

Associations between Physical Performance and Golf Shot Data: A Pilot Study of Touring Professional Female Players

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Abstract

This study examined the relationship between a comprehensive physical testing battery and golf shot data in touring professional female golfers. Nineteen players (age: 31.00 ± 5.64 years; height: 170.84 ± 7.24 cm; body mass: 67.74 ± 9.16 kg; wingspan: 127.37 ± 14.21 cm) volunteered to take part in the study. Each player completed a dynamic warm up, prior to engaging in a 90-minute testing session which gathered information on both physical capacity and golf shot data, all of which was collected at a single Ladies European Tour event. Golf shot data included: clubhead speed (CHS), ball speed, carry distance and smash factor, using a Trackman 4 launch monitor. Physical testing included: anthropometry data, seated thoracic rotation, isometric mid-thigh pull (IMTP), isometric bench press, countermovement jump (CMJ), and seated medicine ball throws for distance. Pearsons r correlations showed the CMJ to have the strongest and most consistent associations with golf shot performance ($r = 0.51$ - 0.60). Additionally, force at 100 ms during the IMTP also demonstrated large associations with carry distance ($r = 0.59$), further highlighting the significance of rapid force production in the lower body. Collectively, the findings demonstrate the importance of lower body ballistic force production for female golfers, providing important information for practitioners regarding the relevant physical capacities for testing and training.

Key Words: Women's golf; tour professionals; strength and conditioning; golf shot metrics

Introduction

Golf is a popular sport that is underpinned by skill, with the primary aim to complete 18-holes in as few shots as possible (10). Through consistently achieving lower scores, a reduction in golfing handicap (which is a shot allowance system) can be achieved and serves as an indicator of skill level for amateur players (5,7). At the professional and elite amateur level, players utilise no handicap system and compete against the ‘par of the course’ to achieve a gross score each round (3). In the last 20 years or so, performance science in golf has developed dramatically, which is largely driven by the increased amount of data that can be captured. For example, a concept called ‘Strokes Gained’ (9) measures the impact of golf shots throughout the round, based on starting location and final proximity to the hole. Specifically, previous literature has shown that a 20-yard improvement in distance off the tee, equates to saving 0.75 strokes per round in PGA Tour players (10). Additionally, the concept of strokes gained (and therefore the benefits) becomes magnified when applied to amateur players (10). With such information highlighting the competitive advantage that can be obtained from hitting the ball further, there has been a big cultural shift in understanding how to maximise physical development for golfers (14), given its contribution to aspects like clubhead speed (CHS) and shot distance (3).

Historically, golf is not a sport with a strong tradition of strength and conditioning (S&C) training. However, recent reviews from Ehlert (16), Brennan et al. (8), and Robinson et al. (29), indicate that improving physical capacities represent low hanging fruit for many golfers. Specifically, with respect to lower body strength, Oranchuk et al. (25) found a large correlation ($r = 0.64$) between one repetition maximum (1RM) back squat and CHS in collegiate male golfers. In contrast, Leary et al. (23) reported small, non-significant associations between peak force during the isometric mid-thigh pull (IMTP) and both average CHS ($r = 0.19$) and maximal CHS ($r = 0.20$). For lower body explosive strength, Brennan et al. (7) reported large

associations between countermovement jump (CMJ) height and CHS ($r = 0.73$), ball speed ($r = 0.82$), and carry distance ($r = 0.82$) in high-level amateur golfers. Similar findings were found in the CMJ for the metrics of positive impulse and peak power with CHS ($r = 0.61$ – 0.79) (19,36,37). Conversely, Leary et al. (23) reported both jump height and peak power from the CMJ to show non-significant relationships with average CHS (jump height: $r = 0.20$; peak power: $r = 0.23$) and maximal CHS (jump height: $r = 0.25$; peak power: $r = 0.22$). Similarly, Coughlan et al. (13) reported trivial to small, non-significant relationships between CMJ height and CHS, in both male ($r = 0.11$) and female ($r = 0.02$) youth golfers. When focusing on the upper body, research demonstrates moderate to large correlations between upper body strength (1RM bench press) and CHS ($r = 0.50$), peak ball speed ($r = 0.61$), and average ball speed ($r = 0.62$) (21,33). More recently, Brennan et al. (7) found large relationships between CHS and peak force during the isometric bench press ($r = 0.76$), in addition to force at 200 ms ($r = 0.74$) and force at 300 ms ($r = 0.76$). Despite the somewhat conflicting evidence supporting the development of strength and explosive strength for golfers, all of the aforementioned studies were conducted in males. Due to the inherent biological differences between sexes, further research is needed to determine the magnitude of these relationships in female players.

To the best of the author team's knowledge, only four studies investigating the association between physical performance variables and golf performance have been conducted in female players. However, two of these have exhibited questionable methodologies, employing dubious (24) and somewhat reductionist (11) test measures which have focused on balance and isolated grip measures, respectively. Of the remaining two, Coughlan et al. (13) showed moderate to large relationships between CHS and CMJ peak power ($r = 0.60$), seated medicine ball throw for distance ($r = 0.35$), and rotational medicine ball throw for distance in both directions ($r = 0.56$ – 0.57). However, these test measures predominantly examined outcome measures-based data with only one study utilising more in-depth testing protocols in female players. Robinson

et al. (28) undertook a comprehensive physical testing battery in elite amateur female players, consisting of the CMJ, IMTP, isometric bench press, medicine ball throws, mobility and anthropometry measurements. When examining relationships with CHS, the data showed moderate to large associations with the IMTP ($r = 0.38$ to 0.62) and isometric bench press and CHS ($r = 0.48$ to 0.70), and trivial to large relationships with CMJ variables ($r = -0.11$ to 0.61). Although the evidence base is limited, it appears that both strength and explosive strength are important for amateur female golfers as well. However, this information is based off two empirical investigations and to date, no study has been conducted examining the relationships between physical performance measures and touring professional female players. This information is critical because such a study would be able to establish whether these associations hold up for players who are on tour for large parts of the year, with constraints in place for S&C training due to frequent travel schedules. Thus, the aim of this study was to examine the associations between a comprehensive physical testing battery and golf shot data in touring female professional golfers.

Methods

Experimental Approach to the Problem

The current study was based on similar, previous work in elite amateur female players (28). The participants completed all physical testing in a single session, lasting approximately 90 minutes. Physical testing took place over two consecutive days (Monday and Tuesday) at the KPMG Irish open; a Ladies European Tour (LET) event in 2024, within a well-equipped S&C gym owned by the Irish Rugby Football Union. Data collection for golf shots (with a driver) were also collected at the tournament on the driving range, which took place before any physical testing in an attempt to minimize fatigue being a factor. Prior to data collection,

participant's height (cm), body mass (kg) and wingspan (cm) were measured. Three trials were performed for physical testing and golf shot data in line with previous research (13,28), with a mean score for all trials calculated for subsequent data analysis.

Subjects

Nineteen female tour professional players (age: 31.00 ± 5.64 years; height: 170.84 ± 7.24 cm; body mass: 67.74 ± 9.16 kg; wingspan: 127.37 ± 14.21 cm) volunteered to participate in this study. All participants possessed LET membership and held their 'professional playing card' for the 2024 season and a minimum of three consecutive previous years. Players provided written informed consent prior to testing, with ethical approval provided by the *** deleted for peer review *** at *** deleted for peer review ***.

Procedures

Warm-Up

Before data collection took place, the Head of S&C on the LET took each player through a structured warm-up to fully prepare them for subsequent testing. The warm-up started with a series of dynamic stretches consisting of one set of 12 repetitions for the following exercises: forward and lateral lunges, forward and lateral hip swings, elbow to in-step with thoracic rotation, bodyweight squats and glute bridges, in line with previous golf research (3,28). Following this, players were provided with five minutes to undertake any additional warm-up activities. This ensured individual preferences were embedded, noting that testing occurred at a professional tournament and players may have additional routines that they believe to be an

important part of their pre-tournament preparation – a concept that has been previously applied in golf research (4,7,28).

Golf Shot Data

Testing took place on the driving range at the event, with data collected using each player's driver. Players were instructed to "hit the ball as hard as you can", whilst aiming for a consistent target on the driving range, in line with previous research (28). Players were told to use a self-directed tee height, using Titleist ProV1 golf balls for each shot, with a minimum of 90-seconds rest between each recorded shot. All data was collected utilising a TrackMan 4 launch monitor (Trackman, Vedbaek, Denmark), which is regarded as the most accurate launch monitor available in the field for golfers and one that all players were familiar with (4,6). CHS, ball speed, carry distance, and smash factor (calculated as ball speed ÷ CHS) were the selected metrics owing to previous research showing acceptable reliability both within (6) and between test sessions (4).

Seated Thoracic Rotation

When assessing thoracic rotation, the iPhone compass application has been reported as being a valid and accurate tool in comparison to other gold standard goniometers (17). Before testing, researchers demonstrated the movement, instructing participants to sit flat on a plyometric box (ensuring approximately 90° of flexion at the hips and knees), with feet firmly on the ground. A second researcher ensured alignment of both knees and hips during testing, to ensure consistency in procedures for all players. Players were then directed to cross their arms over their chest, sitting upright. The iPhone was placed between the T1 and T2 vertebrae of each participant, ensuring the iPhone read 0° on the compass app (28). The iPhone was held securely

against the participant, as they rotated in one direction at a time. Once a trial to the left (or right) was conducted, a trial for the other side was conducted until three trials were completed in both directions. Participants were allowed a 30-second rest period, before the next trial.

Countermovement Jump

To ensure a reliable and robust data set, twin force plates (ForceDecks, V.2, VALD, Brisbane, Australia) were utilised to assess the CMJ. As per guidelines from the manufacturer, force plates underwent standard calibration process, ensuring they were level on the ground. Researchers then confirmed that force plates had completed booting and zeroing, whilst entering pairing mode prior to assessment (28). The researchers then demonstrated the CMJ technique, whilst instructing participants to keep their hands on their hips for the duration of the jump, and perform the descent to a self-selected depth so that no moderations were made to natural jumping coordination patterns. Verbal cues of “jump as high as you can” were provided, ensuring consistent instructions given to all players. The collected metrics included: jump height (calculated using the impulse-momentum method), peak propulsive power (calculated by the peak instantaneous mechanical power applied to the system centre of mass during the propulsion phase), and positive impulse (calculated from the area underneath the force-time curve where force first rose above zero – the point when peak negative velocity of the centre of mass was reached, up to the point that force crossed back over zero and peak positive velocity of the centre of mass was subsequently reached) (36), all of which have previously shown moderate to large associations with golf shot data (8,28,36,37).

Seated Medicine Ball Throw

A 3-kg medicine ball was used to assess upper body ballistic power, with two researchers involved in the data collection. Prior to carrying out the test, a bench was set in an upright position (approximately 110°), with a tape measure parallel to the throwing direction. Participants were provided a demonstration, where the back was placed firmly against the bench, feet planted on the floor, and medicine ball held at chest height (13). From this position, participants propelled the medicine the ball in a ‘chest pass throw’ as far as they could, whilst keeping their back in contact with the bench. Any trial that was deemed technically inaccurate was considered void, and the trial was repeated after a 90-second rest period. Participants were provided with 90-seconds between trials.

Isometric Bench Press

Twin force plates were positioned directly underneath bench press at the end where the head was positioned. To ensure consistency throughout testing, researchers provided a demonstration of the technique, followed by verbal cues before and during the assessment (28). Participants were instructed to lie flat on the bench, beneath the bar, with their forearms positioned vertically. Researchers ensured that 90° flexion was achieved at the elbow, with the bar aligned over the mid-chest. Both demonstration and verbal cueing highlighted feet to remain on the floor, with no arching of the lower back throughout the test. Prior to data collection, subjects were provided with the opportunity to engage in three practice trials, whilst being asked to provide maximum effort on the final trial (28). Participants were then given a 5-second count down, followed by an instruction to “push as hard and as fast as you can against the bar” as per previous research within isometric testing (12,18), followed by a rest period of three minutes between each isometric effort. Peak force (the maximum force value in Newtons (N) recorded during the protocol) was collected, in addition to force at 100 ms and force at 200

ms time points on the force-time curve. These specific time points were replicated from previous golf research showing moderate to large associations with golf shot data in both high-level male (7) and female (28) players.

Isometric Mid-Thigh Pull

Testing was carried out on twin force plates, whilst the bar was initially positioned at a height that allowed players to mimic the start of the second pull position during the power clean (12). Specifically, the bar height was adapted for individuals to achieve optimum knee (125–145°) and hip (140–150°) flexion angles (1,2), with participants able to view demonstrations and the opportunity to engage in three practice trials, as per the isometric bench press. Verbal cueing included: “pull as hard and as fast as possible”, and if any countermovement was evident on the force–time curve by a value that exceeded five standard deviations (SD) of body mass, the trial was deemed void and repeated (26). As per the isometric bench press, three minutes rest was provided between trials, with peak force and force at 100 and 200 ms collected.

Statistical Analysis

Data were initially reported as means and standard deviations (SD) using Microsoft Excel. Normality of the data was confirmed using the Shapiro-Wilk test ($p > 0.05$), whilst within-session reliability was evaluated via a two-way random intraclass correlation coefficient (ICC) with absolute agreement and 95% confidence intervals (CI) and the coefficient of variation (CV). ICC values were interpreted in line with previous research by Koo and Li (22), whereby values < 0.5 = poor, $0.5–0.75$ = moderate, $0.75–0.9$ = good, and > 0.9 = excellent. Pearson’s r correlations were used to quantify the magnitude of relationships between golf shot data and physical capacity measures, with a scale of interpretation of: $0–0.09$ = trivial, $0.1–$

0.29 = small, 0.3–0.49 = moderate, 0.5–0.69 = large, 0.7–0.89 = very large, and ≥ 0.9 = nearly perfect (20). A median split analysis was carried out for the metric of CMJ positive impulse, splitting the sample into higher ($n = 10$) and lower ($n = 9$) sub-groups, and then between-group differences analysed for each golf shot measure. CMJ positive impulse was selected for this form of analysis due to it having the most consistent set of associations with golf shot data for the whole sample and acceptable reliability values. Median split differences were analysed using paired-samples t -tests, with statistical magnitude set at $p < 0.05$ and Hedges' g effect sizes (ES) with 95% CI were used to comprehend practical differences. ES data were interpreted as: $g < 0.35$ = trivial; 0.35-0.80 = small; 0.81-1.50 = moderate; and > 1.5 = large (27).

Results

Mean Data and Within-Session Reliability

Table 1 demonstrates the mean, SD and within-session reliability data for driver performance and physical attributes. ICC data for golf shot performance ranged from moderate to excellent (ICC range = 0.70-0.98), with the lowest ICC value for smash factor (ICC = 0.70) and the highest for CHS (ICC = 0.98). With regards to physical performance data, ICC values ranged from good to excellent (ICC range = 0.80-0.98), with the lowest value evident for force at 100 ms during the isometric bench press (ICC = 0.80) and the highest value for peak power and positive impulse during the CMJ (ICC = 0.98). With respect to CV values, force at 100 and 200 ms during both isometric assessments, exhibited noticeably greater measurement error than all other tests and metrics (CV range = 13.10-21.98%).

**** Insert Table 1 about here ****

Associations with Golf Shot Data

A heatmap has been designed and exhibited to highlight the magnitude of relationships between golf shot data and physical attributes (Figure 1). When examining associations between CHS and physical characteristics, relationships were trivial to small for anthropometric measures ($r = 0.05$ to 0.35), small to large for CMJ variables ($r = 0.10$ to 0.52), small for isometric bench press variables ($r = 0.10$ to 0.28), trivial to moderate for IMTP variables ($r = 0.03$ to 0.32), small for the medicine ball throw for distance ($r = 0.27$), and small to moderate for seated thoracic rotation ($r = 0.28$ to 0.32). For ball speed, associations with anthropometric measures were trivial to moderate ($r = -0.06$ to 0.34), small to large for CMJ variables ($r = 0.12$ to 0.51), small to moderate for isometric bench press variables ($r = 0.19$ to 0.38), trivial to moderate for IMTP variables ($r = 0.07$ to 0.37), small for the medicine ball throw for distance ($r = 0.24$), and moderate for seated thoracic rotation ($r = 0.36$ to 0.30).

For carry distance, associations with anthropometric measures were trivial to small ($r = -0.01$ to 0.14), large for CMJ variables ($r = 0.55$ to 0.60), small for isometric bench press variables ($r = 0.15$ to 0.25), small to large for IMTP variables ($r = 0.26$ to 0.59), moderate for the medicine ball throw for distance ($r = 0.30$), and trivial to small for seated thoracic rotation ($r = -0.07$ to 0.17). Finally, for smash factor, trivial relationships were evident with anthropometric measures ($r = -0.13$ to -0.31), trivial to small for CMJ variables ($r = -0.17$ to 0.03), small for the isometric bench press variables ($r = 0.21$ to 0.24), trivial to small for IMTP variables ($r = 0.05$ to 0.12), small for the medicine ball throw for distance ($r = -0.19$), and trivial for seated thoracic rotation ($r = -0.02$ to 0.06).

***** Insert Figure 1 about here *****

Median Split Analysis

Figure 2 shows the median split analysis for CMJ positive impulse and how this split translates to differences in CHS, ball speed, carry distance and smash factor. No significant differences ($p > 0.05$) were evident between groups; however, small to moderate practical differences were evident. The group with superior positive impulse in the CMJ showed moderate increases in: CHS ($g = 0.72 [-0.29, 1.72]$), ball speed ($g = 0.79 [-0.22, 1.80]$), and carry distance ($g = 0.80 [-0.21, 1.82]$). Smash factor showed small differences between groups ($g = 0.46 [-0.52, 1.44]$), with the group portraying superior positive impulse also recording higher smash factor values.

***** Insert Figure 2 about here *****

Discussion

The aim of the present study was to examine the associations between a comprehensive physical testing battery and golf shot data in touring female professional golfers. Results showed trivial to large associations between physical qualities and golf shot data. Carry distance displayed the largest relationships of all golf shot measures, which was with CMJ variables ($r = 0.55-0.60$). A median split analysis was also conducted, specifically for CMJ positive impulse (owing to it having the strongest associations with golf shot data), and showed that players who exhibited larger CMJ impulse also produced superior CHS ($g = 0.72$), ball speed ($g = 0.79$) and carry distance ($g = 0.80$).

In line with the work of Robinson et al. (28), which was conducted in high-level amateur female golfers, the present study's findings show that CMJ positive impulse exhibited some of the strongest and most consistent associations with golf shot performance ($r = 0.51-0.56$). This is also in agreement with previous research in male players (7,36,37). Previous literature has

outlined the importance of producing large amounts of force over short time frames (i.e., large impulses) in the golf swing (8), which in turn, contributes to higher CHS, ball speed and distance. With this in mind, proxy data that measure similar metrics, albeit from a physical assessment (i.e., impulse from a CMJ) are both likely and expected to be useful measures for support staff practitioners to monitor. Given the volume of literature that has shown large associations between measures of impulse and golf shot data (7,8,29,36,37), it seems that CMJ impulse is important, irrespective of whether practitioners are working with male or female players. Peak power also showed a similar relationship with carry distance ($r = 0.60$), which again, is unsurprising. With power being quantified as force multiplied by velocity, the golf swing generating force approximately seven times body mass (15), and swing speeds occurring close to 100 mph, it stands to reason that power would also be a metric with moderate to large associations with golf shot data; something which prior research has also shown (34).

In addition to the CMJ, force at 100 ms during the IMTP exhibited large relationships with carry distance ($r = 0.59$), emphasising the importance of rapid force production in the lower body for female golfers. Interestingly, both Robinson et al. (28) and Brennan et al. (7) noted similar findings in high-level female and male players, respectively. This may be explained by the duration of the golf swing. For example, Brennan et al. (8) reported the duration of the golf swing from address to impact is approximately one second. However, it has been reported that golfers typically take 0.2-0.3 seconds from the time centre of pressure begins to shift towards the lead leg, prior to the initiation of the downswing until impact (30,31). Furthermore, Turner et al. (35) highlighted that for maximal force production to be achieved, it may take a minimum of 0.4 seconds. Therefore, it seems plausible to suggest that golfers may not have enough time to produce maximal force, which is why rapid force production likely plays a more important role in effectively delivering the clubhead to the golf ball – a notion that recent meta-analytical data supports (8). Despite the large association with force at 100 ms during the IMTP, this was

also one of the metrics exhibiting noticeably higher variance ($CV = 21.98\%$). Thus, if practitioners choose to use the IMTP (and this individual metric), further familiarisation may be required to reduce the associated measurement error.

It should be acknowledged that many of the associations in the present study are relatively low, in comparison to previous studies in high-level female (28) and high-level male (7) players. This is likely due to the participant pool engaging in this research being part of the same cohort that completed a survey study at an earlier professional tour event in the 2024 season (30). Within the survey results, many players highlighted: *'fear of injury'*, *'I don't know how to do S&C safely'* and *'I only engage in S&C during the off-season'* as factors which hindered their involvement in regular S&C-based training. Thus, despite the participants in the current study possessing professional tour membership, some players are only engaging in S&C on an ad-hoc basis, and subsequently, likely have a low physical training age in comparison to professional athletes in other sports. Additionally, when viewing Figure 1, it becomes apparent that many of the relationships between physical measures and CHS or ball speed, are similar. Previous research has shown that metrics such as CHS and ball speed exhibit near perfect correlations over more than one test session ($r = 0.98-0.99$) (4); thus, similar associations between physical testing and these two golf proxy measures are to be expected. Interestingly though, the same study showed that carry distance also exhibited near perfect relationships with CHS ($r = 0.94-0.95$) and ball speed ($r = 0.97-0.98$) (4). However, in the present study carry distance showed noticeably larger associations with some physical measures (e.g., CMJ height and force at 100 ms during the IMTP). These discrepancies can be partly explained by two reasons. Firstly, the present investigation collected golf shot data outdoors, whereas Bishop et al. (4) collected data in an indoor biomechanics lab; thus, differences in data collection (and also results) should be somewhat expected. Given the Trackman launch monitor uses radar technology, numerous articles have suggested the technology to be superior outdoors (4,6).

Secondly, given the study design collected data over two consecutive days, any discrete changes in weather (e.g., wind direction and speed) may well have confounded the result of metrics such as carry distance, but perhaps not CHS. As a final point of consideration, it is also worth noting that smash factor showed the smallest correlations with physical testing data. Although this metric is a product of ball speed and CHS, it is a ratio, which means it is often subject to greater measurement error (4), (as shown by the noticeably lower ICC value in Table 1). Consequently, when a linear relationship is being determined, and one of the variables in question exhibits greater variability (as opposed to two relatively consistent variables), it stands to reason that magnitudes of correlation are detrimentally affected.

A median split analysis (Figure 2) was undertaken for the metric of CMJ positive impulse, and then data subsequently compared between high and low impulse groups for golf shot data. Although the differences in shot data did not reach statistical significance, this is likely a by-product of the relatively small sample size in each sub-group. Despite this limitation, this finding still offers support staff practitioners with meaningful information, with ES data showing that the larger impulse group also exhibited superior CHS, ball speed and carry distance ($g = 0.72-0.80$). This offers further supporting information that impulse is an important physical proxy measure in female golfers, and should be prioritised from both a testing and training standpoint.

Despite the present study being the first of its kind in female touring professionals, some limitations should be acknowledged. Firstly, all data was collected over a single time point; as is the nature of trying to gather data at a professional golf tournament. Where possible, it is recommended that future research collects data longitudinally throughout the golfing season which would provide a deeper understanding of physical performance data and whether any existing associations with golf shot data are repeatable over time in professional female players. Secondly, the sample size ($n = 19$) was small, hence we termed this a pilot study. Again, where

possible, future research should focus on gathering data from a larger participant pool, which would provide a more comprehensive insight on the relationships between physical capacity and golf shot data. Related to the point about sample size, the present study was conducted on European based professional players and professional players from North America or Asia may show different physical profiles; something future research should aim to address where possible. Finally, it would be remiss not to acknowledge that each player used their own driver in the present investigation, which has been custom fit for their own feel and ball flight characteristics. Whilst most fittings factor in maximizing carry distance as a key priority, other ball flight data such as spin rate and shot dispersion may also be factored in to driver fittings. This is especially relevant if these metrics are regarded as having a negative impact on a player's performance off the tee, which in turn, may actually detrimentally impact distance. Thus, we cannot discount individual driver characteristics impacting some of the associations reported in the present study.

Practical Applications

Given the small sample size in the present study, we have chosen to provide some suggestions for practitioners working in golf re: how to use such data on an individual basis – a concept which has been previously suggested to be important in an individual sport like golf (3). Figure 3 displays two golfers from the existing data set, with data portrayed relative to the rest of the participants in the study. Golfer one demonstrates high CHS, CMJ impulse and IMTP peak force values in comparison to the rest of the group. In contrast, their isometric bench press peak force value was average. Robinson et al. (28) found the isometric bench press showed the strongest associations of any physical tests in high-level female amateur players; thus, it seems logical that this would be a relevant physical attribute in professionals as well. With this in

408 mind, we would suggest that whilst all other physical key performance indicators (KPI's) are
409 maintained (or developed), a scenario like this for golfer one represents an opportunity to
410 consider improvements in upper body strength. In comparison, golfer two has poor values for
411 all KPI's. Thus, in this situation, it is fair to assume that a comprehensive approach to
412 improving upper and lower body strength and power represents a significant window of
413 opportunity, which would likely have a positive effect on shot data over time.

414

415 ***** Insert Figure 3 about here *****

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Table 1. Mean $\pm$ standard deviation (SD) data, coefficient of variation (CV) and intraclass correlation coefficients (ICC) with 95% confidence intervals (CI).

Test or Metric	Mean $\pm$ SD	CV (%)	ICC (95% CI)
<i>Golf Shot Data:</i>			
Clubhead Speed (mph)	97.49 $\pm$ 3.92	0.55	0.98 (0.96, 0.99)
Ball Speed (mph)	144.99 $\pm$ 5.36	0.68	0.97 (0.94, 0.98)
Carry Distance (yards)	238.58 $\pm$ 14.32	1.25	0.94 (0.88, 0.97)
Smash Factor	1.49 $\pm$ 0.02	0.63	0.70 (0.49, 0.84)
<i>Anthropometry:</i>			
Height (cm)	170.84 $\pm$ 7.24	-	-
Body Mass (kg)	67.74 $\pm$ 9.16	-	-
Wingspan (cm)	127.37 $\pm$ 14.21	-	-
<i>Countermovement Jump:</i>			
Jump Height (cm)	26.06 $\pm$ 4.61	2.49	0.97 (0.95, 0.99)
Peak Power (W)	2725.72 $\pm$ 392.35	1.70	0.98 (0.97, 0.99)
Positive Impulse (N·s)	231.35 $\pm$ 32.28	2.16	0.98 (0.96, 0.99)
<i>Isometric Bench Press:</i>			
Peak Force (N)	284.16 $\pm$ 127.79	8.99	0.97 (0.94, 0.98)
Force at 100 ms (N)	128.72 $\pm$ 65.00	20.72	0.80 (0.64, 0.90)
Force at 200 ms (N)	174.96 $\pm$ 73.81	13.35	0.91 (0.82, 0.96)
<i>Isometric Mid-Thigh Pull:</i>			
Peak Force (N)	1262.54 $\pm$ 283.90	6.40	0.93 (0.86, 0.96)
Force at 100 ms (N)	338.89 $\pm$ 204.51	21.98	0.84 (0.71, 0.92)
Force at 200 ms (N)	686.93 $\pm$ 222.95	13.10	0.81 (0.66, 0.90)
<i>Medicine Ball Throw:</i>			
Distance (m)	3.69 $\pm$ 0.42	4.14	0.86 (0.74, 0.93)
<i>Seated Thoracic Rotation:</i>			
Left (degrees)	58.14 $\pm$ 10.73	3.91	0.97 (0.94, 0.99)
Right (degrees)	55.60 $\pm$ 6.11	5.60	0.83 (0.69, 0.91)

		Clubhead Speed (mph)	Ball Speed (mph)	Carry Distance (yards)	Smash Factor
Anthropometry	Height (cm)	0.05	-0.06	0.10	-0.31
	Body Mass (kg)	0.35	0.34	0.14	-0.13
	Wingspan (cm)	0.02	-0.04	-0.01	-0.18
Countermovement Jump	Jump Height (cm)	0.10	0.12	0.55	0.03
	Peak Power (W)	0.42	0.45	0.60	-0.06
	Positive Impulse (N·s)	0.52	0.51	0.56	-0.17
Isometric Bench Press	Peak Force (N)	0.10	0.19	0.24	0.23
	Force at 100 ms (N)	0.17	0.27	0.25	0.24
	Force at 200 ms (N)	0.28	0.38	0.15	0.21
Isometric Mid-Thigh Pull	Peak Force (N)	0.03	0.07	0.26	0.12
	Force at 100 ms (N)	0.32	0.37	0.59	0.06
	Force at 200 ms (N)	0.20	0.24	0.45	0.05
Med Ball Throw	Distance (m)	0.27	0.24	0.30	-0.19
Mobility	Left Rotation (degrees)	0.32	0.36	0.17	0.06
	Right rotation (degrees)	0.28	0.30	-0.07	-0.02

Figure 1. Heatmap showing Pearson's r correlations between physical performance tests and golf shot data in 19 touring professional female golfers. *Note:* green = large correlation; yellow = moderate correlation; orange = small correlation; red = trivial correlation.

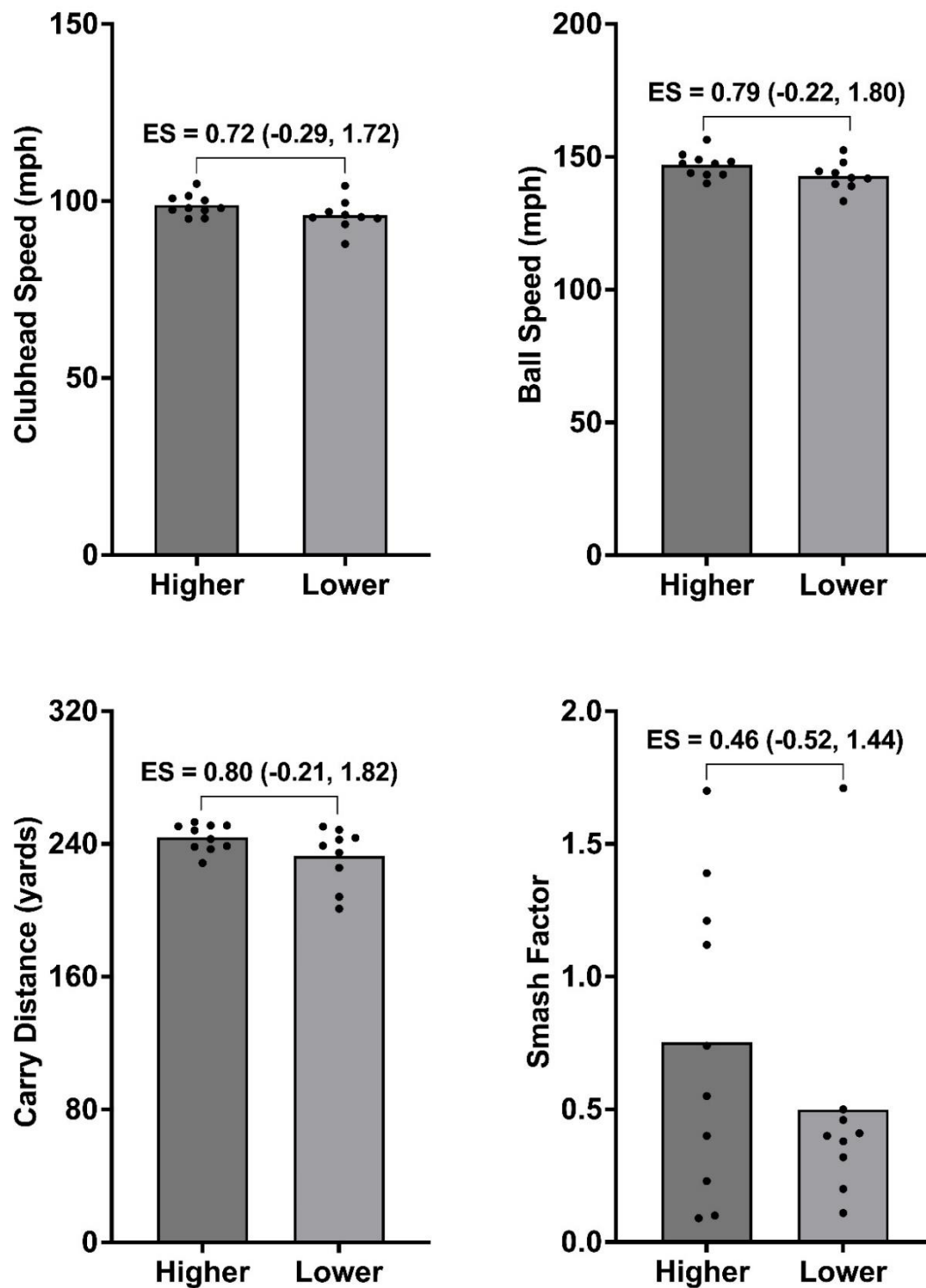


Figure 2. Practical differences in golf shot data, as shown by Hedges g effect sizes with 95% confidence intervals after a median split for positive impulse during the countermovement jump. *Note:* $n = 10$ for the higher group and $n = 9$ for the lower group.

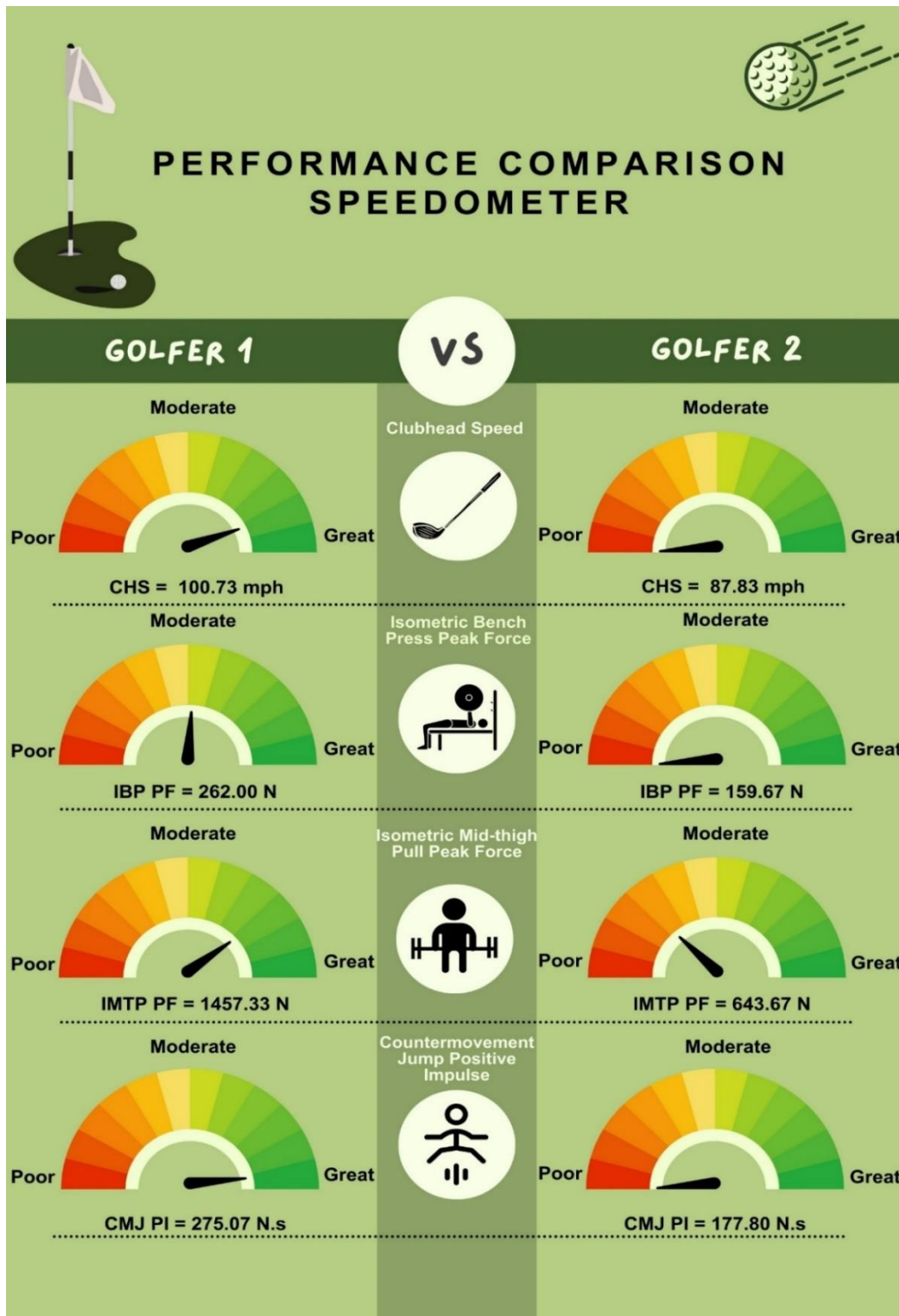


Figure 3. Schematic representation of two example golfers from the present sample. Golfer one who performs above average and golfer two who performs below average on all test measures. *Note:* CHS = clubhead speed; IBP PF = isometric bench press peak force; IMTP PF = isometric mid-thigh pull peak force; CMJ PI = countermovement jump positive impulse; mph = miles per hour; N = Newtons; N·s = Newton seconds.