

1 TITLE

2 Can the variance in DP World Tour Golfers' drive distance be predicted from kinetic variables
3 during a countermovement jump and isometric mid-thigh pull?

4 BRIEF RUNNING HEADER

5 Predicting drive distance from a countermovement jump and isometric mid-thigh pull.

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ABSTRACT

Over recent years a growing body of research has investigated the relationships clubhead velocity has with kinetic variables during a countermovement jump (CMJ) and isometric mid-thigh pull (IMTP). However, to date, no research has investigated the relationships these kinetic variables have with real-world drive distance (DD) in elite DP World Tour golfers. The purpose of this investigation was to assess if CMJ positive impulse (PI), CMJ net impulse (NI), IMTP peak force (PF), force at 200 ms, force at 250 ms and force at 300 ms could predict the variance in elite DP World Tour golfers DD during a real-world tournament season. Twenty-five DP World Tour golfers performed CMJs and IMTPs on force plates in a real-world setting, with DD assessed using DP World Tour statistics. Hierarchical multiple regression analysis was employed to assess if kinetic variables significantly predicted the variance in DP World Tour Golfers' DD. Statistical significance for this investigation was set at $p \leq 0.05$ with effect size determined using the f^2 statistic. The results of the investigation note that model two (CMJ PI and CMJ NI) significantly predicted ($R^2=0.279$, $p \leq 0.05$) the variance in DP World Tour Golfers' DD and was considered a large effect size ($f^2 = 0.39$). These findings support the use of CMJ PI and CMJ NI when physically profiling elite golfers. In addition, strength and conditioning practitioners should consider utilising modalities aimed at increasing CMJ impulse when working with golfers.

Key words

Golf, strength and conditioning, impulse, peak force.

INTRODUCTION

In recent years, there has been a growing interest from golfers to increase their drive distance (DD) as this is linked to success within the game. For instance, PGA Tour players who hit the ball over greater distances (Par-4 fairway average = 280.0 yards, Par-5 fairway average = 293.1 yards [converted from meters to yards]) are significantly more likely to achieve lower scores on Par-4 and Par -5 holes (20). In addition, DP World Tour golfers who hit the ball over greater distances (2017 average = 291.5 yards, 2018 average = 294.7 yards, 2019 average = 294.8 yards) have shown significantly lower scoring on par-5 holes during the 2017 to 2019 seasons (4). These findings are supported by Broadie (7), who noted that PGA Tour professionals who drive the ball 20-yards further, typically save 0.75 shots per round. Given this equates to 3 shots over a 4-day tournament, this would have made the difference between winning (Ryan Fox: €1,435,857.57) and placing 5th (Viktor Hovland: €358,119.77) at the 2023 BMW PGA Championship (32).

Given that DD is a performance determining factor, a number of investigations have utilised this as a performance measure within their research designs (5, 14). With respect to impact factors, research has highlighted that the greatest determinants of DD are clubhead velocity (CHV) ($\beta = 0.757$) and centredness of strike ($\beta = -0.266$) (measured in cm away from the centre of the face) (3). Given the conservation of momentum principle, greater CHV (assuming no change in centredness of strike), would increase the momentum, and therefore velocity of the golf ball, thus enabling greater shot distance. Given that centredness of strike can be a confounding variable, research has traditionally utilised CHV as a dependent variable when measuring less-skilled golfers (22). However, when working with elite players, such as DP World Tour professional golfers, it could be argued that DD is preferential given that it is an ecologically valid measure of

golf performance. Further still, Betzler et al., (2) noted that highly-skilled players (handicap ≤ 5.4) achieve a more centred strike (7.86 ± 5.54 mm) when compared to less skilled players (handicap ≥ 21) (11.21 ± 7.67 mm). As such, utilising DD as a dependent variable appears entirely appropriate when assessing DP World Tour players since their skill level negates for issues around centredness of strike.

From a mechanistic standpoint, to increase DD, there needs to be an increase in the momentum ($mass \times velocity$) imparted from the clubhead to the ball. Although the mass of the clubhead can be manipulated through custom fitting, attaining greater momentum is typically achieved through increasing CHV. Impulse ($force \times time$) is directly proportional to the change in momentum, which a golfer can therefore manipulate through increasing the application of force, or increasing the time in which average force acts. Indeed, recent research has highlighted that at the point between the mid-backswing (club horizontal to the ground) and late backswing (club vertical), highly-skilled golfers apply ground reaction forces (GRF) to reverse their momentum back towards the target (19). Newton's First Law of Inertia dictates that in order to change the velocity of an object, we need to produce an external force or torque, and to do this, the golfer needs to apply a contact force to the ground (23). As such, the interaction between the ground and the golfer is of great importance for developing DD. Although GRFs work in all three principal directions, the greatest magnitude is in the vertical direction, which can be extremely large for golfers with high CHV (23). Further to this, research has reported significant relationships between peak vertical GRFs during the swing and CHV in highly-skilled golfers ($r = 0.327$, $p < 0.05$) (19). This is likely due to the ability to increase frontal plane torque, which has also been shown to significantly relate to

CHV ($r = 0.319, p < 0.05$) (19). As such, physically profiling golfers utilising vertically orientated tasks would appear both logical and appropriate.

Previous research has reported a strong significant relationship ($r = 0.54, p < 0.01$) between a 1-repetition maximum (RM) back squat and CHV (21). In support, Parchmann and McBride (29) noted a strong significant relationship ($r = 0.805, p < 0.05$) between a relative 1-RM back squat and CHV. Although these field-based procedures appear insightful on face value, there are a number of important considerations which may affect their application with professional golfers. Firstly, the load lifted in a RM is dependent on both skill and capacity. For instance, if a golfer has poor technical ability in an exercise like the back squat, this is likely to affect the load lifted. This also places large emphasis on the requirement for numerous familiarisation sessions which are unfeasible when working in elite sports. Additionally, a RM test can take a substantial amount of time to administer and is fatiguing (31), neither of which are conducive to performing physical profiling assessments during tournament conditions. However, the use of an isometric mid-thigh pull (IMTP) provides an opportunity to physically profile golfers since this has a strong positive correlation with 1-RM back squats ($r = 0.97, p < 0.05$) (24) and is also likely to require substantially less skill. Indeed, recent research has reported a significant relationship between CHV and IMTP peak force (PF) in highly-skilled golfers ($r = 0.482, p < 0.01$) (34). To date, however, there is no research that has assessed the relationship between DD during tournament play and IMTP PF in professional tournament golfers.

When considering the application of vertical ground reaction forces during the downswing, there appears to be a rapid rise in these forces (in the lead leg) ~250-300 ms prior to impact (19). Further

still, for the combined forces (lead and trail leg), this increase in vertical ground reaction forces is observed from ~200 ms prior to impact (19). Assessing the force producing capabilities within these time points and their relationships with DD would therefore be insightful. Using an IMTP, previous research has noted moderate and strong relationships between carry distance and force at 200 ms ($r = 0.48$) and force at 300 ms ($r = 0.61$), respectively (5). To date, however, no research has sought to assess the predictive ability of these variables within elite level golfers.

In addition to isometric testing, the use of a countermovement jump (CMJ) has received considerable attention when seeking to physically profile golfers within both laboratory and field-based settings (30, 34). Hellström (21) and Read et al., (30) noted significant relationships between CHV and both CMJ peak power and jump height. However, these field-based assessment are limited in their analysis and application. For example, jump height is confounded by the mass of the golfer (35), therefore changes in jump height could be due to fluctuations in mass throughout a tournament season. Additionally, despite the widespread use of peak power within golf research, it is important to recognise that this is an instantaneous variable representing a small moment in time. Indeed, a growing body of research has questioned the use of power as a physical profiling variable given that this fails to directly determine motion, whereas impulse does (36). Wells et al., (35) reported strong significant relationships between $n = 50$ highly-skilled golfers' CHV and CMJ positive impulse (PI) ($r = 0.695$, $p < 0.001$) and net impulse (NI) ($r = 0.689$, $p < 0.001$). However, there is currently no published evidence assessing the relationship between DD during tournament play and CMJ performance in professional golfers. Investigating the associations that CMJ PI, CMJ NI, IMTP PF, IMTP force at 200 ms, force at 250 ms and force at 300 ms have with DP World Tour Golfers' DD will better inform the physical assessment and application of strength

and conditioning (S&C) to elite level golfers. Therefore, the purpose of this investigation was to assess if the variance in elite DP World Tour golfers DD during a real-world tournament season could be predicted by CMJ PI, CMJ NI, IMTP PF, IMTP force at 200 ms, force at 250 ms and force at 300 ms.

METHODS

Experimental Approach to the Problem

A cross-sectional study design was used to assess if kinetic variables during a CMJ and IMTP could predict the variance in elite DP World Tour Golfers DD. Impulse in a CMJ and PF, force at 200 ms, force at 250 ms and force at 200 during an IMTP were employed as predictor variables given that these procedures have been used previously with golfers (5, 33, 34, 35). DD was employed as the criterion variable since this represents an externally valid and real-world performance outcome for DP World Tour Golfers. This investigation was conducted with professional DP World Tour golfers during the 2019-2020 seasons. The DP World Tour is a professional golf tour involving tournaments in over 15 countries and across various continents including Asia, Africa and Europe. All kinetic variables during the IMTP and CMJ were collected by DP World Tour S&C staff who were trained in the appropriate procedures. After collection, the DP World Tour combined the IMTP and CMJ data with online DD data which was anonymised and then provided to the lead author for analysis.

Subjects

Twenty-five male elite DP World Tour golfers (age: 30.04 ± 5.34 years, height: 1.82 ± 0.07 m, mass: 82.17 ± 6.99 kg, professional career experience: 9.41 ± 5.16 years) were included in this investigation. An a priori power analysis (G*Power, version 3.1.9.7, University of Dusseldorf, Germany) was conducted and showed that with an f^2 effect size of 0.28, an alpha level of 0.05, statistical power of 0.80 and six predictor variables, a total of 24 golfers were required (12). All subjects were injury free and provided informed consent prior to engaging in this research. Ethical approval was granted by the University's Research Ethics Committee.

Data collection occurred during the 2019 (November 2018 - November 2019) and 2020 (November 2019 - November 2020) DP World Tour seasons. Due to the nature of the DP World Tour season and working alongside professional athletes, some golfers engaged with multiple test sessions throughout the season, up to a maximum of three. For players who were tested more than once over the two seasons, the earliest dataset was included (and all others excluded) in order to ensure each subject's level of experience with these tests remained standardised.

Procedures

Data collection was conducted in the European Tour Performance Institute (ETPI) unit which is a bespoke service transported to each event. As part of the service offered by the ETPI, players were invited to engage in physical profiling measures including the IMTP and a CMJ as part of their usual support. During profiling, each procedure was undertaken by experienced members of the DP World Tour S&C team. In order to ensure familiarization with procedures, a training day was provided to educate practitioners on physical profiling procedures. These procedures were based

on previous research with elite-level golfers (33). Prior to data collection, subjects performed a self-directed warm-up. Both IMTP and CMJ tests occurred on the same day, and the order of tests remained consistent throughout, with IMTP performed first. The CMJ and IMTP were recorded on dual PASCO Scientific force plates (PASCO Scientific 2141, California, USA) sampling at 1000Hz. Previous research has supported the validity of the PASCO Scientific plates when compared to gold-standard measures (33). Prior to data collection, subjects were provided with a demonstration and standardised verbal instruction. A total of three recorded attempts were completed for both IMTP and CMJ, with the highest values taken forward for analysis.

Isometric mid-thigh pull

Testing was conducted using a squat rack (Elite Sport Performance, ESP, United Kingdom), customised by inverting the J-hooks, with the bar held in place with resistance bands. The squat rack was secured to the ground by bolts in order to ensure no movement occurred during testing. Subjects were placed into their individual second-pull position of the clean, as this position has been shown to attain the greatest force output (16). Hands were secured using lifting straps to facilitate maximum effort without grip restrictions. Prior to data collection, each subject performed a sub-maximal trial to ensure familiarisation. Subjects were instructed to pull the bar as “hard and as fast as possible”, completing a 5-second maximal isometric effort (17, 34). Between efforts, subjects rested for three-minutes, but remained attached to the bar to ensure consistent hand positioning throughout (34). Researchers carefully observed the technique of the subjects in order to ensure a countermovement was avoided. If the subjects performed a countermovement, the trial was repeated up to a maximum number of three attempts.

Countermovement jumps

The CMJs were performed with the feet hip-width apart and hands placed on their hips. Subjects were instructed to stand as still as possible to ensure the ‘weighing’ phase of the jump accurately determined body weight (25). Each CMJ was initiated with the subjects stood upright, before lowering themselves down into a self-determined squat depth with the instruction to jump ‘as high and as fast as possible’ on the command ‘3, 2, 1, jump’. The participants initiated the downward phase of the CMJ following the word ‘jump’, with the force plates sampling at least one second before this movement. This was to ensure that there was at least one second of ‘quiet time’ in order to accurately determine the first meaningful change in force. Each CMJ was separated by a two-minute rest interval (34). Subjects were able to take up to three sub-maximal practice jumps to ensure an appropriate technique was achieved.

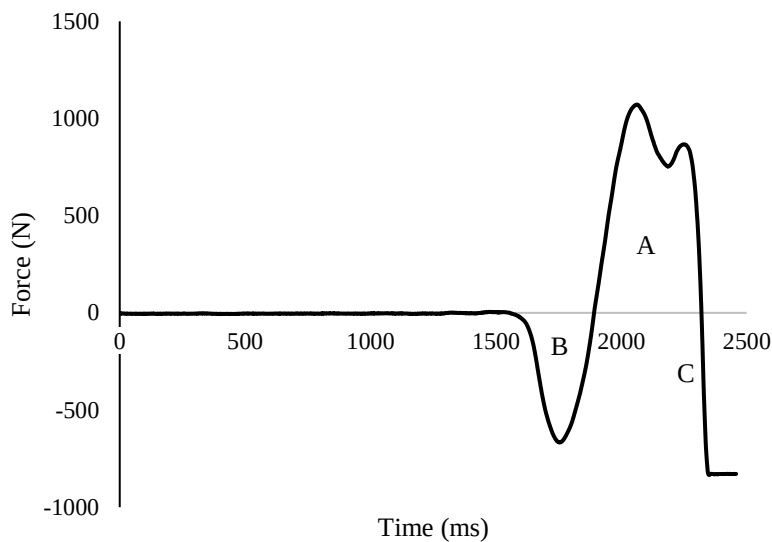
Driving distance

The DP World Tour website database (<https://www.europeantour.com/dpworld-tour/>) was accessed to collect each players’ average DD’s for both the 2019 and 2020 seasons. DD was attained using ShotTracker, which is used by the DP World Tour to track each shot distance hit by the players. The average DD included for a given subject was taken from the same season in which the first CMJ and IMTP data was collected.

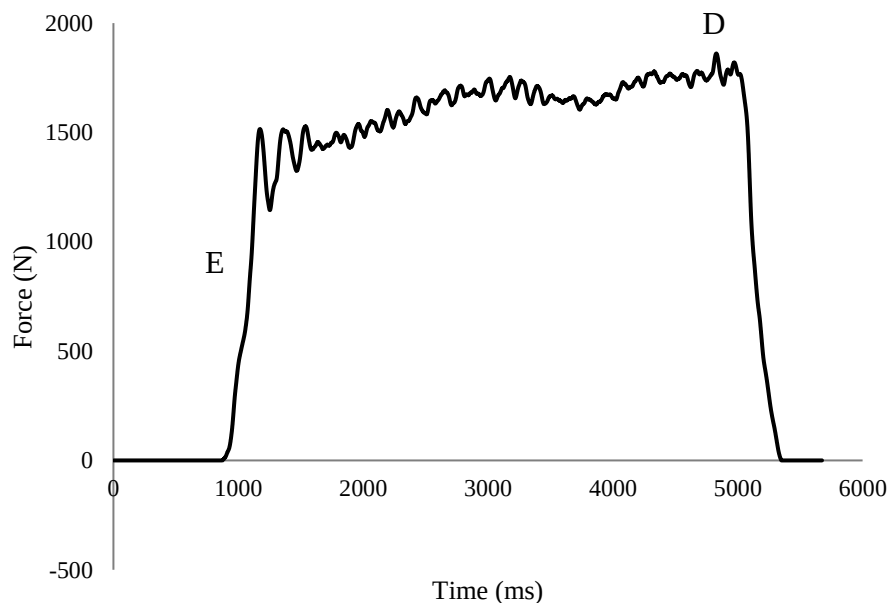
Data analysis

Countermovement jump: The initiation of the unweighting phase in the CMJ was determined using a 10N shift from baseline. Impulse was calculated by the summation of each force-time integral using the trapezoid rule. PI for the CMJ was calculated from the area underneath the force-time curve (above baseline) where force first rose above zero up until the point that force crossed back over zero. These phases represent the time point when peak negative (downward) velocity of the COM is reached, and peak positive (upward) velocity of the COM is reached (Figure 1: area A) (25). NI was calculated from the area underneath the force-time curve (PI), minus the area below baseline from the initiation of unweighting until take-off (Figure 1: area's B and C). Both PI and NI were calculated from the net force, which excludes the vertical GRFs generated by the system weight (27). Peak data for both NI and PI were taken forward for statistical analysis.

Isometric mid-thigh pull: PF was calculated as the greatest force value achieved during the 5-second period (Figure 2: point D), minus system weight (absolute PF) (18). Force at 200 ms, force at 250 ms and 300 ms were measured with system weight removed (Figure 2: point E). For each of the metrics analysed, the peak values were taken forward for statistical analysis.



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 271 Figure 1: A countermovement jump force-time curve. The letter A represents the area of the curve used to
 272 calculate PI. The letters B and C represent the areas below baseline which were subtracted from PI to
 273 calculate NI (i.e. $A - [B + C]$).
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275
 276 Figure 2: Isometric mid-thigh pull force-time curve. The letter D represents PF whereas E reflects the
 277 gradient used to measure force at 200 ms, 250 ms and 300 ms.

Statistical analyses

Within-session reliability was calculated using the coefficient of variation (CV) and their respective 95% confidence intervals, with acceptable reliability deemed when CV values were $\leq 10\%$ (9). Data were analysed using a multiple regression using hierarchical analysis based on the findings of previous research (33, 34). All data analysis was completed using IBM SPSS (version 29.0; Chicago, USA), with statistical significance set at $p \leq 0.05$. Owing to the issues with solely analysing the p value, effect sizes were calculated using the f^2 statistic (8), using the equation: $f^2 = R^2 / 1 - R^2$, with the size of the effect determined as ≥ 0.02 = small, ≥ 0.15 = moderate and ≥ 0.35 = large (8). The assumption of independent errors and multicollinearity were assessed using the Durban-Watson statistic and Tolerance diagnostics respectively. A Pearson correlation of $r = >0.80$ between predictor variables (13) and Tolerance below 0.2 (26) were used as indicators of multicollinearity. The fit of each regression model was assessed using Akaike's information criterion (AIC).

RESULTS

All statistical assumptions were met within the data. Descriptive statistics and correlations between DD and the kinetic variables are displayed in Table 1. High reliability levels were noted for CMJ PI, CMJ NI and IMTP PF. Force at 200 ms was deemed unreliable, whereas force at 250 ms and force at 300 ms were both considered acceptable. The results from this investigation show a significant correlation between DD and both CMJ PI ($r = 0.461$, $p=0.01$) and CMJ NI ($r = 0.431$, $p=0.016$) (see Table 1). There was no significant correlation between DD and IMTP PF, force at 200 ms, force at 250 ms and force at 300 ms (see Table 1). Owing to issues surrounding

multicollinearity, careful consideration was made on the variables added to the regression model. Given that 200 ms failed to meet acceptable reliability, this was omitted from the regression. In addition, Pearsons' correlation noted very strong relationships ($r = 0.926$) between force at 250 ms and force at 300 ms. As such, given that DD had the larger relationship with force at 250 ms, this was added to the regression model. Multiple regression analysis noted that model one (CMJ PI) significantly predicted the variance in DP World Tour Golfer's DD ($R^2 = 0.212$, $p=0.02$) presenting a moderate effect size ($f^2 = 0.27$). Model two (CMJ PI and CMJ NI) significantly predicted the variance in DD ($R^2 = 0.278$, $p=0.028$) indicating a large effect ($f^2 = 0.39$). Furthermore, model three (CMJ PI, CMJ NI, force at 250 ms) significantly predicted the variance in DD ($R^2 = 0.328$, $p=0.036$) with a large effect size ($f^2 = 0.49$). When IMTP PF was added in model four, this was not statistically significant ($R^2 = 0.329$, $p=0.079$) but represented a large effect size ($f^2 = 0.49$). When considering the fit of each of the models, AIC determined that model two was the best.

Table 1: Descriptive statistics for each variable, alongside the correlation coefficient (r) between DD and the kinetic variables, and their respective 95% confidence intervals (CI).

Variable	Min	Max	Mean	SD	CV%	95% CI for CV		r
						Lower	Upper	
DD (Yards)	-	-	295.86	11.71	-	-	-	-
IMTP PF (N)	1443.19	2862.11	1991.32	380.17	3.32	2.14	4.12	0.220
Force at 200ms (N)	194.96	1834.98	1188.07	398.22	13.38	9.23	17.53	0.290
Force at 250 ms (N)	526.22	2005.85	1336.57	374.71	9.71	5.09	14.32	0.265
Force at 300 ms (N)	626.64	2143.54	1429.83	352.44	9.38	3.72	15.04	0.237
CMJ PI (N.s)	269.38	366.80	320.88	25.94	4.41	3.47	5.45	0.461*
CMJ NI (N.s)	177.46	293.85	218.15	23.69	5.51	2.81	8.21	0.431*

Note: DD minimum and maximum values were excluded to protect player anonymity. * $p < 0.05$

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355 **Table 2:** Linear model for the predictors of DD presenting the R^2 , unstandardized beta coefficients
356 (b) and their respective 95% confidence intervals (CI), standard errors (SE B) the standardised
357 beta (β) coefficients, and the tolerance for each predictor within the four models.

		95% CI						
Model		R^2	b	Lower	Upper	SE B	β	Tolerance
1	Constant	0.212*	229.089	173.464	284.714	26.889		
	CMJ PI		0.208	0.035	0.381	0.084	0.461*	1.000
2	Constant	0.278*	216.337	158.625	274.726	27.828		
	CMJ PI		0.152	-0.036	0.341	0.091	0.337	0.811
	CMJ NI		0.141	-0.066	0.347	0.099	0.284	0.811
3	Constant	0.328*	210.621	152.702	268.539	27.851		
	CMJ PI		0.135	-0.053	0.324	0.091	0.300	0.793
	CMJ NI		0.149	-0.056	0.354	0.098	0.301	0.807
	Force @ 250 ms		0.007	-0.005	0.018	0.006	0.227	0.978
4	Constant	0.329	211.072	151.347	270.796	28.632		
	CMJ PI		0.139	-0.059	0.338	0.095	0.308	0.754
	CMJ NI		0.149	-0.062	0.359	0.101	0.301	0.807
	Force @ 250 ms		0.008	-0.008	0.023	0.007	0.253	0.583
	IMTP PF		-0.001	-0.017	0.014	0.008	-0.043	0.553

358 Note: $R^2 = 0.212$ for step 1 ($p=0.02$), $\Delta R^2 = 0.066$ for step 2, $\Delta R^2 = 0.050$ for step 3, $\Delta R^2 = 0.001$
359 for step 4 * $p < 0.05$
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DISCUSSION

The aims of this investigation were to assess if kinetic variables during a CMJ and IMTP in a real-life setting could predict the variance in elite DP World Tour golfers DD. The results showed that the assessment of CMJ PI, CMJ NI and IMTP PF presented high intra-session reliability, which supports the use of these methods for physically profiling DP World Tour golfers. However, reliability for force at specific time intervals presented mixed results. Force at 200 ms was considered unreliable (CV = 13.38%), whereas force at 250 ms (CV = 9.71%) and force at 300 ms (CV = 9.38%) presented acceptable reliability. The reader should be cognisant to the 95% CIs given the upper bound limits were larger than the 10% threshold (see Table 1). The CV% for CMJ PI, CMJ NI, IMTP PF and force at specific time intervals are similar to that of previous research assessing golfers' (CMJ PI: CV = 1.79%, CMJ NI: CV = 1.93%, IMTP PF: CV = 4.09%, force at 200 ms: CV = 10.85%, force at 300 ms; CV = 6.02%) (5, 34, 35) under laboratory conditions. Pearson's correlation analysis (Table 1) noted significant relationships between DP World Tour golfers DD with both CMJ PI and CMJ NI, but not IMTP PF, force at 200 ms, force at 250 ms and force at 300 ms. Multiple regression analysis indicated that model one significantly predicted the variance in DP World Tour Golfers DD. Specifically CMJ PI accounted for 21.2% of the variance in DP World Tour golfers DD which was determined as a moderate effect ($f^2 = 0.27$). When CMJ NI was added, model two significantly accounted for 27.8% of the variance in DD and was deemed to be a large effect ($f^2 = 0.39$). The addition of force at 250 ms to the model significantly accounted for 32.8% of the variance in DD, representing a large effect size ($f^2 = 0.49$). Model four, which saw the addition of IMTP PF, failed to predict the variance in DP World Tour Golfers' DD. When considering the overall regression models, AIC indicated that model two was the best fit.

To increase DD, greater momentum needs to be imparted from the club to the ball. Assuming no adverse changes in centredness of strike, increasing momentum of the clubhead at impact will cause the golf ball to attain greater momentum due to a direct change in velocity. Given the impulse-momentum relationship, a golfer can increase their momentum by increasing the application of GRFs or increasing the time in which these forces act. Increasing the application of impulse during the downswing would facilitate frontal plane torque, which has been observed to significantly related to CHV (19). Mechanistically, this rationalises the findings between CMJ impulse and DD within the current investigation. These findings are also supported by that of Wells et al., (35) who noted that CHV has a strong significant relationship with both CMJ PI and CMJ NI within highly-skilled golfers.

When CMJ NI was added to model two, this significantly predicted the variance in DD and was considered as a large effect size ($f^2 = 0.39$). The key difference when comparing these impulse variables is that net impulse subtracts the area under the force-time curve from the area above it. During a CMJ, the initial unweighting phase causes force to drop to its vertex before rising back to zero. This area of the force-time curve represents negative momentum applied to the golfers' COM, thus causing negative displacement. This is of interest given that peak negative (unweighting) and peak positive (upwards) vertical ground reaction forces during the swing have been observed to significantly relate to CHV (19). Theoretically, an increase in force (assuming no change in time) would lead to a greater impulse within the swing. From a practical standpoint, the predictive ability of CMJ impulse on DD is of great value to the applied practitioner. For instance, Wells et al., (35) presented equations whereby CMJ NI can be attained through measuring a golfer's jump height and mass. From establishing jump height, inverse dynamics can be applied

to calculate take-off velocity, which, when multiplied by body mass, would equate to CMJ momentum. Since impulse is directly proportional to the change in momentum, the value obtained for CMJ momentum will be identical to that of CMJ impulse. Therefore, a S&C practitioner can measure CMJ NI without the use of force plates. This is of particular interest given that a recent systematic review and meta-analysis noted that CMJ impulse has the single largest association with CHV (Fishers $Z_r = 0.82$) when compared to a wider number of physical attributes (6).

Model three, which saw the addition of force at 250 ms, significantly predicted 32.8% of the variance in DD and presented a large effect size ($f^2 = 0.49$). When considering the predictive ability of model three, it is plausible to suggest that the addition of force at 250 ms reflects both the timing and application of vertical ground reaction forces during the downswing. For instance, evidence from Han et al., (19) indicates a rapid rise in vertical force ~250-300 ms prior to impact within highly-skilled golfers, despite the entire duration of the swing lasting ~1 s. This signifies the importance in the rapid rise in force during this time within the downswing. However, it is important to recognise that the underlying physiological mechanisms of force production after 150 ms are similar to those produced during maximal voluntary contractions (15), indicating that this metric is very much representative of lower body strength. Brennan et al., (6) noted that the combined pooled data for lower body strength had a small relationship with CHV (Fisher $Z_r = 0.47$, which perhaps indicates why model three is not the best fit. Furthermore, given that Brennan et al., (6) reported CMJ impulse to have the strongest relationship with CHV, this supports the findings within the current investigation noting that model two was the best fit.

For model four, the addition of IMTP PF was unable to significantly predict the variance in DP World Tour Golfers' DD. As noted previously from their systematic review and meta-analysis, Brennan et al., (6) identified small relationships between DD and lower body strength. The data from the current investigation observed a negligible change in the R^2 of 0.01% when IMTP PF was added. As previously mentioned, a likely explanation for this can be rationalised through understanding the neuromuscular determinants of force at specific time points. Folland, Tillin and Hannah (15) assessed the neurological and contractile determinants of PF during discrete time points, noting that isometric PF explained 93% of the total variance in force at 150 ms. Thus, although force at 250 ms and IMTP PF are discrete metrics, the underlying neuromuscular (e.g. neural drive and muscle volume) determinants of force production for these variables are not disparate. This likely explains why model four was unable to significantly predict the variance in DP World Tour Golfers DD, which is supported by AIC suggesting this model was the worst fit for the data.

It is important to recognise the limitations within the current investigation. The pragmatic nature of the research means that there are compromises to the internal validity of the investigation. For instance, DD was established from the data gathered by ShotTracker over a tournament season. Whilst ecologically valid, it is difficult to fully appreciate the shot the player is trying to hit. For instance, it could be that a player decides to compromise distance over accuracy due to the risk of hazards. Additionally, not all the players would have competed in the same events due to their own tournament schedules. However, all players competed in a minimum of twelve events throughout the tournament season, thus their average distance over the season has been captured. Future research should consider opportunities to gather other key performance metrics for both impact

(i.e. CHV, centredness of strike) and ball flight (i.e. ball velocity, spin rate, launch angle, initial start direction). Additionally, there is very little research that has been conducted within female players, therefore, future research should seek to assess the relationships between DD and physical performance within Ladies European Tour golfers.

PRACTICAL APPLICATIONS

For S&C coaches who are seeking to physically profile golfers using force plates, the results of this investigation indicate that CMJ PI, CMJ NI, IMTP PF, force at 250 ms and force at 300 ms can be measured reliably. Since model two within the regression was the best fit, the authors advise measuring CMJ PI and CMJ NI when physically profiling golfers. For practitioners who are unable to utilize force plates, CMJ NI can be calculated using the equations proposed by Wells et al., (35). Practitioners first need to attain the mass (in kg) of the golfer, which is easily established using scales. Following this, practitioners then need to assess CMJ height, which can be accurately measured using the MyJump app (1). Once jump height has been obtained, inverse dynamics can then be employed to calculate take-off velocity. For a golfer who has a CMJ jump height of 0.40 m and a mass of 78 kg, this would be calculated as follows:

$$\text{Take-off velocity} = \sqrt{(d * (2 * g))}$$

$$\text{Take-off velocity} = \sqrt{(0.40 * (2 * 9.81))}$$

$$\text{Take-off velocity} = 2.81 \text{ m} \cdot \text{s}^{-1}$$

Where d = jump height in meters, and g = gravity at $9.81 \text{ m} \cdot \text{s}^{-2}$

Multiplying take-off velocity by an individual's mass will then establish the golfer's overall CMJ momentum ($\text{mass} \times \text{velocity}$) Given that impulse is directly proportional to the change in

momentum, the value obtained for CMJ momentum will be the same for CMJ NI. This can be calculated using the following equation:

$$\text{CMJ net impulse} = m \cdot v$$

$$\text{CMJ net impulse} = 78 \cdot 2.81$$

$$\text{CMJ net impulse} = 219.18 \text{ N}\cdot\text{s}$$

Where m = mass and v = take-off velocity.

This is of great value to the applied practitioner given the strong associations between impulse and CHV (6). In addition, practitioners can calculate CMJ NI and use the values as a reference to compare their golfer to DP World Tour players (based on the findings within this paper) and highly-skilled golfers (handicap ≤ 5 strokes) (35).

For S&C practitioners seeking to enhance a golfer's performance, physical interventions that help to generate impulse would appear both logical and appropriate. The use of ballistic training (i.e. trap bar jumps, CMJs) present an ideal opportunity as these exercises have been observed to enhance both CHV and CMJ performance (11). However, it is also important to recognise the value of utilising strength training (i.e. back squats, trap bar deadlifts) with golfers, as this will help improve maximal force generating capacity, which rapid force production and velocity scale to (10). From a practical standpoint, the use of heavy strength training and ballistic jumps used in combination (i.e. contrast training) is noteworthy, as this has been shown to be superior at enhancing CMJ performance than resistance training alone (28). Specifically for the golfer, a

contrast training programme with descending loads could be utilized as follows: 85% RM Back squats for 5 repetitions, 30% RM trap-bar jumps for 5 repetitions, maximal air swings with a driver for 5 repetitions. However, it is important to ensure that the golfer has an adequate level of resistance training experience before exposing them to this stimulus.

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REFERENCES

- 1) Balsalobre-Fernández C, Glaister M. and Lockett RA. The validity and reliability of an iPhone app for measuring vertical jump performance. *Journal of sports sciences*, 33(15), pp.1574-1579, 2015
- 2) Betzler NF, Monk SA, Wallace ES, Otto SR. Variability in clubhead presentation characteristics and ball impact location for golfers' drives. *Journal of Sports Sciences* 30(5): 439-448, 2012.
- 3) Betzler NF, Monk SA, Wallace ES, and Otto SR. The relationships between driver clubhead presentation characteristics, ball launch conditions and golf shot outcomes. *Proceedings of the Institution of Mechanical Engineers, Part P: Journal of Sports Engineering and Technology* 228(4):242-9, 2014.
- 4) Bliss A. Modelling Elite Golf Performance: Predictors of Hole Score on the European Tour From 2017-2019. *International Journal of Golf Science* 9(1), 2021.
- 5) Brennan A, Murray A, Coughlan D, Wells J, Xu J, Turner A, Brearley S. and Bishop C. Associations and within-group differences in physical characteristics and golf performance data in high-level amateur players. *Applied Sciences* 14(5), p.1854, 2024a.
- 6) Brennan A, Murray A, Mountjoy M, Hellstrom J, Coughlan D, Wells J, Brearley S, Ehlert A, Jarvis P, Turner A. and Bishop C. Associations Between Physical Characteristics and Golf Clubhead Speed: A Systematic Review with Meta-Analysis. *Sports Medicine* pp.1-25, 2024b.

- 550
551
552 7) Broadie M. *Every Shot Counts*. USA: Penguin Group, 2014.
- 553
554 8) Cohen JE. *Statistical power analysis for the behavioural sciences*. New Jersey: Lawrence
555 Erlbaum Associates, 1988.
- 556
- 557 9) Cormack S, Newton RU, McGuigan M, Doyle T. Reliability of measures obtained during
558 single and repeated countermovement jumps. *International Journal of Sports Physiology and*
559 *Performance* 3: 131-144, 2008.
- 560
- 561 10) Cormie P, McGuigan MR, Newton RU. Adaptations in athletic performance after ballistic
562 power versus strength training. *Medicine & Science in Sports & Exercise* 42(8): 1582-1598,
563 2010.
- 564
- 565 11) Coughlan D, Taylor MJ, Wayland W, Brooks D. and Jackson J. The effect of a 12-week
566 strength and conditioning programme on youth golf performance. *International Journal of*
567 *Golf Science*, 8(1), 2019.
- 568
- 569 12) Faul F, Erdfelder E, Buchner A, Lang AG. Statistical power analyses using G*Power 3.1:
570 Tests for correlation and regression analyses. *Behavior Research Methods* 41: 1149-1160,
571 2009.
- 572
- 573 13) Field A. *Discovering Statistics Using IBM SPSS Statistics*. London: Sage, 2014.
- 574

- 14) Fletcher IM, Hartwell M. Effect of an 8-Week combined weights and plyometric training programme on golf drive performance. *Journal of Strength and Conditioning Research* 18(1): 59-62, 2004.
- 15) Folland JP, Buckthorpe MW. and Hannah R. Human capacity for explosive force production: neural and contractile determinants. *Scandinavian journal of medicine & science in sports* 24(6), pp.894-906, 2014.
- 16) Garhammer J. A review of power output studies of Olympic and powerlifting: Methodology, performance prediction, and evaluation tests. *Journal of Strength and Conditioning Research* 7(2): 76-89, 1993.
- 17) Haff GG, Ruben RP, Lider J, Twine C, Cormie P. A comparison of methods for determining the rate of force development during Isometric Midthigh Clean Pulls. *Journal Of Strength and Conditioning Research* 29(2): 386-395, 2015.
- 18) Haff GG, Stone M, O'Bryant HS, Harman, E, Dinan, C, Johnson, R. and Han, KH. Force-time dependent characteristics of dynamic and isometric muscle actions. *The Journal of Strength & Conditioning Research* 11(4): 269-272, 1997.
- 19) Han KH, Como C, Kim J, Lee, S, Kim, J, Kim, DK. and Kwon, YH. Effects of the golfer-ground interaction on clubhead speed in skilled male golfers. *Sports Biomechanics* 18(2): 115-134, 2019.

- 20) Hellstrom J, Nilsson J, Isberg L. Drive for dough. PGA Tour Golfers' tee shot functional accuracy, distance and hole score. *Journal of Sports Sciences* 32(5): 462-469, 2014.
- 21) Hellstrom J. The relationship between physical tests, measures and clubhead speed in elite golfers. *International Journal of Sports Science and Coaching* 3(Supp 1): 85-92, 2008.
- 22) Leary BK, Statler J, Hopkins B, Fitzwater R, Kesling T, Lyon J, Phillips B, Bryner RW, Cormie P. and Haff GG The relationship between isometric force-time curve characteristics and club head speed in recreational golfers. *The Journal of Strength & Conditioning Research* 26(10): 2685-2697, 2012.
- 23) Lynn SK, Wu W. The use of ground reaction forces and pressures in golf swing instruction. In: *Routledge International Handbook of Golf Science*. M Toms, ed. Oxford: Routledge, 15-25, 2017.
- 24) McGuigan MR, Newton MJ, Winchester JB. and Nelson AG. Relationship between isometric and dynamic strength in recreationally trained men. *Journal of Strength and Conditioning Research* 24: 2570-2573, 2010.
- 25) McMahon JJ, Suchomel TJ, Lake JP. and Comfort P. Understanding the Key Phases of the Countermovement Jump Force-Time Curve. *Strength and Conditioning Journal* 40(4): 96-106, 2018.

- 26) Menard, S. *Applied logistic regression analysis*. Sage University Paper Series on Quantitative Applications in the Social Sciences, 07-106. Thousand Oaks, CA: Sage, 1995.
- 27) Mundy PD, Smith NA, Lauder MA. and Lake JP. The effects of barbell load on countermovement vertical jump power and net impulse. *Journal of Sports Sciences* 35: 1781-1787, 2017.
- 28) Pagaduan J, Schoenfeld BJ. and Pojskić H. Systematic review and meta-analysis on the effect of contrast training on vertical jump performance. *Strength & Conditioning Journal*, 41(3), pp.63-78, 2019.
- 29) Parchmann CJ. and McBride JM. Relationship between functional movement screen and athletic performance. *Journal of Strength and Conditioning Research* 25(12): 3378-3384, 2011.
- 30) Read PJ, Lloyd RS, De Ste Croix M. and Oliver JL. Relationships between field-based measures of strength and power and golf club head speed. *Journal of Strength and Conditioning Research* 27(10): 2708-2713, 2013.
- 31) Stone MH, O'Bryant HS, Hornsby G, et al. Using the isometric mid-thigh pull in the monitoring of weightlifters: 25+ years of experience. *Professional Strength and Conditioning* 54: 19-26, 2019.

- 32) The European Tour. Results – BMW PGA Championship 2023 [Internet]. 15 November 2023. [Accessed 25 August 2024]; Available from <https://www.europeantour.com/dpworld-tour/bmw-pga-championship-2023/results?round=4>
- 33) Wells JET, Charalambous LH, Mitchell AC, et al. Relationships between Challenge Tour golfers' clubhead velocity and force producing capabilities during a countermovement jump and isometric mid-thigh pull. *Journal of Sports Sciences* 37(12): 1381-1386, 2019.
- 34) Wells JET, Mitchell ACS, Charalambous LH, Fletcher IM. Relationships between highly skilled golfers' clubhead velocity and force producing capabilities during Vertical Jumps and an Isometric Mid-Thigh Pull. *Journal of Sports Science* 36(16): 1847-1851, 2018.
- 35) Wells JET, Mitchell ACS, Charalambous LH, Fletcher IM. Relationships between highly skilled golfers' clubhead velocity and kinetic variables during a countermovement jump. *Sports Biomechanics* 1-13, 2022.
- 36) Winter EM, Abt G, Brookes CFB, et al. Misuse of “Power” and Other Mechanical Terms in Sport and Exercise Science Research. *Journal of Strength and Conditioning Research* 30: 292-300, 2016.