Wishon (2012), a prominent clubfitter, a strong golfer with an aggressive swing will increase the likelihood of hitting low hooks if they use a high (6°) torque shaft. This suggests that an increase in shaft torque will be associated with more counter-clockwise twist (delofted and closed face) at impact. This position is in agreement with Saternus (2013) who contends that torque has a major impact on where the ball finishes, and if other variables are held constant, then conventional wisdom suggests a shaft with higher torque will lead to a club face that is pointed further left at impact for a right-handed golfer. To the contrary, other popular golf literature suggests that higher torque shafts would result in the shaft being twisted more clockwise at impact, which would produce higher ball trajectories with more spin (Kozuchowski, 2013; Tursky, 2016). Butler and Winfield (1994) used shear strain gauges to measure the amount of shaft twist during the driver swings of three golfers and appear to provide the only published measurements of shaft twist. Their tabular data shows that, at impact, the shaft was twisted *clockwise* ("open") about 0.4° for two golfers, while it was twisted *counter-clockwise* ("closed") by 0.4° for the remaining golfer. The twist-time profile plots seem to demonstrate that, for all swings, the shaft was twisted clockwise leading up to impact (although the precise moment of impact is not clearly discernable). The maximum shaft twist during the swing for any golfer was approximately 1°. Their research was limited in that only three golfers using a single shaft were measured, only a single swing from each was reported, and also by the fact that only a single strange gauge placed on the tip of the shaft was used to measure twist. Shafts do not deform uniformly throughout the downswing (Joyce, Burnett, & Matthews, 2013; Mather, Smith, Jowett, Gibson, & Moynihan, 2000), which suggests that the location of strain gauge placement on the shaft will have an influence.

Given the lack of published scientific research and apparent uncertainty on the influence of shaft torque on performance in the popular golf literature, the purpose of this study was to investigate the influences of shaft torque on clubhead kinematics at impact and the resulting flight of the ball. Based on the data presented by Butler and Winfield (1994), it was hypothesized that an increase in shaft torque would be associated with a more open face position at impact and consequently shots landing further to the right of the target line for a right-handed golfer.

2. Methods

2.1. Participants

Forty right-handed golfers (age: 33.4 ± 8.1, handicap: 10.7 ± 4.5) volunteered to participate. The study was approved by the University's Research Ethics Board, and testing procedures, risks, and time required were fully explained to each participant before they read and signed an informed consent document.

2.2. Procedures

Participants performed a standardized golf warm-up consisting of dynamic stretches and swings of increasing intensity, which lasted approximately 5 minutes. Following this initial warm-up, participants hit 6 practice drives and were instructed to imagine that they were hitting for an equal balance of distance and accuracy, with their most typical shot shape (e.g., high draw), on a long par-4. Ball flight simulation software (FlightScope Software V10.1, FlightScope Ltd, Orlando, FL, USA) was used to display a target, and resulting shot trajectory, onto a projection screen.

Following the practice drives, participants hit 28 drives, in blocks of 7, with 30 s of rest between shots and 120 s of rest between blocks. All tests were conducted with the same Ping G 10.5 driver head, set in the neutral face angle position. Odd numbered participants (e.g., Participant #1) hit the first 7 drives with the low torque shaft (LT), while even numbered participants hit the first 7 drives with the high torque shaft (HT). Shafts were changed every 7 shots and participants were informed that the shafts were different, but were given no indication as to what parameter(s) were dissimilar. The 6 practice drives were performed with the same shaft used for the first 7 drives. The torque ratings for the LT (2.0°) and HT (8.0°) shafts represented the extremes in the golf industry, while the other shaft and assembled club properties were very similar (Table 1). Torque values were empirically validated with the reported values representing the amount of twist in degrees the shaft experiences when subjected to 1 ft-pound of torque across the length of the shaft. The tip and butt deflection values in Table 1 represent the amount of cantilever deflection that occurs when the shaft is fixed at the tip or butt end and a transverse load is applied at the opposite end. For the butt deflection measurement, the first six inches of the butt end of each shaft was clamped, and a 3.9 lb load was applied 1 inch from the tip. For the tip deflection measurement, the first inch of the shaft tip was clamped, and a 2 lb load was applied 1 inch from the butt end. The deflection values were measured through the use of a light table and bespoke image processing software. Lastly, the frequency of each shaft was measured in cycles per minute (cpm) by clamping the first six inches of the butt end and placing a 205-gram weight on the tip end. The tip of the shaft was then excited and the cycles were measured using an accelerometer that was mounted to the tip mass. MOI was checked using an Auditor MOI Speed Match system (Technorama Co Ltd., Kaohsiung City, Taiwan). Twelve Titleist ProV1 balls were used for testing and were replaced after every 10 participants.

2.3. Data collection and processing

Golf club kinematics were collected using an 8-camera optical system (Raptor-E, Motion Analysis Corporation, Santa Rosa, CA, USA). Four tracking markers were placed near the grip end of the club to create a grip reference frame and four tracking markers were placed on the club head to create a clubface reference frame (Figure 1). If ball contact was made with the lie, loft, and face angle equal to 0°, then the clubface reference frame would be perfectly aligned with the global reference

Table 1. Club properties.

	Shaft Torque deg	Butt Deflection cm	Tip Deflection cm	Shaft Mass g	Club Length cm	Shaft Freq. cpm	Club Mass g	Swing Weight
LT	2.8	8.7	12.9	68.1	114.9	261	323	D3
HT	8.8	8.7	12.1	68.3	114.9	261	323	D3

frame. During a calibration trial, markers were temporarily placed on wands extending from the shaft in order to calculate virtual markers located within the length of the shaft. During this calibration trial, markers were also precisely placed on the face of the driver to create the clubface reference frame (Figure 1). Two virtual face reference frames were created. One virtual face reference frame was calculated throughout the swing based on the tracking markers on the clubhead. This indicated the actual position and orientation of the face. A second virtual face reference frame was calculated throughout the swing based on the tracking markers at the grip. This 2nd face reference frame indicated how the face would be positioned and oriented if the shaft were perfectly rigid. Camera shutter speeds were set to 4000 Hz, and data were sampled at 500 Hz. The software application Cortex (version 5.3, Motion Analysis Corporation, Santa Rosa, CA, USA) was used to generate and export the 3D coordinate data for each marker. The residuals reported by the system were < 1 mm and the accuracy (root mean square error when measuring a known distance) and precision (SD of the length of a rod) were approximately 0.3 mm. A bespoke software program was written in MatLab (version R2010a, MathWorks, Natick, MA, USA) to process the 3D coordinate data and generate dependent variables of interest. All variables reported at impact were calculated using the marker data up to and including the last frame before impact. A forward prediction procedure was then employed to determine the value of each variable at the anticipated moment of contact with the ball. The forward prediction procedure involved fitting a 2nd order polynomial to the 13 data points before impact as a function of time. The polynomial was then evaluated at the predicted time of impact. Following the testing sessions, participants were asked to comment on their perceived differences, if any, between the two shafts in terms of feel as well as which shaft they preferred.

2.4. Statistical analysis

Paired t-tests were used to compare the effects of the two levels of shaft torque on specific dependent variables at impact. Effect sizes, specific to repeated measures tests, were also calculated (Dunlap, Cortina, Vaslow, & Burke, 1996). Effect sizes under 0.2 were considered small, while those greater than 0.8 were considered large. There were 14 data points per condition for each participant; therefore, it was possible to make reasonable inferences at the individual participant level using t-tests as well. Statistical significance was set at $\alpha \leq .05$ for all tests. Statistical analyses were performed using SPSS V22.0 for Windows (IBM Co., NY, USA).

3. Results

On average, the ball landed significantly further right (4.5 m) with the HT shaft relative to the LT shaft ($t(39) = 3.3$, $P = .002$, $d = .32$) (Figure 2(a)). This was the result of the ball launching 0.6° right relative to the LT shaft ($t(39) = 3.4$, $P = .001$, $d = .22$) and with 195 deg/s more "rightward side-spin" ($t(39) = 3.5$, $P = .001$, $d = .21$) (Figure 2 (b,c)). There was no significant difference in either horizontal clubhead path (LT = 3.3° left, HT = 3.4° left, $P = .23$) or horizontal impact spot on the face (LT = 7 mm towards toe, HT = 6 mm towards toe, $P = .19$). The *dynamic* face angle for the HT shaft was, on average, 0.9° open relative to the LT shaft ($t(39) = 4.0$, $P < .001$, $d = .32$) (Figure 2(d)). Dynamic face angle was reported by the Doppler radar launch monitor and is influenced by the mechanics of impact as well as the bulge on the driver face.

On average, the *delivered* face angle for the HT shaft was significantly more open (by 1.0°) relative to the LT shaft ($t(39) = 5.1$, $P < .001$, $d = .24$) (Figure 3(a)). Delivered face angle was measured using the optical motion capture methodology and represents the face angle at the center of the face. Average bend face, at impact, for the LT shaft (–5.5°) was significantly more closed than that for the HT shaft (–4.3°) ($t(39) = 8.2$, $P < .001$, $d = 0.53$) (Figure 3(b)). Bend face represents the contribution to delivered face due to both the amount of shaft flex *and* shaft twist at impact. At the individual level, 60% of the participants (25/40) demonstrated a statistically significant difference between shafts in terms of bend face with the HT condition being more open for all cases (Figure 4). Considering grip orientation at impact between the two conditions, there was no significant difference in

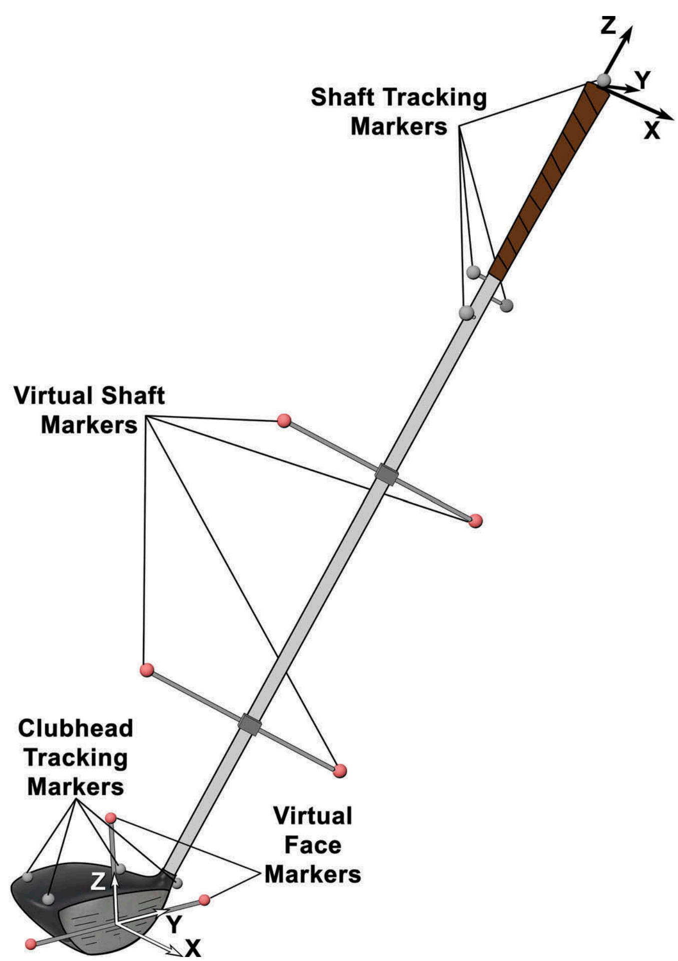

Figure 1. Grip reference frame, clubface reference frame, and marker set. If ball contact was made with the lie, loft, and face angle equal to 0°, then the clubface reference frame would be perfectly aligned with the global reference frame.

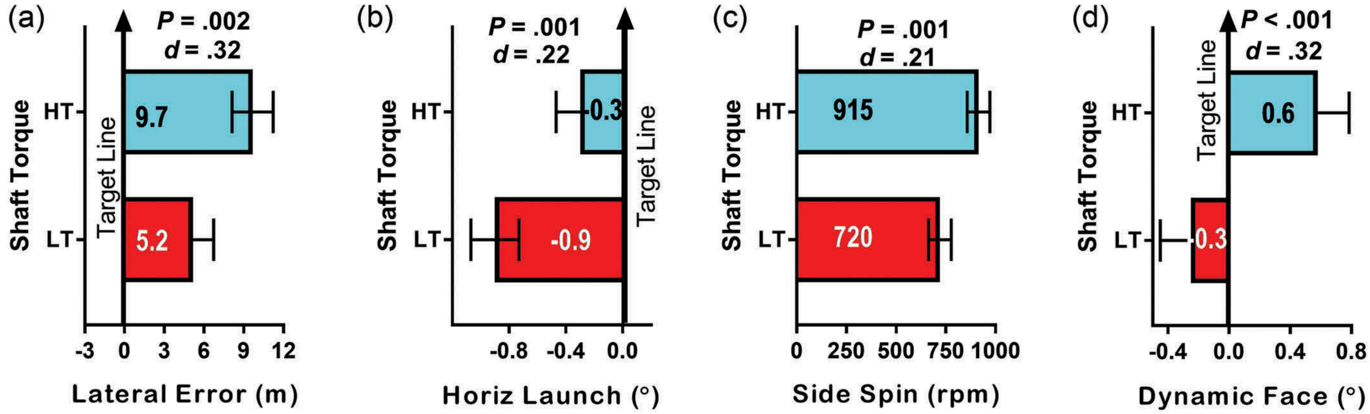

Figure 2. (a) Lateral error represents the average ball finish position relative to the target line. (b) Horizontal launch angle represents the initial ball flight direction relative to the target line. (c) Side spin represents the component of the ball's total spin about a vertical axis. (d) Dynamic face angle was calculated by the Doppler radar system. These are average values across all participants. Error bars represent 95% within-subject confidence intervals. P-values and effect sizes for the two-tailed paired t-tests are also included.

either the "lie angle" (rotation about the grip X axis) or "twist" (Z axis) of the grip at impact. There was a small but statistically significant difference in amount of grip "lean" (Y axis), with the LT shaft having 0.3° more lean towards the target at impact (t(39) = 2.9, P = .007, d = .09) (Figure 3 (c)). This rotation would tend to open and deloft the face of the LT shaft relative to the HT shaft condition. Average clubhead speed for the LT shaft (45.1 m/s) was not

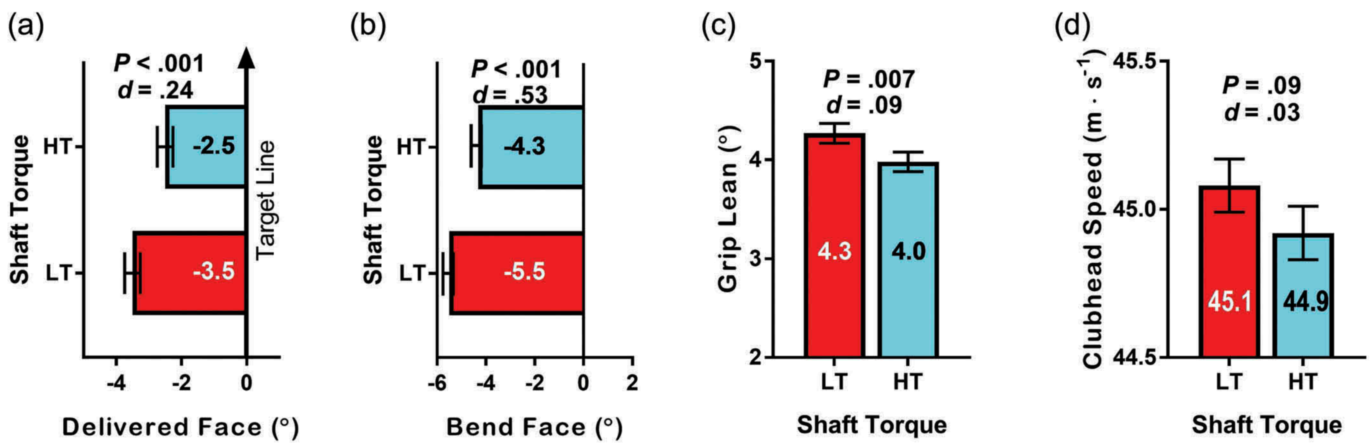

Figure 3. (a) Delivered face angle was calculated using the motion capture data. (b) Bend face at impact (c) Grip lean at impact. Positive grip lean opens the face. (d) Clubhead speed at impact. These are average values across all participants. Error bars represent 95% within-subject confidence intervals. P-values and effect sizes for the two-tailed paired t-tests are also included.

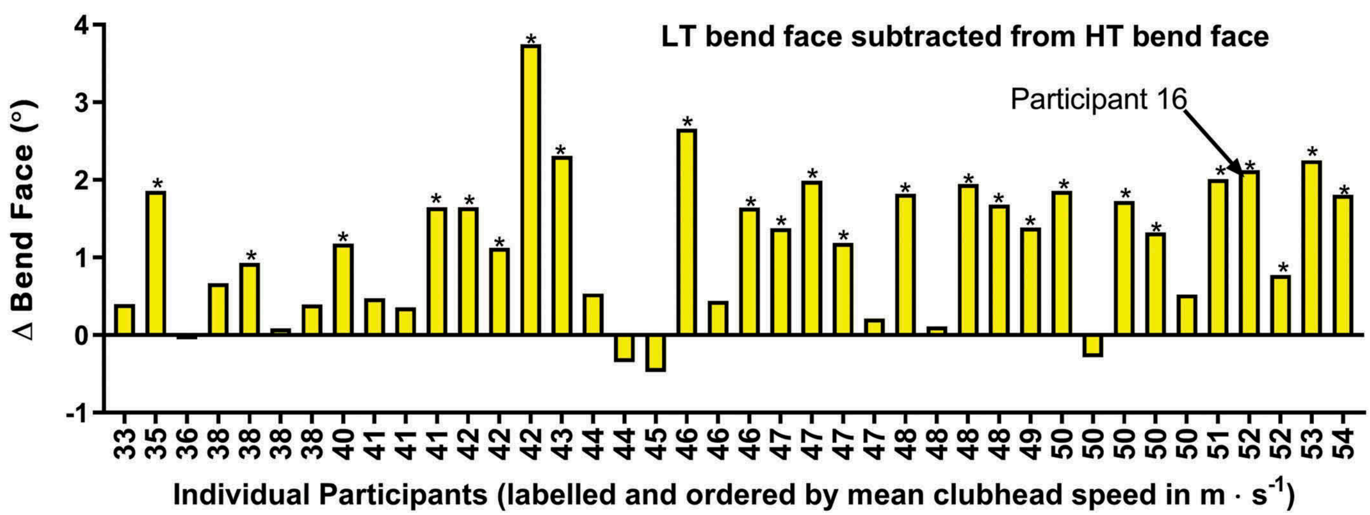

Figure 4. Each bar represents the average difference in bend face angle between shafts for each participant. Positive values indicate a more open face with the HT shaft. As determined by a two-tailed paired t-test (α = .05), the * indicates a significant difference between shafts for that participant.

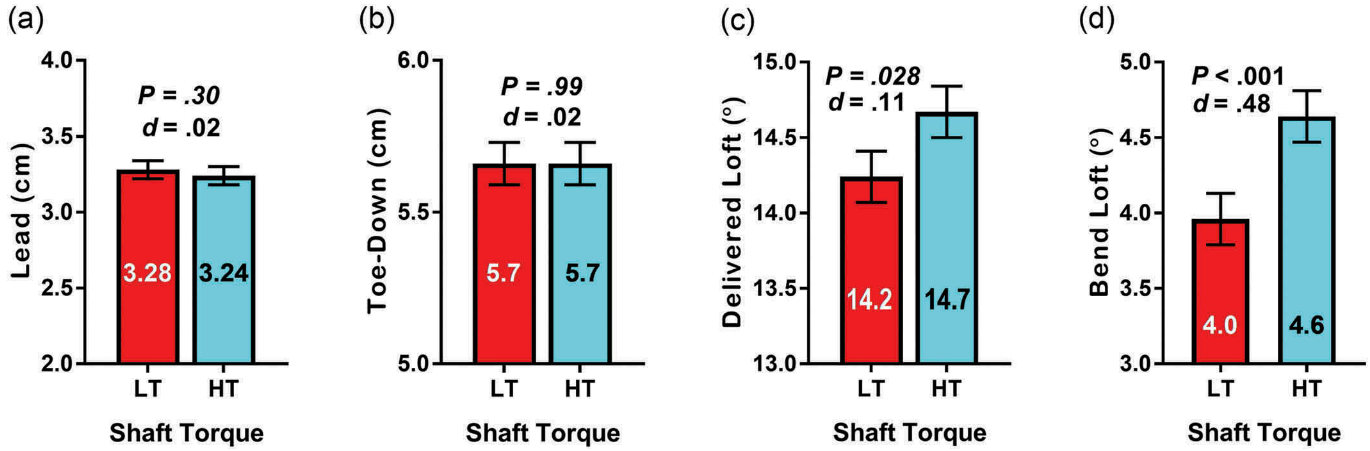

Figure 5. (a) Lead deflection at impact (b) Toe-down deflection at impact (c) Delivered loft (d) Bend loft at impact. These are average values across all participants. Error bars represent 95% within-subject confidence intervals. P-values and effect sizes for the two-tailed paired t-tests are also included.

significantly higher than that for the HT shaft (44.9 m/s) (t (39) = 1.7, P = .09, d = .03) (Figure 3(d)). At the individual level, 6 participants had statistically significant differences in terms of clubhead speed with 5 of those 6 generating more speed with the LT shaft; the greatest average difference in clubhead speed for a single participant was 2.0 m/s.

There was no discernible difference between shafts for either the amount of lead deflection (t(39) = 0.7, P = .47, d = 0.02) or toe-down deflection (t(39) = 0.4, P = .70, d = 0.02) at impact (Figure 5(a, b)). Lead and toe-down deflection reflect the distance between a point at the center of the hozel calculated from the clubhead markers and a point at the center of the hozel calculated from the shaft markers, which assumes a perfectly rigid shaft (MacKenzie and Sprigings (2009).There was a small but statistically significant difference in amount of delivered loft, with the HT shaft having, on average, 0.5° more loft at impact ($t(39) = 2.3$, $P = .028$, $d = .11$) (Figure 5(c)). Average bend loft, at impact, for the HT shaft (4.6°) was significantly higher than that for the LT shaft (4.0°) (t (39) = 5.1, $P < .001$, $d = 0.48$) (Figure 5(d)).

The average within-participant standard deviations of the dependent variables (e.g., impact spot, lateral error, clubhead speed, etc.) for each set of 14 swings with each shaft were also compared using paired t-tests. No significant differences were found for any variables. For example, the average within-participant standard deviation for the impact spot along the Y-axis of the face was 11.2 mm for the LT shaft and 10.6 mm for the HT shaft.

Relative to other dependent variables, shaft torque had the largest influence on delivered face angle. At the individual level, 13 participants had an average delivered face angle for the HT shaft, which was significantly more open relative to the LT shaft. While six participants did show average delivered face angles that were more open with the LT shaft, none of these six average differences were statistically significant. It was possible that certain "golfer characteristics" such as handicap, clubhead speed, shot shape, or lateral miss tendency might be associated with how shaft torque influenced delivered face angle. For example, maybe all six participants that delivered a more open face with the LT shaft tended to draw the ball. Correlations between the four aforementioned variables and the difference in delivered face angle (HT minus LT) were performed and no significant relationships were found. The strongest association was with lateral miss ($r = -.21$, $P = .09$), which suggests that missing right of the target line was associated with delivering the face more open with the LT shaft. However, this is clearly a misleading correlation as the six participants that had average misses furthest to the right all delivered a more open face with the HT shaft. Additionally, grouping participants based on these variables and performing four t-tests on the "difference in delivered face angle" variable revealed no significant findings.

There were no clear trends in the qualitative comments from participants following testing. Six participants stated that the HT shaft felt more flexible than the LT shaft, while seven felt the reverse. Two participants felt the HT shaft was heavier, while one felt the reverse. Ten participants said they preferred the HT shaft, 16 preferred the LT shaft, while the remaining 14 had no preference.

4. Discussion

The purpose of this study was to investigate how shaft torque influences clubhead kinematics at impact and the resulting flight of the ball. Although there is no published scientific research that has systematically investigated the relationship between shaft torque and performance, Butler and Winfield (1994) did provide some evidence to suggest that the shaft used in their study was twisted open at impact. Based on this, it was hypothesized that the HT shaft would have a greater tendency to be twisted open, at impact, relative to the LT shaft. Although shaft twist was not directly measured in this study, a strong argument can be made that the findings support this hypothesis. While the perceived influence of shaft torque on clubhead delivery seems divided within the industry, our results align with the insights of Kozuchowski (2013) and Tursky (2016), in that the higher torque shaft resulted in the clubhead being twisted more open at impact.

As expected, the HT shaft was associated with shots travelling significantly further to the right of the target line due to significant differences in both the ball launch direction and spin (Figure 2). Given the controlled conditions in the lab, the launch and spin of the ball will be determined by clubhead speed, path, impact spot, and face angle. Considering there were no significant differences in speed, path, or impact spot, the differing launch conditions were primarily the result of the face of the driver being delivered in a significantly more open orientation (1° more) with the HT shaft (Figure 3(a)). The delivered clubhead orientation is completely determined by grip orientation and shaft deformation at impact. The grip of the LT shaft had significantly more positive rotation about the Y-axis of the grip (grip lean) at impact (Figure 3(c)). This would tend to open the face of the LT shaft relative to the HT shaft; therefore, grip orientation cannot explain the more open delivered face angle for the HT shaft. In contrast, bend face, which represents the contribution of shaft deformation to delivered face angle explains the difference in delivered face between shafts. Shaft deformation, at impact, tended to close the face 1.2° more for the LT in comparison to the HT shaft condition (Figure 3(b)).

Bend face is the result of an indistinguishable mix of both shaft flexing and shaft twisting, as such, more information is needed to determine the contribution from shaft twist to clubhead orientation at impact. The magnitudes of toe-down and lead deflection at impact provide a strong indication of how much shaft flexing contributes to clubhead orientation. In this paper, the position of the *hozel*, compared to where it would be if the shaft was rigid, was used to eliminate the influence of shaft twist on lead and toe-down deflection. Toe-down deflection tends to open the face, while lead deflection tends to close the face (MacKenzie Mechanisms paper). There was effectively no difference in the magnitudes of lead and toe-down deflection between conditions (Figure 5(a,b)). As such, it can be reasoned that a difference in shaft twist was the cause of the 1° delivered face angle discrepancy between conditions. A similar argument can be constructed to explain why the HT shaft was associated with 0.5° more delivered loft relative to the LT shaft (Figure 5(c)). Since the lead and toe-down deflections at impact were so similar, the additional bend loft for the HT condition (Figure 5(d)) was the result of the shaft being twisted more open with the HT shaft relative to the LT shaft.

While the two disparate levels of shaft torque generated statistically different results for several key performance variables, it is important to gain some perspective on the practical meaningfulness of these results. The effective sizes associated with the significant results ranged from very low (d = 0.11 for delivered loft) to moderate (d = 0.53 for bend face). Perhaps most relevant to the golfer is the finishing location of the golf ball, and at an average lateral difference of 4.5 m, there appears to be little justification for being concerned about shaft torque. However, there were six participants that had average lateral differences over 15 m further right with the HT shaft. This magnitude of difference would be impactful on tight holes that curve to the left. It also interesting to note the incremental adjustments available on popular driver models. For example, an incremental hosel adapter setting change from neutral to the "small minus" for the Ping G driver used in the study represents a change of 0.6° of loft and 0.3° of face angle, which are similar in magnitude to the differences in delivered lofts and face angles found between shafts in this study.

In qualifying the practical importance, it is also relevant to compare the influence of shaft torque to that of other shaft parameters, such as flex, which has been well established as having important implications for clubhead delivery. MacKenzie and Boucher (2017), in comparing disparate level of shaft stiffness found average differences in bend loft and bend face of 2.0° and 0.4° respectively. While these differences were statistically significant, they did not translate into significant differences in delivered angles, at the group level, due to coupled changes in grip orientation. The magnitude of difference in bend face in this study (1.2°) was greater, and did translate into a significant difference in delivered face (1.0°). Similarly, a significant difference in delivered loft (0.5°) was also found in this study. So, when comparing at the group level, the data suggest that shaft torque is more uniformly influentially on performance than shaft stiffness. However, it is important to consider that shaft stiffness was found to have a larger influence on performance at the individual golfer level. It is also relevant to note that the LT and HT shafts represent the extremes for torque ratings and that other club properties were tightly controlled; therefore, it is likely that the findings from this study reflect the limits of influence due to shaft torque. In contrast, the shaft flex's used by MacKenzie and Boucher (2017) were not as close to the ends of the spectrum.

The current practice in shaft manufacturing is primarily to provide options for flex and have shaft torque vary in a proportional manner. This practice is dismissive of the perceived independent influence that shaft torque has on how a club feels. According to Summit (2000) and Saternus (2013), the lower the torque measurement of a shaft, the stiffer the shaft would feel to the golfer; and the higher the torque, the more flexible the shaft would tend to feel. Interestingly, only 15% of the participants had a perception that matched the actual shaft properties. Regardless, there was a relatively equal distribution of participant shaft preferences in this study, which suggests there may be value in offering at least three torque options for a given level of shaft stiffness. However the expenses associated with decoupling torque and flex as well as tripling the number of skews may prove prohibitive.

Given the current methodology, it seems certain that the findings shown in Figure 4 were due to a difference in shaft twist at impact; however, it was not possible to determine the average magnitude or direction of twist for a particular condition. For example, consider Participant 16 in Figure 4, whose lead and toe-down deflections (not shown) were virtually identical between shafts. It is not possible to determine if: 1) both shafts are twisted open at impact, with the HT shaft twisted open more, 2) both are twisted closed, with the HT shaft twisted less closed, or 3) the LT shaft is twisted closed and the HT shaft is twisted open. The insertion angle of the shaft into the head, the non-uniform deformation along the length of the shaft, the large magnitude of shaft flex relative to twist, and the ambiguities associated with computing 3D angles all contribute to the challenge in estimating the amount of shaft twist using motion capture methods. A possible solution would be to create numerous reference frames along the length of the shaft and compute the successive contribution to overall twist; however, attaching the necessary hardware along the length of the shaft would make this impractical. While the shafts were extremely similar in all properties with the exception of torque, the HT shaft had a slightly stiffer tip section (Table 1). As shown by MacKenzie & Boucher, 2017; Figure 5(d)), a stiffer shaft will tend to result in a more closed face; therefore, it seems unlikely that shaft flexing can explain the more open face delivery with the HT shaft.

While indoor testing allows for higher internal validity, it does introduce limitations. For example, if the final outcome is desired, then ball flight must be modelled based on measured ball launch parameters. Details on the measurement abilities of the launch monitor reported values are not available; however, comparison to the motion capture data suggests it was operating with a sufficient level of reliability in this study. The radar data agreed very well with the 3D optical data. For example, FlightScope reported a difference of 0.9° in face angle between shafts, while the optical analysis found a difference of 1.0° and both were associated with very similar p-values ($P < .001$). The FlightScope face angle data is calculated based on the measured ball flight data; therefore, it is logical to assume that the ball flight data were recorded with a sufficient level of reliability as well.

5. Conclusions

This study has provided novel insights into the understanding of how shaft torque influences clubhead kinematics at impact with a driver and the resulting ball flight. Increasing shaft torque (reducing torsional stiffness) tended to increase delivered loft and open the face of the driver, which led to more right biased trajectories. These effects were not mediated by the swing speed of the player. Theoretically, golfers looking to fight a miss to the left or to the right of the target line could possibly benefit from using a shaft with either a higher or lower torque value, respectively. It should be noted though that there are a number of other fitting variables such as club head center-of-mass, shaft stiffness, and club weight that can have a significant influence on left-right trajectory. As stated earlier, the torque values evaluated in this study represent an extreme range from low to high. From a practical standpoint, the shafts of a given stiffness that are available in a typical fitting environment will only span a torque range of 3 to 4 degrees. Of the fitting variables mentioned, shaft torque would serve as a minor variable during a driver fitting, while club head center-of-mass would serve as a major variable, producing a more noticeable change in ball flight. Lastly, fitting a golfer with a club that has a preferred feel should be factored into the fitting process, and in most cases a balance of feel and improved ball flight produces optimal results.

Disclosure statement

No potential conflict of interest was reported by the authors.

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