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Relationships Between Vertical Ground Reaction Forces and Clubhead Velocity in NCAA Division I Female Golfers

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by

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ABSTRACT

Golf biomechanics research has focused on clubhead velocity (CHV) for over a decade with the intent of discovering the physical attributes that contribute the most to CHV. Previous research has displayed the significant correlations of strength and power attributes to CHV, giving evidence for practitioners to integrate training to improve these attributes. Recent studies have referenced vertical ground reaction forces (vGRF) and how they affect CHV. In this study, vGRFs are tested for their correlations to CHV in NCAA Division I female golfers. Clubs of various lengths were used to determine correlations between each club and vGRFs. Correlations between CHV and vGRFs were statistically insignificant. Despite the lack of statistical significance, the effect sizes were large, and *p* values could be lower due to small sample size. Of all values recorded, peak lead leg force was the greatest correlate throughout each club (r = 0.53-0.72). Data showed strong correlation coefficients between the clubhead velocity of each club and lead leg forces. Data also showed that club length may have had effects on the correlation of vGRFs to CHV. While previous research has focused on CHV correlations in male golfers, this study provided support that CHV values for females have stronger correlates than those for males. Despite the lack of significance, the effect sizes and correlation coefficients are promising values. Limitations of this study are small sample sizes and lack of diverse body types in the study. A multi-sex study with larger sample sizes would increase significance of values.

Keywords: *Golf; physical performance; ground reaction force; clubhead velocity; physical attributes*

DEDICATION

To my Lord and Savior Jesus Christ, thank you for giving me a reason to live in this world. Thank you for showing me Your grace and mercy. I pray that I always live in a way that is pleasing to You and to win the world with Your Gospel.

To my parents, Allen and Donna Bush, thank you for all the support each of you has given to me. I strive to make you proud of the work that I put forth and aim to be as caring and virtuous to others as you have been to me.

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LIST OF ABBREVIATIONS

1-RM	One-Repetition Maximum
ANOVA	Analysis of Variance
CHV	Clubhead Velocity
D1	Division 1
GSCWC	Golf Swing Specific Cable Woodchop
ICC	Intraclass Correlation Coefficient
IMTP	Isometric Mid-Thigh Pull
MBTV	Medicine Ball Throw Velocity
MC	Mid-Thigh Circumference
ROM	Range of Motion
SD	Standard Deviation
vGRF	Vertical Ground Reaction Force
WC	Waist Circumference

CHAPTER I: INTRODUCTION

Golf performance has been researched for over a decade by laboratories across the world. When determining how to measure golf performance, studies relied upon the value of driving distance to be the marker for performance (Hume et al., 2005). Driving distance was used for many years; however, many extrinsic factors can cause the driving distance to be inaccurate (Wells et al., 2018). This information was then used to determine other methods of measuring golf performance such as clubhead velocity (CHV). Clubhead velocity measures how fast the clubhead is moving at the time of impact with the golf ball. This value takes out many extraneous factors that could cause driving distance data to be skewed.

Since CHV is considered the "gold standard" of measuring golf performance, research has been directed towards finding the correlations to CHV. By determining the relationship to CHV, practitioners will be able to formulate and execute training programs that increase the CHV. Increases in CHV will give golfers added distance to each shot as between 75% and 82% of ball speed is determined by CHV (Sweeney et al., 2013). This increase in distance enhances the ability to be closest to the green to lower the golfer's score.

Many of the studies conducted around CHV have used the driver as the highest CHV values are found with this club. As CHV would gradually decrease based on the length of the club, there is limited information in regard to comparisons across clubs (Hur et al., 2005.)

Strength, a common physical attribute of the human body, can be defined as the ability to produce maximum force during a muscle contraction. Strength exercises have been used by practitioners in golf performance (Oranchuk et al., 2020). Several investigations have analyzed lower body strength as it relates to CHV using cross-sectional and longitudinal methods (Hellström, 2008; Keogh et al., 2009; Parchmann & McBride, 2011; Oranchuk et al., 2020). Studies have shown that elite golfers use a proximal to distal muscle activation pattern starting with the large muscles of the lower body (Hume et al., 2005; Nesbit and Serrano, 2005). Thus, improvement of the force generating capacities of the lower body would be of interest when trying to increase CHV. Keogh et al. (2009) used low- and high-handicap golfers to identify if there are differences in strength and CHV. Though no differences in hack squat one repetition maximum were found, they did see a significant difference in CHV between groups. While not statistically different, there was a difference of 13 kg in the one repetition maximum between groups.

In addition to strength assessments such as those mentioned above, force production testing has been conducted as it relates to CHV (Wells et al., 2018; Wells et al., 2022; Leary et al., 2012). While inconsistent findings have been reported regarding relations to the jump testing and CHV, isometric midthigh pull vertical ground reaction forces (vGRF) have been shown to strongly correlate to CHV values. While current research using jump tests and isometric contraction tests suggests the importance of force production values, the literature is still limited as to force production during the downswing of the club.

Hur et al. (2005) showed that ground reaction forces did not differ across a range of clubs, suggesting that the length of the club had a large influence on CHV. Han et al., (2019) found that the lead leg ground reaction force production was strongly correlated to

CHV, while the back leg served in more of a pivot capacity. While interesting, these investigations were performed using only male golfers. As females typically have lower force production values it would be of interest to see if similar relationships exist. The purpose of this study is to determine the relationship between force production and CHV in a sample of female collegiate golfers. The researcher hypothesizes that bilateral force production will be strongly correlated to clubhead velocity in collegiate golfers.

CHAPTER II: LITERATURE REVIEW

Golf Performance Defined

The definition of golf performance has been a fluid discussion over the past few decades. In the past, many studies relied on using driving distance as a measure of golf performance (Hume et al., 2005; Broadie, 2014). The basis of this discussion was that if a golfer is able to drive the golf ball a great distance, then this would aid the golfer in reaching the green in fewer strokes. While this theoretically sounds correct, driver distance is heavily affected by extraneous variables (Wells et al., 2018). These variables can be environmental such as weather conditions, ball strike quality, and ground friction (Wells et al., 2018). While driving distance was determined as less significant, clubhead velocity began to be measured as the model for golf performance (Hume et al., 2005). In theory, the more speed that the driver hits the golf ball with, the farther the ball will travel. This measurement only takes into account CHV, which is not affected by any extraneous factors. When CHV increases, driver distance has been shown to increase. This relationship has been related to the effect of force production on distance.

CHV measurement tools have become popular since the value has been considered the standard of golf performance. CHV has been measured by photo sensing timers and indoor launch monitors such as Trackman and Zelocity (Oranchuk et al., 2020; Gordon et al., 2009; Olivier et al., 2016; Parchmann and McBride, 2011). The Trackman launch monitor has been studied in-depth to determine its ability to be used in research; data revealed that the Trackman is reliable and valid for determining ball velocity, clubhead velocity, and spin rate (Leach et al., 2017).

Clubhead Velocity and Physical Performance

Within the past decade, there has been a rise in improving physical traits such as strength, flexibility, and power to have more success on the course. Physical performance can be classified as the measurement of an individual's exercise and performance capacity. Physical performance can be measured differently depending on the specific populations being treated. Clubhead velocity can be hypothesized to increase with greater physical performance due to higher force production outcomes (Wells, 2018; Wells, 2022). Understanding how force production affects clubhead velocity will provide the greatest support for the relationship between golf physical performance and clubhead velocity.

Clubhead Velocity and Flexibility

Flexibility of different body segments has been studied to determine its correlation to CHV. Research showed that rotational flexibility training yielded trivial gains (1.62%) in CHV among intercollegiate male and female golfers (Doan et al., 2006). Another study supported this evidence by showing no significant correlations (r = -.27, $p < 0.05$) between trunk flexibility and CHV among male golfers with a handicap of 8 or less (Gordon et al., 2009). This study measured trunk flexibility by utilizing a trunk rotation strength machine. Removing the weight stack from the machine, researchers were able to determine the rotation of the trunk based on the distance traveled from before and after rotation. Rotational flexibility does not correlate significantly because high swing speeds have been found to be generated from other physical attributes such as strength and power variables (Hellström, 2008; Parchmann and McBride, 2011). Other measures of flexibility such as internal/external hip rotation and wrist abduction/adduction do not have statistically significant relationships with CHV (Keogh et al., 2009). By using range of motion (ROM) tests coupled with joint markers to measure displacement, Keogh (2009) showed that specifically back leg hip internal rotation was not correlated to CHV in low-handicap and high-handicap golfers (r = -0.252, $p < 0.05$). Using a field-based testing technique (sit and reach), Donahue, Wilson, and Szymanski (2021) also found no statistically significant relationship to CHV in male collegiate golfers. The evidence for the lack of these correlations is contrary to current golf training practices that focus on flexibility training in golf athletes (Smith, 2010). With this new research, golfers need to shift the focus of training from flexibility to other physical attributes such as strength and force production.

Clubhead Velocity and Anthropometrics

Anthropometric data has been researched for sports performance variable correlations for a considerable time. Many variables constitute the body of anthropometrics such as body mass, height, and segment length. Studies began to center around the correlation of body mass with CHV. Hellström (2008) proposed that higher body mass of an individual would be evidence of more muscle mass. Larger muscle mass would mean a higher CHV. Hellström's data (2008) called for future research into the relationships between fat-free mass and CHV. Following this data, research began to highlight body mass and body mass index, as well as fat mass, fat-free mass, and different arm measurements (Keogh et al., 2009; Donahue, Wilson, and Szymanski, 2021). Donahue et al. (2021) found no statistically significant relationship between body mass and CHV in male collegiate golfers. A full anthropometric profile provides multiple arm length values such as acromial-stylion length, radiale-stylion length, and acromialradiale length. One study showed that the full anthropometric profile of a golfer did not provide any significant correlations between any anthropometric variables and CHV (Keogh et al., 2009). Keogh's study was done with low-handicap golfers (advanced) and high-handicap golfers (novice); it showed no statistically significant correlation with either group or CHV.

Anthropometric values for standing height were also researched for their significance in producing CHV levels. No significant relationships (r = 0.38) were found between standing height and CHV (Read et al., 2013). More recently, a similar finding has been reported with male collegiate golfers with a higher correlation coefficient (r = 0.55) (Donahue, Wilson, Szymanski, 2021). As more anthropometric values were tested for correlations with clubhead velocity, research turned towards more health-related concepts such as waist circumference (WC) and mid-thigh circumference (MC). One study examined the WC and MC correlations to clubhead velocity in male and female collegiate golfers; data showed that WC (r = 0.012) and MC (r = 0.235) had no significant correlations with CHV (Son et al., 2016).

Contrary to anecdotal beliefs in the golf community, data suggests that height, body mass, and body mass index are not correlated to the CHV of a golfer (Sheehan et al., 2019). Contrary to prior information, recent data has shown that anthropometric data such as mass and height has provided strong relationships to clubhead velocity in youth female elite golfers (Coughlan et al., 2020). The young male golfers did not show a specific correlation to clubhead velocity. Theoretically, this could be due to the earlier stages of puberty for females as compared to males. Nevertheless, the values for anthropometry are not considered to be significant correlates to CHV. Further research needs to be performed into how fat-free mass may relate to CHV

Clubhead Velocity and Lower-Body Strength

While physical attributes such as flexibility and anthropometrics do not provide strong correlations to CHV, strength values have been determined to be strongly correlated with CHV. Strength can be defined as the maximum load that a muscle group or system of muscles can undergo in a contraction. Strength training can be related to the amount of force production that occurs during physical performance. Early research showed that lower-body strength variables have important relationships to determining CHV. One study utilizing back squat one-repetition maximum tests among 33 elite golfers (handicap of 5 or less) reported strong, significant relationships ($r = 0.54$, $p < 0.01$) to CHV (Hellström, 2008). The study supported the assertion that those who lifted more on the One-Repetition Maximum (1-RM) back squat test also showed higher CHV. Further research tested the hack squat 1-RM to measure lower-body strength and found moderately significant relationships ($r = 0.533$, $p < 0.05$) to CHV (Keogh et al., 2009). Keogh's study involved low-handicap and high-handicap golfers, supporting the assertion that strength measurements correlate to CHV values despite golf performance level. The concept being evaluated is fat free mass effect on strength values. With more fat-free mass, more muscle fibers are recruited for the duration of the golf swing, which could be correlated to the CHV. Therefore, fat-free mass is a possible indicator of muscular strength, which has a slightly moderate correlation ($r = 0.432$) to CHV (Keogh et al., 2009).

Further research of lower body strength and CHV relationships resulted in similar findings. A study on collegiate Division 1 golfers showed that testing back squat one-repetition maximums provided strong relationships ($r = 0.805$, $p < 0.0001$) to CHV (Parchmann and McBride, 2011). The study describes the linear relationship between the CHV and strength level of the golfer. In another study, female collegiate tennis players were found to have increased ball velocities after performing resistance training programs (Kraemer et al., 2003). Other studies have added onto the evidence of lower-body strength's importance to CHV. One study showed how back squat one-repetition maximum tests were strongly correlated ($r = 0.674$, $p < 0.05$) to peak CHV in collegiate golfers (Oranchuk et al., 2020). Deadlifts and back squats heavily activate the quadriceps and hamstring muscle groupings, which gives more evidence to the use of maximum effort (strength) by the lower body. Lower-body strength values have strong relationships to CHV; practitioners can use this relationship to establish strength and conditioning protocols (Oranchuk et al., 2020). With the onset of strength variables' importance, many other associated variables became important such as power and force production. The importance of lower-body strength can be seen through the use of the lower kinetic chain in the golf swing, primarily the downswing. Therefore, lower-body strength has been measured in various tests such as the isometric mid-thigh pull (IMTP).

Early research using IMTP tests confirmed the correlations of allometrically scaled force at 150 ms to CHV (Leary et al., 2012). While these studies provided information to support testing methods, biomechanists have focused on the mechanical underpinnings of force production (Wells et al., 2018). Examples of these are impulse, rate of force development, and peak force variables. Earlier research highlighted the importance of peak force variables (Hellström, 2008; Leary et al., 2012; Read et al., 2013; Coughlan et al., 2020). While this data is supported, other studies point out that peak force takes longer time to develop than the impact of a golf swing (Wells et al., 2018). Wells provided data to support that impulse variables are strong correlates to CHV (Wells et al., 2018; Wells et al., 2022). This data provides the importance of vGRF variables to clubhead speed; however, current research has not highlighted the relationship of CHV and force production in the golf swing. In this study, the research is set out to determine the role of force production related to the CHV of collegiate golfers.

Clubhead Velocity and Upper-Body Strength

Strength is commonly defined as the ability for a muscle or muscle group to provide maximum effort (strength) in a contraction. While much evidence has supported the importance of lower-body strength, upper-body strength has been only moderately correlated to golf swing velocity. Early studies show that the total mass lifted in calisthenic exercises such as vertical sit-ups has significant correlations ($r = 0.42$, $p < 0.05$) to CHV in elite golfers (Hellström, 2008). While calisthenic exercises are commonly used to measure endurance, the total mass lifted can be an assessment of upper-body strength. However, strength is determined more accurately when applying weight to overload the muscle and reach maximum effort. Upper-body strength measurements such as bench press one-repetition maximum and golf swing specific cable woodchop (GSCWC) values provided significant correlations ($r = 0.500$, $p < 0.05$; $r = 0.706$, $p < 0.01$) to CHV in low- and high-handicap golfers (Keogh et al., 2009). Keogh et al. (2009) explained the GSCWC strength value to be a high correlation due to the similarity of the movement to a simulated golf swing. While assumptions state that

GSCWC strength could have caused the increase in clubhead velocity from low-handicap golfers compared to high-handicap golfers, data has not supported that this specific variable is the root cause of this phenomenon.

While chest strength from the bench press had a small correlation in the Keogh et al. (2009) study, other data suggested the importance of chest strength to CHV. One study discovered that chest strength (measured by a pectoral deck machine) had significant correlations ($r = 0.69$, $p < 0.05$) to CHV in advanced male golfers (Gordon et al., 2009). The upper-body strength variables are important in increasing CHV. Even when combined with lower-body strength variables such as a power clean, muscular strength remains a statistically significant contributor to CHV (Oranchuk et al., 2020). The information from strength research has been used to create training protocols for athletes to improve their CHV, yet strength alone is not the factor that creates higher clubhead speeds. Strength is the maximum force produced; however, the speed at which it is produced is also important.

Clubhead Velocity and Upper-Body Power

As lower-body study has shown strong correlations to CHV, upper-body power has also proven to be a strong contributor to CHV. In one study, three-kilogram medicine ball hip tosses had a strong correlation to CHV ($r = 0.54$, $p < 0.05$) in advanced male golfers (Gordon et al., 2009). Studies like these have been seminal contributions to placing total rotational power exercises into training protocols. Research has shown as well that IMTP variables have strong correlations to CHV in different golf populations (Leary, 2012; Wells, 2018; Wells, 2022). Variations of medicine ball tests have revealed strong correlations ($r = 0.706$) to CHV by showing that seated and rotational medicine ball throw distance tests were related to an increase in CHV (Lewis et al., 2016). Other studies have supported Lewis' data that seated and rotational medicine ball throws show significant correlations to CHV (Read et al., 2013; Coughlan et al., 2020). While this data does add evidence to support the medicine ball hip toss correlation to CHV, the testing method has been criticized for the same reasons driver distance was debunked. Distance is affected by extraneous variables which makes it not reliable as a measurement of power. Sheehan and colleagues were able to measure medicine ball throw velocity (MBTV) through use of an accelerometer, and this experiment showed a significant correlation ($r = 0.52$, $p < 0.05$) between MBTV and CHV (Sheehan et al., 2019). Contrasting findings have been reported with no statistically significant correlation ($r = 0.29$) when using MBTV (Donahue et al., 2021). Thus, further research is warranted using these more appropriate methods.

CHAPTER III: METHODS

A cross-sectional correlational study was designed and performed to determine the magnitude of relationships between the force production throughout a golf swing and the recorded clubhead velocities in female collegiate Division 1 (D1) golfers. All subjects performed multiple swings with various pre-determined golf clubs to determine their associated effects on force production and clubhead velocity.

Subjects

Six Division I female golfers agreed to participate in the study. All subjects were members of The University of Southern Mississippi's Men's or Women's golf teams. All participants were over the age of 18, members of a collegiate golf program, without injury, and cleared for sports activity by sports medicine staff. All participants passed a prescreening process and were informed of all possible risks and outcomes of participation in the study. After listening and confirming their understanding of the written consent form, the participants signed and dated consent to be used on file.

Procedures

The study involved the participants completing ten full swings with three different golf clubs (driver, 5 iron, and 7 iron). The subjects were allowed to take up to three warmup swings before testing each club. The study used indoor launch monitor (Trackman) to monitor the clubhead velocity, ball speed, and carry distance (placed at manufacturer recommendations with regard to position and distance from the participants). If any mishits were seen according to the normal values for these measurements, these hits were disregarded. Then, the golf swing was repeated for that swing sequence.

Data Analysis

Ground reaction force data was collected at 1200 Hz. All raw data was exported to a customized Excel spreadsheet for data processing (Microsoft Corporation, 2022). Prior to the initiation of each swing, participants stood as still as possible for approximately one second. This one second of quiet stance was used to determine the body mass for each participant. The peak force for the lead and rear foot was calculated during the swing movement. Relative peak force was calculated as the peak force divided by the calculated body mass.

Statistical Analysis

Two separate analyses were performed in this investigation. First Pearson product moment correlation coefficients were calculated between all force variables and CHV. Separate coefficients were calculated for each of the three clubs used. An a priori alpha level of 0.05 was used in determining significant relationships. Correlation coefficients were interpreted as trivial ($r = 0.00 – 0.1$), small ($r = 0.1 – 0.3$), moderate ($r = 0.3 – 0.5$), large ($r = 0.5 – 0.70$), very large ($r = 0.7 – 0.9$), and nearly perfect ($r = 0.9 – 1.0$) as recommended by Hopkins (Hopkins, 2000).

To determine if differences were present between club conditions for both force production and CHV, a one-way repeated measures analysis of variance (ANOVA) was performed for each variable. Mauchly’s Test of sphericity was used to test the assumption of sphericity. If the assumption was violated, a Greenhouse – Geisser correction was used in the interpretation of findings. Partial eta squared effect sizes were calculated and interpreted as small (0.01 - 0.05), medium (0.06 - 0.13), and large (> 0.16). Post hoc analysis was completed using a least significant difference. An a priori alpha level of 0.05 was used.

CHAPTER IV: RESULTS

All ground reaction force variables displayed acceptable levels of reliability (ICC > 0.8) and were normally distributed (Table 1). Mean and standard deviation (SD) for each variable of interest are presented in Table 2. No statistically significant correlations were found between ground reaction force and CHV in the driver (r = 0.08 – 0.53) (Table 3) (Figure 1). No statistically significant correlations were present between ground reaction forces and CHV of the 5 iron (r = -0.30 – 0.65) (Table 3) (Figure 2). Similarly, no significant correlations were found between ground reaction forces and CHV in the 7 iron (r = -0.36 – 0.72) (Table 3) (Figure 3). Though no significant correlations were found, large to very large coefficients were present between lead leg peak force and CHV in all three conditions (Figures 1-3). Rear leg ground reaction forces and CHV displayed the lowest coefficient values across all conditions.

Table 1: Interclass correlation coefficients (ICC)

	Driver	5 Iron	7 Iron
Peak Lead (N)	0.99	0.99	0.99
Peak Rear (N)	0.88	0.97	0.99
Peak Relative Lead (N/kg)	0.99	0.99	0.99
Peak Relative Rear (N/kg)	0.83	0.96	0.98

When comparing ground reaction force values, no statistically significant differences were present when comparing peak ground leg ground reaction forces between clubs ($F(2,10) = 1.13$, $p = 0.36$) (Table 2). No statistically significant differences were present when comparing peak rear leg ground reaction forces between clubs ($F(2,10) = 2.12$, $p = 0.17$) (Table 2). Relative peak lead leg ground reaction forces displayed no statistically significant differences between clubs ($F(2,10) = 1.15$, $p =$

0.36). Relative peak rear leg ground reaction forces displayed no statistically significant differences between clubs (F(2,10) = 2.03, p = 0.18). Though no significant differences were seen between clubs, each variable displayed large partial eta-squared effect sizes, with driver ground reaction forces values being higher than those for both the 5 iron and 7 iron. A statistically significant difference was present in CHV between clubs (F(2,10) = 329.806, p = < 0.001). Post hoc comparisons revealed significant differences between each club with driver having the greatest CHV (42.16 m/s ± 2.40), followed by 5 iron (36.55 ± 1.75) and the slowest being the 7 iron (35.33 ±1.72) (Table 2).

Table 2: Comparison of ground reaction forces and clubhead velocity across conditions

	Driver	5 Iron	7 Iron	p	η_p^2
Peak Lead (N)	759.87 ± 197.08	735.86± 192.06	743.38 ± 218.19	0.36	0.19
Peak Rear (N)	504.58 ± 77.67	484.19 ± 52.36	484.69 ± 150.10	0.17	0.30
Peak Relative Lead (N/kg)	1.33 ± 0.25	1.29±0.24	1.30 ± 0.28	0.36	0.19
Peak Relative Rear (N/kg)	0.89±0.11	0.86 ± 0.08	0.86 ±0.08	0.18	0.29
Clubhead Velocity (m/s)	42.16 ± 2.40	36.55 ± 1.75	35.33 ±1.72	< 0.001	0.99

Table 3: Correlation Coefficients between ground reaction force and clubhead velocity

	Driver CHV (m/s)	5 Iron CHV (m/s)	7 Iron CHV (m/s)
Peak Lead (N)	0.53	0.65	0.72
Peak Rear (N)	0.39	0.29	0.28
Peak Relative Lead (N/kg)	0.41	0.52	0.61
Peak Relative Rear (N/kg)	0.08	-0.30	-0.36

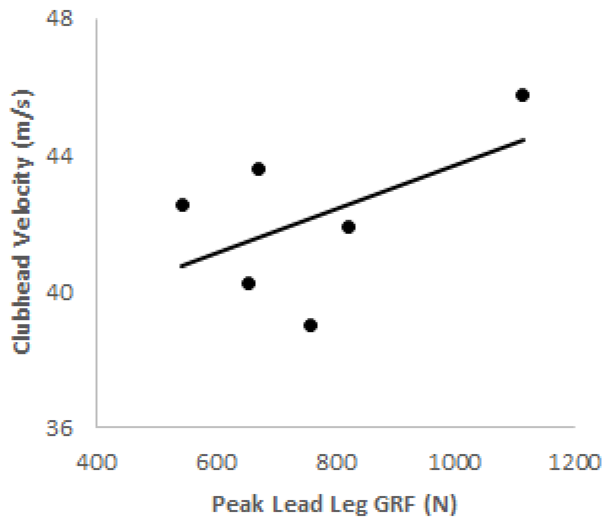

Figure 1: Relationship between ground reaction force and clubhead velocity in the driver

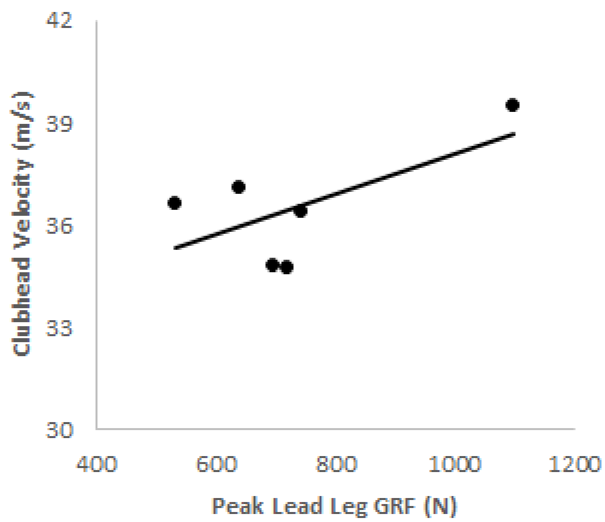

Figure 2: Relationship between ground reaction force and clubhead velocity in the 5 iron

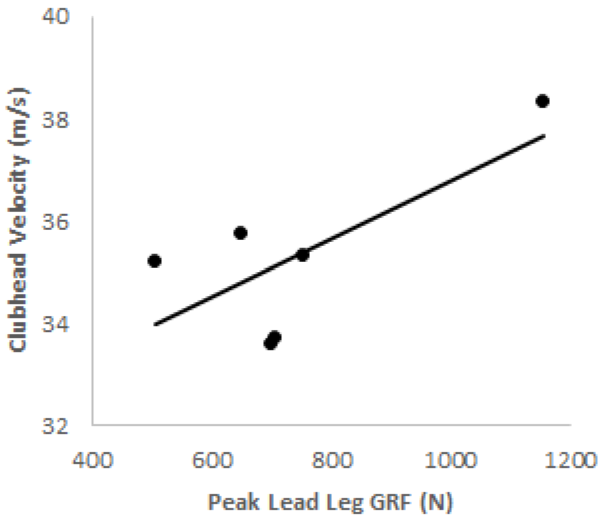

Figure 3: Relationship between ground reaction force and clubhead velocity in the 7 iron

CHAPTER V: DISCUSSION

Throughout this study, research was centered around possible relationships and correlations between the force production values in a golf swing with the related clubhead velocities. No statistically significant correlations were found between clubhead velocity and ground reaction force. Of all variables, the peak force in the lead leg showed higher correlation coefficient (*r*) values when compared to the other clubs swung; however, the values were still insignificant (Table 3). Other results from the study showed that swinging the driver produced greater ground reaction forces than the two irons that were selected (5 and 7 iron) (Table 2).

Peak force values presented as the most significant correlates in the study. In particular, peak lead leg values showed higher correlations than the peak rear leg and both relative force values. Previous research has displayed data that peak lead leg forces in males correlates with CHV (Han et al. 2019). In this study, female peak lead leg forces had even greater correlations to clubhead speed. While this was not a comparison study, data showed that the lead leg displayed greater peak and relative force values compared to the rear leg. Han et al. (2019) showed that males, peak and relative rear values were of no statistical significance. In this study, while still lower than lead leg values (r = 0.28-0.39), peak rear values were higher in females than in males (Han et al., 2019). Previous research has stated the importance of using relative force values correlated to CHV to compare data among different studies (Chu et al., 2010). The data for female players also had higher relative force correlation coefficients than the male player data. This provides support to show ground reaction forces do correlate towards CHV in females as well as males. Previous studies have supported the assertions that force production is highly correlated to CHV (Wells et al., 2018; Wells et al., 2022). The peak leg force data is shown to provide some support for these previous findings that force production is correlated to CHV. The relative and peak force values are similar to those obtained in previous research done with males and females (Chu et al., 2010; Okuda et al., 2010).

Throughout this study, different clubs were used which provided significant results. Data showed that longer club lengths usually correlated with more CHV. This finding can support the assertion that force production is related to CHV since the only recorded difference between the clubs is club shaft length and weight. Other factors could be considered for difference in results such as club head centeredness of impact and body mass. If body mass was a cause of increased CHV, this data could support the assertion that the vGRFs are related to CHV. More research needs to uncover the factors that are responsible for the difference of CHV correlations using different club lengths.

Within this study, data also showed that CHV values in female golfers were lower than previous research has determined with male golfers. Male collegiate golfers have commonly been found to have CHV values at or near 49 m/s (Wells et al., 2020). However, this study found values to be significantly lower near 42 m/s. These are novel findings and are of significant interest for future research considerations. Possible explanations of these findings may be different body mass values, training programs used, and possibly variance in testing methods between this and previous studies. While the CHV values were different, it is important to note that CHV correlations to vGRFs were higher in the female player sample in this study than males in previous studies.

Using this information, golf practitioners have data to support that training centered around the increasing of ground reaction forces could prove to be beneficial to improving clubhead velocity. Future research needs to use larger sample sizes to make the data significant. While these values have shown not to be significant, other physical values in previous literature have provided this information. Lower-body strength and upper-body power variables are factors that seem to increase clubhead velocity after training.

While ground reaction force did not provide the support for a significant correlation with CHV that was expected, limitations of the study did exist. Due to small sample size, values can portray more evidence than they entail. Data was only recovered from one sex, while a study of this nature would benefit greatly from a multi-sex study. The results provide data to suggest that a correlation between peak force in the lead leg with clubhead velocity may be possible. Greater sample sizes and improved methodologies would help provide an answer in future research.

APPENDIX A: IRB APPROVAL LETTER

Office *of*
Research Integrity

THE UNIVERSITY OF SOUTHERN MISSISSIPPI.

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NOTICE OF INSTITUTIONAL REVIEW BOARD ACTION

The project below has been reviewed by The University of Southern Mississippi Institutional Review Board in accordance with Federal Drug Administration regulations (21 CFR 26, 111), Department of Health and Human Services regulations (45 CFR Part 46), and University Policy to ensure:

- The risks to subjects are minimized and reasonable in relation to the anticipated benefits.
- The selection of subjects is equitable.
- Informed consent is adequate and appropriately documented.
- Where appropriate, the research plan makes adequate provisions for monitoring the data collected to ensure the safety of the subjects.
- Where appropriate, there are adequate provisions to protect the privacy of subjects and to maintain the confidentiality of all data.
- Appropriate additional safeguards have been included to protect vulnerable subjects.
- Any unanticipated, serious, or continuing problems encountered involving risks to subjects must be reported immediately. Problems should be reported to ORI via the Incident submission on InfoEd IRB.
- The period of approval is twelve months. An application for renewal must be submitted for projects exceeding twelve months.

PROTOCOL NUMBER:	22-007
PROJECT TITLE:	Examination of Sport-Specific Performance Parameters in Collegiate Golfers
SCHOOL/PROGRAM	Kinesiology
RESEARCHERS:	PI: Paul Donahue Investigators: Donahue, Paul~
IRB COMMITTEE ACTION:	Approved
CATEGORY:	Expedited Category
PERIOD OF APPROVAL:	24-Jan-2022 to 23-Jan-2023

Donald Sacco Jr.

Donald Sacco, Ph.D.
Institutional Review Board Chairperson

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