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Title

Partial swing golf shots: Scaled from full swing or independent technique?

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Abstract

During practice and competition, golfers are required to use submaximal effort to hit the ball a given distance, i.e. perform a partial shot. While the full golf swing has undergone extensive research, little has addressed partial shots and the biomechanical modifications golfers employ. This study investigates the biomechanical changes between full and partial swings, and determines if the partial swing is a scaled version of the full swing. Using a repeated measures design, thirteen male golfers completed a minimum of 10 swings in the full and partial swing conditions, whilst club, ball, kinematic and kinetic parameters were recorded. Large and statistically significant reductions in body motion (centre of pressure ellipse: 33.0%, p = 0.004, d = 2.26), combined with moderate reductions in lateral shift (25.5%, p = 0.004, d = 0.33) and smaller reductions in trunk rotation (arm to vertical at top of backswing: 14.1%, p = 0.002, d = 2.58) indicate golfers favour larger reductions in proximal measures, combined with diminished reductions as variables moved distally. Furthermore, the partial swing was not found to be a scaled version of the full swing implying a new approach to coaching practices might be considered.

Word Count: 193

Keywords

Coordination, Motion Analysis, hitting/batting.

Introduction

In competitive golf, the final shot into the putting green is often termed the 'approach shot'. This shot determines the distance of the ball from the hole for the first putt. The accuracy of the approach shot will influence the likelihood of success in the following putt (Stökl, Lamb, & Lames, 2011). Golfers will therefore employ course management strategies in an attempt to position the ball in the most advantageous location for distance and approach angle to the hole, with the penultimate shot to the approach. However, researchers, disregarding possible environmental influences, have identified that minor inaccuracies in the contact between the club face and ball will alter ball launch characteristics and result in an unplanned final ball position (Betzler, Monk, Wallace, Otto, & Shan, 2008). Given the final position being unplanned, the ball may be at a distance 'between clubs' or shorter than that achievable with a full swing of the most lofted club in the bag. As golfers are limited in number of clubs (n=14) (The R&A, 2016) allowable to be carried, which alter in length and loft (the angle of the club face to the vertical axis), of which each will have a known shot distance. The golfer will need to alter their planned approach shot, through modification of swing, performing a reduced effort swing, termed a partial shot.

Partial shots are postulated to be more difficult than full swing shots (Pelz, 2006; James & Rees, 2008; Robertson, Burnet & Gupta, 2014), as outcomes measured using percentage error index (PEI) are significantly worse than those of full swings. Percentage error index is derived from shot distance divided by the error from target reported as a percentage (Pelz, 2006). James and Rees (2008) identified a 17% reduction in accuracy for shots between 50-100 yards when compared to those from 100-200 yards during the 2006 PGA tour. Despite the general understanding of this, partial shots in golf are relatively common, between 2012 and 2016 the season average for PGA tour professional was 201 approach shots or 3 per round, defined as being less than 100 yards (PGA Tour, 2017). Considering these statistics, a better understanding of partial shots would be advantageous to golfers, as three shots that are significantly less accurate would result in an increase in putts required and higher scores.

Surprisingly, the partial swing has received very little attention in the academic literature. Initial investigations addressing distance control (Neal, Abernethy, Moran, & Parker, 1990) and muscle activity (Abernethy, Neal, Moran, & Parker, 1990) during partial swings, highlighted that level of muscular activation did not linearly increase with shot distance (Abernethy et al., 1990) and the temporal sequencing of partial shots were not scaled to full swings (Neal et al., 1990). More recently, researchers have established that the proximal to distal sequencing (PDS) patterns experienced in the full swing (Cheetham, Martin, Mottram, & St Laurent, 2001; Neal, Lumsden, Holland, & Mason, 2007; Tinmark, Hellstrom, Halvorsen, & Thorstensson, 2010), were qualitatively similar for shots from 40m, 55m and 70m, however duration of downswing was significantly reduced (Tinmark et al., 2010). Parallel work in drop punt distance control within Australian Rules Football (Ball, 2008; Peacock, Ball, & Taylor, 2017) identified reduction in foot velocity, comparable to club head velocity for golfers, was the determinant of impact parameters associated with reductions in distance. Indicating that the velocity of the implement at contact needed to be manipulated to mitigate the distance requirements of the task (Peacock et al., 2017). Reductions in foot velocity were not proportional to those required in distance, however the nature of the task was proposed as the determining factor as the task did not require the ball to come to rest at the target distance. Rather the ball was aimed at a training mannequin and as such the authors proposed that participants may have altered parameters on the basis of the task, rather than absolute distance control.

Importantly, issues arise from these approaches, as the lack of linear relationship to full swing (or maximum distance) is likely to have been driven by the absolute distances used (20m, 40m, and 60m; 40m, 55m and 70m; 20m and 60m) by Neal et al. (1990), Tinmark et al.

(2010) and Peacock et al. (2017), respectively. Moreover, the effort required for each golfer to hit the desired distance, as measured by the percentage of full swing distance, would likely have been different both across and within ability groups. Alternatively, the applied field of golf coaching promotes a staged reduction in the length of the backswing (Cowle, 2010; Pelz, 2006), possibly evidenced by the alterations in downswing duration (Tinmark et al., 2010). This approach has received limited support from empirical research, as elite and amateur golfers have demonstrated significant staged increases in all measures, when participants were instructed to swing easy, medium and hard with a 5 iron (Meister et al., 2011). However, the ambiguous instruction of swing effort provided to the participants limits the comparability between participants.

Previous research has identified specific biomechanical parameters associated with maximising club head and ball velocity including; the x-factor (McTeigue, Lamb, & Mottram, 1994), the x-factor stretch (Cheetham et al., 2001), ground reaction forces (Worsfold, Smith, & Dyson, 2007), coefficient of restitution (CoR) of the ball (Chou, Gobush, Liang, & Yang, 1994), weight transfer (Jorgensen, 1994) and centre of pressure range and rate of motion (Ball & Best, 2011). These parameters could provide an inverse theoretical framework from which a scaled reduction of these, in line with the suggested coaching practices (Cowle, 2010; Pelz, 2006), would be present in the partial shot. Recently some support for this theoretical approach was found in the ground reaction force under the lead foot during the swing (McNitt-Gray, Munaretto, Zaferiou, Requejo, & Flashner, 2013). This was characterised by a significant reduction in the magnitude of peak horizontal ground reaction force during the swing, whilst the orientation of the force application did not change during a partial swing (McNitt-Gray et al., 2013).

Despite recent findings, neither the kinetic or kinematic contributors used by golfers to achieve partial shots, or how these differ from the full shots, are understood. Furthermore, the limitations associated with use of absolute distance assessment of partial shots (Abernethy et al., 1990: Neal et al., 1990; Tinmark et al., 2010), the qualitative similarities in PDS (Tinmark et al., 2010) and the continued anecdotal coaching approaches to learning partial shots (Cowle, 2010; Pelz, 2006), indicating partial shots may be scaled full shots, suggest further investigation is warranted. Therefore, the purpose of this study was twofold; to assess the biomechanical differences between full and partial golf swings, and to assess if partial shots are scaled from full shots. It was hypothesised that there would be a significant difference in measured biomechanical variables associated with carry distance and the partial swing would be not significantly different in measured biomechanical variables associated with carry distance from a scaled full swing.

Methods

Participants

The study protocol was approved by the Canterbury Christ Church University Ethics Committee and all testing procedures were carried out in accordance with Declaration of Helsinki. Thirteen male participants (40 ± 16 years of age, 1.82m ± 0.05m in height, mass 90kg ± 20kg, UK Council of National Golf Unions (CONGU) handicap of 13 ± 9) took part after providing written, informed consent. Post hoc power assessment of sample size using club head speed as the main determinant of carry distance (Hume, Keogh, & Reid, 2005), computed using G*Power 3 (Faul, Erdfelder, Lang, & Buchner, 2007), demonstrate statistical power greater than 0.95. Inclusion criteria stipulated that they had no current injury that would affect their ability to perform a minimum of 20 golf swings and had played or practiced golf within a year of testing. Prior to testing the participants had retro reflective markers placed on 8 anthropometric sites bilaterally through manual palpation including, the lateral malleolus of the fibula, the acromion process of the scapula, the olecranon process and the ulnar styloid; all markers were placed directly onto the skin.

Testing Procedure

Following a self-selected duration for warm-up and familiarisation, participants performed a minimum of 10 full golf shots in an indoor testing facility, hitting to their maximum comfortable carry distance, defined as distance travelled from ball strike to calculated first ball ground contact, with a pitching wedge. Full shots were captured first allowing calculation of partial shot target distance in the proceeding condition. Pitching wedge was selected as club face loft is standard (45°), where wedges used with lofts greater than this are inconsistent across individuals due to preference. The pitching wedge was either a men's standard length and lie, provided to participants who used standard sets, or the participants custom fitted pitching wedge. Each shot was aimed towards a target line marked on a wall 5.3 m from the driving mat, with a safety net 4.8 m from the driving mat; distances were determined by lab dimensions, participant safety, and minimum distance required for ball tracking (4m).

On completion of the 10 full swings, participants were given a self-selected break, no less than 10 minutes, and the 80% target distance for the partial shot was calculated (mean carry distance*0.8). The participant was informed of the new target distance, all distances were verbally reported to the participant in yards as the golfing standard unit. A second period of familiarisation to the target distance was completed; verbal feedback was provided during this familiarisation as either 'good', 'too long' or 'too short'. When the participant reported they had sufficient familiarisation the participant completed a second set of 10 shots to an 80 ± 5 % distance of the full swing distance, as measured by the Flightscope X2 Doppler Ball-Tracking Radar (EDH Ltd, South Africa). Only shots within the accepted margin of error were recorded for further analysis. Verbal feedback, either ‘too long’ or ‘too short’, continued to be used to aid the participant in ranging failed trials.

Equipment

During each shot two dimensional (2D) kinematic data were collected using a Fastec TS5QM4256 high-speed digital camera (Fastec Imaging Company, USA) operating at 400Hz (focusing range ∞ m, aperture *f*/2.8, shutter speed 2488μs and resolution 1536 x 1536 pixels) centred on the participants’ hands at address, perpendicular to the line of flight of ball. An initial swing capture was recorded and analysed prior to data collection to establish that all markers remained in frame for the full golf swing.

During all swings ball flight and club statistics were measured using a Flightscope X2,

3.2m behind the target line, ensured by using the ball origin test score of 0°, a role angle and tilt angle within manufacturer recommendations (±0.3°, 9-12° respectively). Pataky (2014) defines the Flightscope as ‘a system with a manufacturer-specified accuracy of approximately 99%, achieved through constant during-flight ball monitoring’. Each shot used a Titleist ProV1 golf ball with a metallic dot applied and orientated in the direction of the intended shot. Centre of pressure data was captured using an RS Scan 1m pressure plate (RS Scan International, Belgium) sampling at 100 Hz for 5 seconds using RS Scan version 7 balance software (RS Scan International, Belgium).The pressure plate system was selected to assess the variations in centre of pressure (CoP), as previously it has been shown to be a valid tool for assessing CoP motion associated with balance and performance during static and dynamic movements (Cloak, Nevill, Clarke, Day, & Wyon, 2010; Cloak, Wyon, Nevill, & Day, 2013; Fletcher & Long, 2013; Morrin & Redding, 2013).

Processing and data extraction

Swing kinematics and kinetics were used to compare the techniques used by golfers to perform both full and partial golf shots. The three swing events were; Address, which was the last frame before the initiation of movement of the club in a clockwise direction; Top of the backswing, which was the last frame before motion of the downswing, as indicated by the first movement of the club in the opposite direction to the backswing; and Ball Contact, which was defined as the frame at which the club first made contact with the ball. From these measures backswing duration was the time between the address frame and the top of the backswing, the downswing duration was the time between the top of the backswing and ball contact and the total swing duration was the time between address and ball contact frames. The kinematic variables were the lead forearm angle to vertical at the top of the backswing (AV), the lead wrist angle at the top of the backswing - defined as the angle between the forearm and the shaft of the club, and stance width - defined as the distance between retroreflective markers placed on the left and right lateral malleolus of the fibula. The kinetic variables were the centre of pressure excursion (CoPE) - defined as the total distance that the centre of pressure travelled throughout the duration of the golf swing, the range of the centre of pressure in the anteroposterior direction (CoPy) and the range of the centre of pressure in the mediolateral direction (CoPx) between the start and the end of the swing. Finally, the ellipse area (CoP Ellipse), a combined measure indicating the total motion of the centre of pressure during the swing, is considered indicative of the overall weight transfer during the swing was calculated. Thus, providing a single indicator of weight transfer motion during the swing for coaching application. Extraction of the kinetic data at relevant swing events was performed using the vertical force trace on the RSScan software and the method employed by Worsfold et al. (2007).

Flightscope® X2 measurements were club head velocity (CHV) (m/s), shot accuracy as measured as lateral displacement of the ball to the target line (m), Ball velocity (m/s) and carry distance of the ball (m), all of which were reported by the Flightscope® X2 software. Performance Error Index (PEI) was also calculated by dividing the mediolateral error of the shot (m) by the carry distance that golf shot achieved (Pelz, 2006), which allows comparison of error to be drawn between golfers who can hit to different shot distances with the same club. Initial analysis was undertaken to determine if golfing ability, as measured by handicap, was an influencing factor. The participant group was split into low (n= 6; handicap 4.8±5.4) and high (n=7; handicap 19.3±3.7), cut off set at 12, upon which independent samples t-tests, with a Holm's sequential Bonferroni correction, were conducted on all variables. No variable displayed statistical significance (p>0.05) between the low handicap and high handicap groups, in either full or partial shots. Therefore, all golfers were grouped for the statistical analysis.

Statistical Analysis

Prior to statistical analysis parametric assumptions were tested using a Shapiro-Wilk test, any variables violating parametric assumptions were compared using a Wilcoxon signed rank test, while paired sample t-tests were used for those that did not. To minimise the chance of type one errors Holm's sequential Bonferroni correction was applied. Effect sizes (Cohen's D) were calculated for all statistically significant findings using an online calculator (Lenhard & Lenhard, 2016), which were evaluated as small, medium or large effects based on the values of 0.2, 0.5 or 0.8 respectively (Cohen, 1988). Two rounds of statistical tests were completed on the data firstly comparing partial shot (PS_m) to the full shot (FS), to identify whether the full and partial shots are different. A secondary analysis to determine if the partial shot (PS_m) was a scaled version of the full swing by calculating a theoretical 80% (PS_t) value for the full swing (variable*0.8). Not all variables were included in the secondary analysis, only those expected to change to reduce carry distance based on Cheetham (2014). The level of statistical significance was set at $p \leq 0.05$ for all tests. The statistical analysis was performed with SPSS version 24.0 (SPSS Inc., Chicago, IL, USA).

Results

Full Swing versus Partial Swing

All data are reported as mean ± standard error (SE). The analysis of the Flightscope data for carry distance showed that during the partial shot session all golfers managed to hit within the required target distance and margin of error (80% ± 5%). The analysis of the kinematic data showed that AV significantly reduced between the full and partial shots (z = -3.059, p = 0.002, d = -2.58), whereas wrist angle was found not to be significantly different between the two swing conditions. Lateral shift ($t(10)$ = 3.667, p = 0.030, d = -0.33) and stance width ($t(11)$ = 3.785, p = 0.024, d = -0.54) also displayed significant changes between the full swing and the partial swing (table 1).

TABLE 1 NEAR HERE

Figure 1 shows the analysis of the pressure excursions, significant differences were found in the CoPE (FS: 0.858 ± 0.047 m, PS_m: 0.654 ± 0.054 m; $t(11)$ = 6.591, p < 0.001, d = 1.17) and CoPx (FS: 0.349 ± 0.025 m, PS_m: 0.305 ± 0.029 m; $t(12) = 3.944$, $p = 0.021$, $d = 0.46$), both of which were significantly lower during the partial shot compared to the full shot condition. This translated into the CoP Ellipse also exhibiting significantly lower area in the PS_m ($z = -2.903$, $p = 0.004$, d = 2.26) (table 1).

FIGURE 1 NEAR HERE

The lateral distance of the shot to the target line was found not to be significantly different between full (4.73 ± 0.41 m) and partial (4.05 ± 0.53 m) shots, as was PEI (FS: 4.35 ± 0.04%, PS_m: 4.51 ± 0.70%, $p > 0.05$). Both CHV ($t(12) = 19.918$, $p < 0.001$, $d = 1.94$) and ball velocity ($t(12) = 21.083$, $p < 0.001$, $d = 1.47$) significantly reduced between the full and partial shots. Further significances were found in the flight time ($t(12) = 19.716$, $p < 0.001$, $d = 1.98$) and peak height ($t(12) = 17.051$, $p < 0.001$, $d = 2.20$). All Flightscope measures are displayed in table 2.

TABLE 2 NEAR HERE

Partial Swing versus Theoretical Swing

The kinematic variables found that wrist angle at top of back swing ($t(10) = 4.920$, $p = 0.001$, $d = 0.96$) and AV ($z = 2.118$, $p = 0.034$, $d = 1.31$) was significantly higher for the measured partial shot. This was also true for the temporal swing variables, with swing duration (PS_m:

1.09 ± 0.04 s, PS_t: 0.88 ± 0.04 s; $t(10) = 11.597$. $p < 0.001$, $d = 1.44$), back swing duration (PS_m: 0.78 ± 0.04 s, PS_t: 0.65 ± 0.04 s; $t(10) = 10.075$, $p < 0.001$, $d = 1.08$) and downswing duration (PS_m: 0.31 ± 0.01 s, PS_t: 0.24 ± 0.01 s; $t(10) = 16.362$, $p < 0.001$, $d = 2.33$) all being significantly longer for the measured partial swing (figure 2). Centre of pressure measures displayed no significant difference between measured and theoretical partial swings, although CoP Ellipse ($p = 0.084$) and CoPx ($p = 0.067$) neared significance.

FIGURE 2 NEAR HERE

Analyses of the Flightscope variables indicated that both CHV ($t(12) = 5.898$, $p < 0.001$, $d = 0.58$) and ball velocity ($t(12) = 14.286$, $p < 0.001$, $d = 0.56$), were significantly higher for the measured partial shot when compared to the theoretical partial shot value. This was also true for the flight time ($t(12) = 5.693$, $p < 0.001$, $d = 0.69$), but the peak shot height ($t(12) = -6.562$, $p < 0.001$, $d = 0.75$) was significantly lower than the theoretical partial shot (table 1).

Discussion and Implications

Theoretically, the reduced carry distance required of the partial shot, would mean that the expectation for significant differences in measured biomechanical and temporal variables to those of a full swing could be expected. Results, specifically statistically significant differences across measures of kinematic, kinetic, club and ball parameters between whole and partial shots, corroborate this proposition and allow the acceptance of the primary hypothesis. Statistically significant and large decreases in the CoP ellipse, by 33.0% ($z = -2.903$, $p = 0.004$, $d = 2.26$) and the CoPe, by 23.7% ($t(12) = 6.591$, $p < 0.001$, $d = 1.16$) and smaller, yet still significant declines, in the lateral shift (14.3%) and CoPx (12.5%) measures for the PSm were characteristic of partial swings. The reduction of the CoPx range provides corroborative support to reductions in magnitude of peak lateral forces identified by McNitt-Gray et al. (2013). As lateral motion of the CoP (calculated from the vertical force) will have been caused by a net lateral force being applied to the system, therefore the reduced CoPx will have been a result of a reduced lateral force, as identified by McNitt-Gray et al. (2013). Resultantly, it appears that strategies employed by participants in performing partial shots are associated with a reduction in the magnitude of centre of pressure motion, caused by reduced force application. Furthermore, when these reductions are considered in light of previous work focused on maximising club head velocity (Ball & Best, 2007; Ball & Best, 2011), it appears that participants are intuitively reducing parameters normally maximised for gaining distance. Therefore, the reductions in the motion of the CoP are fundamental in controlling partial shot distance. Meaning that from a coaching perspective, with specific reference to the weight transfer (CoPx), golfers reduce their lateral motion and so advice should focus on limiting the natural weight transfer of the golf swing when practising partial shots.

Examination of swing kinematics provide further insight into the strategies employed by golfers when playing partial shots. The AV angle, a basic two-dimensional indication of the rotation in the upper torso, continued the pattern of reduced motion exhibited in the centre of pressure. The AV was significantly lower for the PSm (135.68 ± 7.33°) than the full swing (157.91 ± 7.38°), inferring that torso rotation was reduced during the partial shot. No significant differences were observed in the wrist cock angle at the top of the back swing, but there was a significant change at ball impact (FS: 180.66 ± 2.64 °, PSm: 178.17 ± 2.57°, d =

2.26). This suggests that the participants used a shortened backswing and may have been trying to actively prevent the natural release of the club through impact, in an attempt to limit club head velocity and therefore better control partial shot distance (Jorgensen, 1994). The change in the wrist angle at impact was not an artefact of alterations in swing set up, as no changes in the wrist angle were detected at address. Interestingly a statistically significant reduction in stance width was identified at address, as golfers narrowed their stance when performing the partial shot ($t(11) = 3.785$, $p < 0.05$, $d = 1.37$). The reduction in the stance width will have consequences for other areas of the swing, in that the golfer will need either to increase the knee bend or hip lean to maintain stance height, or perform the swing in an increased upright position.

Assessment of the club and ball parameters suggest which of the approaches golfers employ in line with the reduced stance width. Specifically, an increase in the club shaft angle was observed at impact in the PS_m condition, suggesting that the golfer stood in an increased upright position. Theoretically, this would have caused the heel of the club to be lifted, opening the face of the club at impact and increasing the likelihood of the toe of the club impacting the ground first causing an off centre strike. It would, therefore, be expected that the lateral accuracy of the shot would have been compromised in the PSm condition, as previously indicated (Abernethy et al., 1990; James & Rees, 2008; Pelz, 2006). However, measures of accuracy (both relative and absolute) did not demonstrate a statistically significant difference between full shots and PSm, likely due to the increase in club shaft angle being insufficient to demonstrate significance after application of Holm's Sequential Bonferroni correction ($t(12) = -2.312$, $p = 0.197$, $d = 0.79$). The main significant findings, with regard to ball motion and shot outcome, were a reduction in ball and club head velocity during the PS_m condition. This had anticipated implications for other variables, namely the statistically significant reductions in flight time and peak height of the shot, given that these depend predominantly on ball velocity, spin rate and launch angle, the final two displaying no significant change between full swing and PS_m,

FIGURE 3 NEAR HERE

Findings in combination suggest an interesting pattern when percentage change from the full swing is considered (figure 3). It is clear that the magnitudes of reduction from full swing to partial swing become less as the location of variables move distally, from a 33.0% reduction in the CoP ellipse to a 1.4% reduction at the wrists. It, therefore, can be proposed that participants prefer a proximal to distal reduction in segment contribution, with greater emphasis on the reduction of the more proximal aspects of the swing such as the hub and trunk motion, as opposed to the more distal aspects, such as lower arms and wrists. This aligns with the PDS findings noted previously (Cheetham et al., 2001; Neal et al., 2007; Tinmark et al., 2010) as reduced foundational movements of the proximal segments automatically decrease the interaction torques available to produce end point velocity, in this instance the velocity of the club head (Putnam, 1993; Hirahima, Kudo, & Ohtsuki, 2003; Hirashima, Kudo, Watarai, & Ohtsuki, 2007). In this way, participants reduce club head velocity at impact by manipulating the larger body segments i.e. the legs and hips, rather than attempting to interfere with the smaller body segments (arms and wrists) that are better suited to fine motor alterations.

Initial analysis indicates that the partial swing is significantly different from the full swing and that the alterations that characterise a partial swing are not consistent across all variables. This speaks directly to the rejection of the secondary hypothesis, routed in applied practice (Cowle, 2010; Pelz, 2006), that the partial swing is a scaled version of the full. Following calculation of a theoretical 80% partial shot (PS_t), statistical analysis highlighted a number of interesting findings. The ball speed and club head speed were significantly greater for the measured partial shot (PSm), furthermore reduction in both variables was not uniform (club head speed: 15.8%, ball speed: 14.9%). This would be indicative of a less efficient transfer of energy from club head to the ball, possibly caused by the increased vertical club shaft angle at ball contact. The direction of this change was unexpected as it has previously been identified that the CoR of a golf ball increases as club head speed reduces (Hill, 2010; Penner, 2002) and so the club head speed would have been expected to be less than the theoretical 80% calculated. Conversely, it appears that greater than 80% of full club head speed is required to propel the ball to 80% distance. This finds support from Peacock et al. (2017), who identified a similar outcome when assessing submaximal kicks in Australian Rules Footballers. However, this finding should be treated cautiously, as the carry distance calculated by the Flightscope software is based on point to point displacement, rather than the full path of the ball flight, and so any fade or draw motion in the trajectory will not have been incorporated. This explanation is supported by a significantly longer measured flight time compared to theoretical (PSm: 4.55 ± 0.12 s, PSt: 4.29 ± 0.09 s, $p < 0.001$, $d = 0.70$), as increased flight time with a significantly lower than theoretically calculated peak height would suggest that the ball did not travel in a straight line. It could, therefore, be proposed that golfers alter not only the force applied within the shot, but also the flightpath of the ball, known as strategic shot selection (Langdown, Bridge, & Li, 2012).

Departing from the ball flight and outcome variables, the temporal and kinematic differences between the PS_m and PS_t exhibited further interesting variations. The total swing, back swing and down swing durations were all significantly longer for the PS_m condition when compared with the calculated PS_t. Furthermore, this duration of various segments of the swing demonstrated no statistically significant change from the full swing. This is in direct contradiction to previous work (Tinmark et al., 2010) that indicated a shorter downswing duration for full swings, although this could have been a direct result of the lower distances examined previously. However, previous findings were potentially limited, as clubs used for the full swing differed to those for the partial swings, and so recommendations from these findings would be to make swing duration comparisons only within club.

Contrasting to the findings between the full and PS_m conditions, the kinematic and kinetic assessment yielded only a single significant difference between PSm and PSs. Lead arm angle to the vertical was significantly higher in the PSm condition, indicating that trunk rotation was higher than predicted. Two of the centre of pressure variables approached significance, CoP ellipse ($p = 0.084$) and CoPx ($p = 0.064$), with the former reducing much more than expected (33.0%) from the full swing. These findings indicate that as initially suggested, golfers moderate a range of biomechanical variables of their full swing during the completion of partial swing shots. However, the percentage reduction in contribution across variables is not uniform; therefore, no claim of the partial swing being a scaled version of the full swing can be made and the second hypothesis must be rejected.

Limitations

This work is not without its limitations, as the golf swing is a 3D multi-planar movement, therefore, the use of a single camera in this study reduces the accuracy of the joint angle measures, due to out-of-plane movements. However, the exploratory nature of the study served to, beyond the central aim of the study, determine if further study, including 3D analysis, is warranted. Furthermore, and more importantly, the two dimensional assessment, used widely by golf coaches, provides a far more applied approach and applicability of these measures.

The protocol could also have been identified as a limiting factor, however the nature of the investigation, trying to determine if there are specific techniques, made the order of testing and the use of participant specific pitching wedges fundamental to the process. As the proportional distances under investigation required full swing distance to be measured first, before proportional distances could be calculated. While the use of participant specific pitching wedges stopped alteration of technique due to change in equipment and was maintained between testing conditions. Therefore, any alterations would be consistent across conditions and unlikely to cause biomechanical changes associated with the partial shot.

Conclusion

Participants demonstrated that performance of partial shots required reduction in centre of pressure motion, lateral shift, trunk rotation and stance width, however the magnitude of these reductions were not uniform across all measured variables. The main hypothesis that partial shots are different from full shots can be accepted. However, the secondary hypothesis that partial shots are scaled full shots, was not supported. Indeed, when performing partial shots participants did not use the same technique that they use for full shots; suggesting that golf coaches may consider dedicating time to training the partial shot as a separate golf skill although, veracity of this proposition would benefit from assessment of partial shots using three-dimensional kinematics. Further, golfers favoured the reduction of movements of the larger body segments i.e. the legs and hips, over the reduction of smaller body segments such as the arms and the wrists to reduce club head speed at impact and therefore shot carry distance. In this way, the swing maintains a proximal to distal pattern, being initiated by larger reductions in proximal segment contribution, causing a diminishing reduction in the more distal measures, although these were not proportional to the initial reduction. Finally, the accuracy of partial shots is not changed when compared to full swing shots; however, the variability of the measures indicates that golfers across the spectrum of golf handicaps can have issues with the performance of partial shots. Future work should attempt to identify optimal movement patterns that golfers can employ to improve relative accuracy in terms of partial shots and kinetic and kinematic differences between golfers with low and high PEI values for partial shots.

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'Table 1. Swing Measures Comparison'

Variable	*Full Swing*	*Measured 80%*	*Theoretical 80%*
Arm to vertical at top of backswing (°)	157.91 ± 7.38*	135.68 ± 7.33 (85.9%)	126.32 ± 5.90†
Wrist angle at address (°)	186.18 ± 1.83	185.48 ± 1.77 (99.6%)	-
Wrist angle at top of back swing (°)	96.93 ± 4.25	93.80 ± 6.34 (96.8%)	77.54 ± 3.40†
Wrist angle at Ball Contact (°)	180.66 ± 2.64	178.17 ± 2.57 (98.6%)	-
Lateral Shift (m)	0.07 ± 0.02*	0.06 ± 0.02 (74.5%)	0.06 ± 0.01
Stance Width (m)	0.48 ± 0.02*	0.45 ± 0.02 (95.3%)	-
Centre of Pressure Ellipse (m^2)	0.011 ± 0.001*	0.007 ± 0.001 (67.0%)	0.009 ± 0.001†

* denotes significant difference between full swing and measured 80% ; † denotes significance between measured 80% and theoretical 80%; alpha level = 0.05.

‘Table 2. Kinetic Ball Measures Comparison’

Variable	*Full Swing*	*Measured 80%*	*Theoretical 80%*
Carry (yards)	122.03 ± 5.32*	97.23 ± 3.93 (79.7%)	97.63 ± 4.26
Carry (m)	111.59 ± 4.87*	88.9 ± 3.6 (79.7%)	89.27 ± 3.89
Lateral Error (yards)	5.18 ± 0.44	4.43 ± 0.58 (85.5%)	4.14 ± 0.36
Lateral Error (m)	4.73 ± 0.41	4.05 ± 0.53 (85.5%)	3.79 ± 0.32
Percentage Error Index (%)	4.35 ± 0.40	4.51 ± 0.70 (103.7%)	3.48 ± 0.32
Ball Speed (mph)	92.89 ± 2.88*	79.01 ± 2.33 (85.1%)	74.31 ± 2.30†
Ball Speed (m/s)	41.53 ± 1.29*	35.32 ± 1.04 (85.1%)	33.22 ± 1.03†
Club Head Speed (mph)	75.46 ± 1.79*	63.56 ± 1.61 (84.2%)	60.37 ± 1.43†
Club Head Speed (m/s)	33.73 ± 0.80*	28.41 ± 0.72 (84.2%)	26.99 ± 0.64†
Spin (rpm)	6559.17 ± 148.36	6628.47 ± 111.67 (101.1%)	5247.34 ± 118.69†
Flight Time (s)	5.36 ± 0.11*	4.55 ± 0.12 (84.9%)	4.29 ± 0.09†
Club Path (°)	5.27 ± 0.67	4.55 ± 0.77 (86.2%)	-
Club Shaft angle(°)	62.81 ± 0.86	64.99 ± 0.66 (103.5%)	-
Launch Angle (°)	25.98 ± 0.67	26.36 ± 0.75 (101.5%)	-
Peak Height (m)	79.79 ± 3.19*	56.90 ± 2.55 (71.3%)	63.83 ± 2.55
Angle of Attack (°)	-5.16 ± 0.56	-4.29 ± 0.65 (83.2%)	-

* denotes significant difference between full swing and measured 80% ; † denotes significance between measured 80% and theoretical 80%; alpha level = 0.05. Percentage in brackets denotes the PS_m of the full swing.

Figure 1. Centre of pressure motion across swings conditions.

Figure 2. Temporal durations for back, down and full swing phases across swing conditions.

Figure 3. Graphical depiction of diminishing changes in the partial swing in comparison to the full swing.