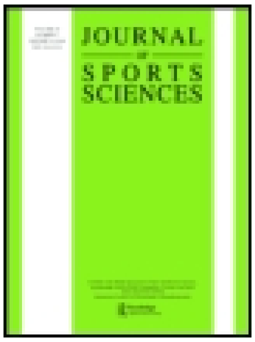

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Relationships between highly skilled golfers' clubhead velocity and force producing capabilities during vertical jumps and an isometric mid-thigh pull

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ABSTRACT

Whilst previous research has highlighted significant relationships between golfers' clubhead velocity (CHV) and their vertical jump height and maximum strength, these field-based protocols were unable to measure the actual vertical ground reaction force (vGRF) variables that may correlate to performance. The aim of this study was to investigate relationships between isometric mid-thigh pull (IMTP), countermovement jump (CMJ), squat jump (SJ) and drop jump (DJ) vGRF variables and CHV in highly skilled golfers. Twenty-seven male category 1 golfers performed IMTP, CMJ, SJ and DJ on a dual force platform. The vertical jumps were used to measure positive impulse during different stretch-shortening cycle velocities, with the IMTP assessing peak force (PF) and rate of force development (RFD). Clubhead velocity was measured using a TrackMan launch monitor at a golf driving range. Pearsons correlation coefficient analyses revealed significant relationships between peak CHV and CMJ positive impulse ($r = 0.788$, $p < 0.001$), SJ positive impulse ($r = 0.692$; $p < 0.001$), DJ positive impulse ($r = 0.561$, $p < 0.01$), PF ($r = 0.482$, $p < 0.01$), RFD from 0–150 ms ($r = 0.343$, $p < 0.05$) and RFD from 0–200 ms ($r = 0.398$, $p < 0.05$). The findings from this investigation indicate strong relationships between vertical ground reaction force variables and clubhead velocity.

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KEYWORDS
Golf; strength and conditioning; peak force; impulse; stretch-shortening cycle

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Introduction

The ability to drive a golf ball over greater distances is considered to be an important factor linked to success within the game of golf (Broadie, 2014). However, extraneous variables such as centeredness of strike, environmental conditions and friction of the landing area can cause error when measuring a golfer's drive distance. Inextricably linked to increasing drive distance is the notion of developing clubhead velocity (CHV) at the moment of impact between the golf ball and clubhead (Hume, Keogh, & Reid, 2005). Since CHV is not subjected to the extraneous variables associated with drive distance, it is a more robust measure of golfers' performance. There are a number of ways to increase CHV including technical alterations or advances in equipment (Cochran & Stobbs, 1999). However, over recent years golfers have devoted an increasing amount of time engaging in strength and conditioning interventions due to research highlighting significant improvements in CHV (Doan, Newton, Kwon & Kraemer, 2006) following resistance training (Fletcher & Hartwell, 2004) and the widespread use of resistance training in professional golfers.

Research has evidenced that the downswing of highly skilled golfers is initiated from the ground-up (Hume et al., 2005), with energy transferred through the body's kinetic chain to the clubhead (Nesbit & Serrano, 2005). While a number of studies have assessed the kinematic parameters of the golf swing, there is a paucity of research assessing the relationship between golfers' CHV and vertical ground reaction forces (vGRF). Despite a number of kinetic mechanisms suggested to relate to CHV; including peak force (PF; Doan et al., 2006), rate of force development (RFD; Read & Lloyd, 2014), impulse (Myers, Lephart, Ysai, Smoglia, & Jolly, 2008) and stretch-shortening cycle (SSC) efficiency (Hume et al., 2005), there has been little research exploring relationships between these parameters and CHV.

Previous research has utilised one repetition maximum (1-RM) back squats (Hellström, 2008; Parchmann & McBride, 2011) and vertical jump performance (Lewis, Ward, Bishop, Maloney, & Turner, 2016; Read, Lloyd, De Ste Croix, & Oliver, 2013) to explore possible relationships with CHV. While these procedures provide useful field based assessments, they are unable to measure variables such as PF, RFD and impulse, which are obtainable through the use of force platforms. Furthermore, there is also a great degree of technical proficiency required when performing a back squat. One method that has previously been used in research and is suggested to be a valid measure of PF and RFD is an isometric mid-thigh pull (IMTP; Haff, Ruben, Lider, Twine, & Cormie, 2015). To date, there is only one study that has utilised an IMTP to examine the relationship between PF, RFD and CHV, with the authors reporting no significant relationship between these variables (Leary et al., 2012). However this study employed a small sample size (n = 12) and comprised a high degree of variability in participant level (handicap: −14.5 ± 7.3).

A SSC is observed when the musculotendinous unit is stretched before shortening rapidly with ideally a small isometric delay between these two actions (Blazevich, 2011). The SSC has been suggested to be a fast or slow action depending

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on ground contact times (<250 ms and >250 ms; Schmidtbleicher, 1992). It is generally accepted that fast SSCs such as drop jumps (DJs) take advantage of series elastic component (SEC) function and stored elastic energy, whereas slower SSCs, such as countermovement jumps (CMJ), draw upon both the contractile element (CE) and SEC (Wilson & Flanagan, 2008). Furthermore, squat jumps (SJs) are often employed to measure the ability of the musculotendinous unit to perform concentric only movements (Kurokawa, Fukunaga, & Fukashiro, 2001). Consequently, jump variations can be employed to establish if a relationship exists between CHV and different lower extremity SSC velocities. One mechanism speculated to relate to golfers' performance is their ability to generate impulse (force x time) (Myers et al., 2008). Indeed, Keogh, Marnewick, Maulder, Nortje & Hume, (2009) suggested that the ability of a golfer to generate impulse using the lower extremities is a factor likely associated with golfers' CHV. Given the impulse-momentum relationship, greater force generated over the duration of the downswing will increase the overall momentum (velocity x mass). Since the mass of a golfer remains constant, the change in impulse will lead to an increase in velocity which ideally will be transferred to the clubhead. Since impulse can be measured during different jump variations, these procedures can be used to assess the relationship between CHV and impulse generated during different SSC actions. Impulse generated during vertical jumps measures the ability of the lower body to utilise different SSCs to produce force over a specified time. Golfers who are able to generate greater impulse during slow SSC activities such as a CMJ, may have an athletic advantage if they are able to successfully transfer this to the clubhead. There is no research however, that examines the relationship between these variables.

Recent research has found that slow velocity field based measurements such as 1-RM back squat strength has a significant positive relationship with CHV (Hellström, 2008; Parchmann & McBride, 2011). This is interesting since research has identified that the downswing lasts from 230 – 284 ms (Cochran & Stobbs, 1999; Tinmark Hellström, Halvorsen & Thorstensson, 2010). Given that it can take up to 900 ms to reach PF (Blazevich, 2011), there may not be the prerequisite time window during the downswing to achieve this. Consequently it may be more important for golfers to generate force quickly (i.e. faster RFD). By utilising an IMTP, this can directly measure PF and RFD which will help to determine whether it is the magnitude or rate that has the greatest relationship with golfers' CHV.

The aim of this study was to investigate relationships between IMTP, CMJ, SJ and DJ vGRF variables and peak CHV in highly skilled golfers. From the current literature, it is hypothesised that CHV would have a significant positive relationship with each of the vGRF variables.

Methods

Participants

Twenty-seven right-handed male category-1 (handicap ≤-5) golfers (age: 19 ± 1.45 years, height: 1.81 ± 0.6 m, mass: 74.85 ± 11.28 kg, handicap: −2.7 ± 1.9) were recruited to participate in this study. All participants were experienced golfers, engaged in an average of 9 hours golf practice per week and had limited experience of resistance training. Participants were injury free, completed a physical activity readiness questionnaire (PAR-Q), attended a familiarisation session and refrained from exercise 48 hours prior to all testing. Ethical approval was granted by the University's Research Ethics panel.

Experimental trials

Laboratory assessment

Anthropometric data (height and mass) were recorded. As a warm-up participants performed pulse raisers on a cycle ergometer for 5 minutes at a cadence of 50 rpm with a resistance that yielded an intensity of 90–100 watts. Following this a series of dynamic stretches were performed including clock lunges, overhead squats, gluteal bridges, scapula wall slides, thoracic rotations, internal and external hip rotations and vertical and horizontal arm swings. Each participant received five minutes rest before completing testing of the SJ, followed by CMJs, DJs and lastly the IMTP. All performance tests were performed on dual Kistler force platforms (Kistler 9281, Kistler Instruments, Winterthur, Switzerland) sampling at 2000 Hz.

Vertical jumps

All participants were taken through a standardised verbal explanation and demonstration by the investigator. Following this, participants performed three practice trials prior to completing the test procedures. Each vertical jump was performed three times with the feet hip width apart, hands placed on the hips, and with the instruction to jump as high and as fast as possible on the command "3, 2, 1, jump". Each trial was interspersed with a two minute recovery period.

Squat jumps

During practice trials participants set their preferential start position with knee (95 ± 12°) and hip angles (84 ± 18°) recorded using a universal goniometer. An adjustable bench was individually set to each participant's preferred squat depth to provide a standardised start position. Force plates were zeroed with the participants set motionless in their lowered position of the squat. The participants held their self-selected squat depth for 5 seconds then performed a concentric only jump. All force-time data was analysed on a computer screen, with a negative vGRF >50 N from the force trace deemed as a prior countermovement (Thomas, Jones, Rothwell, Chiang, & Comfort, 2015). If a countermovement was performed the data was discarded and the trial was performed again following the allocated rest intervals.

Countermovement jumps

Force platforms were zeroed with the participants standing motionless in their start position. Countermovement jumps started with the participants standing upright before lowering themselves into a self-selected squat depth and immediately jumping as high and as fast as possible on the command "3, 2, 1, jump".

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Drop-jumps

A 20 cm high box was set back from the force platforms. On the command "3, 2, 1, jump" participants "dropped" from the box into a hip width stance and attempted to jump as high as possible whilst minimising their ground contact time. The experimenter discarded jumps adopting poor technique such as "stepping down" or "jumping" off the box. Jumps with ground contact time >250 ms were also discarded. After completing all the vertical jumps, the athletes rested for five minutes prior to taking part in the IMTP, which follows previous procedures reported by Leary et al. (2012).

Isometric mid-thigh pull

All isometric testing was performed using a Smith machine (Pro-R, Pullum Sports, Luton, UK), which was set over the dual Kistler force platform system. Prior to data collection, participants performed three sub-maximal isometric pulls, progressively increasing their lifting intensity. Participants were positioned into their second-pull position of the clean, since this has been shown to correspond to the portion of the clean that generates the highest force output (Garhammer, 1993). From this position knee (144 ± 4°) and hip (150 ± 5°) angles were recorded with a universal goniometer. Participants' hands were attached to the bar with lifting straps to enable maximal effort, with the bar fixed in position. Once the lifting position had been set, the participants took "slack" out of the bar and remained motionless whilst the force platforms were zeroed. Participants were informed to pull the bar as hard and as fast as possible (Haff et al., 2015). Each pull was initiated after a countdown of "3, 2, 1 pull" with maximal isometric effort applied for five seconds as recommended by Haff et al. (2015). Following each maximal lift, participants sat on a chair, but remained strapped to the bar. This was to maintain a constant hand position between trials. A total of three pulls were performed with three minutes recovery time between each.

Clubhead velocity assessment

CHV was measured using a TrackMan 3e launch monitor (Interactive Sports Games, Denmark), as used by Oliver, Horan, Evans, and Keogh (2016). The TrackMan 3e measures CHV at the instantaneous moment prior to impact (TrackMan, 2017), and is reported to repeatedly measure this variable to within ±0.18 m/s of the actual CHV (TrackMan, 2013). Clubhead velocity was measured in a customised driving range bay at the Belfry Golf Centre. The TrackMan was set-up based on manufacturer's guidelines with the investigator specifying the intended target line. The warm-up followed the same procedures used as the laboratory testing. Participants also hit a self-selected number of shots (5 ± 1 shots) with a 6-iron whilst gradually increasing their CHV. This was then followed with a self-selected number of shots (6 ± 1 shots) struck with a driver. Participants used their own custom fit 6-iron and driver which comprised either a stiff or X-stiff shaft to ensure shaft flexibility didn't confound CHV data. Prior to data collection the investigator instructed each participant to ensure they struck the ball with maximum effort, whilst maintaining their normal swing mechanics and a centred strike on the clubface. The final two warm-up shots were struck with maximum effort to ensure participants were suitably prepared. Participants self-selected and struck 10 new range balls, aiming at the target and hit off an artificial turf mat and a self-selected tee height. Centeredness of strike was determined by sound, feel and the ball flight, with the investigator checking verbally with the participant after each shot. Any shots that fell outside this remit were discarded and additional shots were performed, up to a maximum of 15 shots.

Data analysis

Smoothing and residual analysis

All data was smoothed with a lowpass 4th order Butterworth filter as described by Winter (2009). Residual analysis was used to determine optimal cut-off frequency (Winter, 2009) which was set at 30 Hz for the IMPT and 100 Hz for all three jump variations (Kawamori, Nosaka, & Newton, 2013). The instant of movement initiation was determined based on a 10 N vGRF threshold shift from baseline measurements as utilised by Tirosh and Sparrow (2003).

Kinetic analysis

Peak force during the IMTP was established from the maximal vGRF on the force-time curve subtracted by the lowest starting force. Rate of force development was calculated as the change in force divided by the change in time generated over pre-determined time integrals of 0–50 ms, 0–100 ms, 0–150 ms and 0–200 ms. Positive impulse was calculated from the area underneath the force-time curve for the CMJ and SJ. Drop jump positive impulse was calculated from the vertical force trace including impulse pertaining body mass and force generated through muscular actions.

Clubhead velocity data

The TrackMan launch monitor provided real-time biomechanical data on each participant's CHV for the ten trials. Peak data for CHV and the vGRF variables were taken forward for analysis.

Statistical analysis

Within-session reliability was determined using the coefficient of variation (CV) statistic and respective 95% confidence intervals. For each variable, acceptable reliability was determined as a CV <15% (Haff et al., 2015). The assumptions of normal distribution was met using the equation $Z_{skewness} = S - 0/SE_{skewness}$ and $Z_{kurtosis} = K - 0/SE_{kurtosis}$. The assumption of linearity and interval data were both met. A one-way Pearson's correlation coefficient was employed using IBM SPSS for Microsoft Windows (version 22.0; Chicago, USA), with an alpha level of <0.05 used as statistical significance. Effect size was deemed weak ($r = < 0.3$), moderate ($r = 0.3–0.5$) or strong ($r = > 0.5$) based on the suggestion of Cohen (1988). Reliability data (Table 1) indicate high levels of reliability for CHV (CV = 0.79%) PF (CV = 4.09%), CMJ positive impulse (CV = 1.62%), SJ positive impulse (CV = 1.92%) and DJ positive impulse (CV = 1.94%). Each of the RFD time integrals were deemed unreliable since all CV's were greater than 15%.

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Table 1. Showing the within sessions coefficient of variation and their respective 95% confidence intervals for CHV and the kinetic variables.

		95% CI	
Parameter	CV%	Lower	Upper
Peak CHV	0.79	0.68	0.89
Peak Force	4.09	3.2	4.98
RFD 0–50 ms	34.69	24.37	45.01
RFD 0–100 ms	28.59	19.79	37.38
RFD 0–150 ms	19.44	12.95	25.92
RFD 0–200 ms	14.54	9.91	19.16
CMJ positive impulse	1.62	1.19	2.06
SJ positive impulse	1.92	1.25	2.59
DJ positive impulse	1.94	1.25	2.62

Table 2. Representing descriptive statistics, correlation coefficient (r) and the coefficient of determinations (R^2) between CHV and the kinetic variables. Significance values are represented as follows.

	Mean	SD	r	R^2
Peak CHV (m.s^{-1})	49.41	2.46	-	-
Handicap (strokes)	−2.7	1.9	0.12	0.014
Peak Force (N)	1604.57	391.47	0.482**	0.232
RFD 0–50 (N/s)	3604.3	1986.75	0.185	0.034
RFD 0–100 (N/s)	4864.13	2331.42	0.286	0.082
RFD 0–150 (N/s)	5018.06	1787.84	0.343*	0.118
RFD 0–200 (N/s)	4863.60	1459.12	0.398*	0.158
CMJ positive impulse (N.s)	286.22	42.19	0.788***	0.621
SJ positive impulse (N.s)	185.05	29.04	0.692***	0.479
DJ positive impulse (N.s)	423.43	58.3	0.561**	0.315

*$p < .05$, **$p < .01$, ***$p < .001$

Results

Descriptive statistics and correlations between peak CHV and the kinetic parameters are presented in Table 2. The results from this investigation indicate that there are a number of significant relationships between golfers' peak CHV and force producing capabilities. Significant correlations were observed between peak CHV and CMJ positive impulse ($r = 0.788$, $p < .001$), SJ positive impulse ($r = 0.692$, $p < .001$), DJ positive impulse ($r = 0.561$, $p < .01$), PF ($r = 0.482$, $p < .01$), RFD from 0–150 ms ($r = 0.343$, $p < .05$) and RFD from 0–200 ms ($r = 0.398$, $p < .05$). No significant correlations between peak CHV and handicap, RFD from 0–50 ms and RFD from 0–100 ms were observed.

Discussion

The aim of this study was to investigate relationships between peak CHV and vGRF variables during an IMTP, CMJ, SJ and DJ. Findings from this investigation suggest that activities less constrained by time, such as CMJ positive impulse, SJ positive impulse, IMTP PF, RFD from 0–150 ms and RFD from 0–200 ms, hold significant relationships with peak CHV. This is interesting since research has purported the downswing of highly skilled golfers lasts from 230 – 284 ms (Cochran & Stobbs, 1999; Tinmark et al., 2010). It is important to recognise that previous research has often measured the downswing from the point that the clubhead is stationary at the top of the backswing, to the moment the club impacts the ball (Burden, Grimshaw, & Wallace, 1998; Tinmark et al., 2010), which may be misleading. As highly skilled golfers' transition into the top of the backswing, the application of force to the ground initiates the downswing whilst their upper body continues to rotate away from the target (McTeigue, Lamb, Mottram, & Pirozzolo, 1994), creating a relatively longer timeframe for the downswing than the 230–284 ms often quoted. Consequently there is actually a greater time frame in which golfers can generate force during the downswing.

Nesbit and Serrano (2005) gave evidence to show that highly skilled golfers worked at slower rates during the start of the downswing when compared to lower skilled golfers. Given the kinetic chain principle, to attain a greater velocity at the most distal segment (i.e. the clubhead), higher levels of force are required to be generated within the more proximal segments (i.e. the lower body) (Hume et al., 2005). It may be that golfers who work at slower rates during the start of the downswing may have more time to generate greater force due to the force-velocity relationship. Consequently the force generating capacities of the lower body appear to be an important physical characteristic for developing CHV. Previous authors have suggested that golfers should utilise training modalities aimed at developing RFD rather than maximal force (Read & Lloyd, 2014). This is due to the time it takes (up to 900 ms) to reach PF (Blazevich, 2011). This has led authors to suggest that the duration of the downswing is too short to be influenced by PF. However the findings from the current investigation indicate that activities less constrained by time have the greatest relationships with CHV. Since the downswing is likely to be longer than the 230 – 284 ms suggested by Cochran and Stobbs (1999) and Tinmark et al. (2010) this affords golfers greater time to recruit higher threshold motor units, thus allowing greater levels of force to be attained during the downswing. Therefore the golf swing may not reflect a fast SCC, which draws on the SECs ability to store and release elastic energy (Wilson & Flanagan, 2008), but instead a slower SSC with the CE important in developing force during shortening.

The findings from this investigation indicate that CMJ peak positive impulse has the greatest relationship with golfers' CHV. Greater force over a specified period of time will lead to an increase in impulse (force x time). Newton's second law of motion suggests that impulse is proportional to a change in momentum (mass x velocity). Since a golfers' mass will stay constant between shots, any increase in impulse and therefore momentum, will result in an increase in velocity which will ideally be transferred to the clubhead. Clearly a golfer's ability to generate positive impulse is an important component relating to CHV. This would indicate that training modalities aimed at increasing impulse during slow SSCs may be preferential when designing future training programmes. Given the significant positive relationship between CHV and PF, the ability of a golfer to generate force with the lower body appears to be a key factor for generating greater CHV. Training modalities incorporating strength training or loaded jumps should be considered when designing a strength and conditioning training programme for golfers, since these exercises have been found to significantly increase PF and impulse (Cormie, McGuigan, & Newton, 2010).

Conclusion

The findings from this investigation indicate that performance measures less constrained by time (CMJ impulse, SJ impulse,

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PF, RFD from 0–150 ms and RFD from 0–200 ms) have a significant relationship with golfers' peak CHV. To the authors' knowledge, this is the first investigation that has attempted to analyse these vGRF variables within highly skilled golfers. Countermovement jump positive impulse and SJ positive impulse had the strongest correlations with golfers CHV. Furthermore, PF was also shown to significantly relate to peak CHV which supports the idea that maximal strength has an important relationship with golfers' drive distances. Although RFD from 0–150 ms and 0–200 ms presented significant relationships with CHV, measurements for RFD across all time integrals were deemed unreliable. From the above data, it appears pertinent to employ intervention strategies aimed at increasing force over slower velocities as opposed to plyometric activities, which require fast SSC function. It is also advised that golfers and PGA Professionals work closely with strength and conditioning coaches and biomechanists in order to enhance golfers' performance.

Disclosure statement

No potential conflict of interest was reported by the authors.

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