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Key Performance Indicators for the Golf Swing in Elite Collegiate Golf Athletes: An Exploratory Study

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ABSTRACT

Golf swing performance has been found to be influenced by health status, physical fitness, and technical abilities. However, as the sport becomes more competitive, athletes and coaches regularly seek novel approaches to optimizing athletic performance. This study sought to identify key performance indicators that are significantly related to golf club head speed within an elite collegiate golf population. Height, weight, vertical and lateral jump, upper-body rotational velocity, club head speed, and swing kinematics for 21 NCAA Division I female (n = 11) and male (n = 10) golf athletes were collected for analysis. Significant differences between female and male athletes were observed for measures of anthropometry, jumping ability, upper-extremity rotational velocity as well as clubhead speed ($p < 0.05$). Of particular interest were findings that suggest load-velocity profiling as a novel (for the sport of golf) but useful tool to support individualized golf swing profiling and technical improvement approaches. However, no significant differences between groups were observed for any rotational kinematic measure ($p > 0.05$). Interestingly, a novel assessment of swing kinematics revealed that peak rotational velocities at specific loads relative to an athlete's body mass were discovered to have a significantly moderate positive correlation with fast club head speed ($p < 0.05$). Altogether, these findings can be utilized by sports performance professionals to improve the assessment, development, and performance capabilities of golfers interested in enhancing their clubhead speed.

Keywords: physical, strength, power, college golf, sport science, fitness.

INTRODUCTION

Globally, golf is one of the most popular sports. To achieve optimal levels of performance, golf athletes must possess adequate levels of flexibility, muscular strength and power, rotational power and technical skills (Smith, 2010). Recently, interest in investigating physiological mechanisms which contribute to neuromuscular power production within the competitive golf population and how they influence golf performance (e.g., club head speed, ball speed, and drive distance) has grown (Annur et al., 2022; Bishop et al., 2022; Brennan et al., 2024; Read et al., 2014). Across sport, jump variations are commonly utilized to assess lower-body neuromuscular power within athletic populations (Anderson et al., 2018; Lockie et al., 2018; McFarland et al., 2016; Stassi et al., 2009). Specific to golf, several authors have reported significant positive relationships between measures of neuromuscular power production expressed through vertical jumping tasks and golf clubhead speed (Annur et al., 2022; Read et al., 2013; Well et al., 2018; Hellstrom et al., 2008). However, specific jump tasks and rotational kinetic characteristics have yet to be thoroughly explored within the elite collegiate golf population. Indeed, this information may be useful within the multidisciplinary performance team assigned with identifying and developing golf talent through golf-specific instruction, as well as strength training.

Several recent investigations have assessed the relationship between physical fitness characteristics and golf performance, as well as the utility of strength and conditioning approaches to enhance physical preparation and sport-specific performance in high-level amateur to elite golf populations (Annur et al., 2022; Brennan et al., 2024; Bishop et al., 2022; Robinson et al., 2024). Measures of anthropometry, joint kinematics, upper- and lower-body isometric strength, upper and lower-body power, thoracic rotation ability, and golf shot data were assessed in the 2024 study conducted by Brennan et al. (Brennan et al., 2024a) where authors suggested that the strongest relationships with golf shot data were isometric upper-body strength and vertical jumping ability (p = < 0.05; r = 0.70-0.82). Furthermore, it was discovered that athletes who were able to effectively express force and power had significantly greater club head speeds (CHS; $p < 0.05$) (Brennan et al., 2024a). In a recent systematic review conducted by Brennan et al. (Brennan et al., 2024b), the authors examined the associations between CHS and a variety of physical characteristics such as anthropometry, flexibility, lower-body strength, upper-body strength, and vertical jumping ability across 20 golf-specific scientific investigations. The authors observed significant associations between anthropometry, lower- and upper-body strength, upper-body explosive strength, vertical jump displacement, peak power, and impulse, and muscle capacity with club head speed (p = < 0.05; r: 0.47-0.82). Altogether, these findings provide evidence of the influence physical fitness characteristics have on golf-specific performance and the need for further investigations to explore more specific contributors to golfing performance. Although additional investigations aimed at observing similar physical fitness characteristics have been conducted, few, if any, have been able to capture discrete variables, or key performance indicators, that relate to the rotational power mechanism commonly seen during the golf swing. Additionally, these investigations were conducted at the professional level, while none have been conducted at the collegiate level.

Conceptually, load-velocity profiling has been most commonly implemented for vertical jumping and sprinting tasks (Cahill et al., 2019; Kotami et al., 2022; Loturco et al., 2023). A recent investigation conducted by Lotturco et al. (Loturco et al., 2023) examining jump squat force-time metrics across several loads identified differences in force, velocity, and power within a cohort of 26 male rugby union athletes. Additionally, Cahill et al., observed significant differences in sprinting force, power, and speed within a cohort of 70 male high school rugby and lacrosse athletes. These marked differences in athletic performance were found to be significantly related to external resistance applied relative to body mass during a 20-30 meter sprinting task. This information can and is currently being utilized to develop strength and conditioning programs to improve athletic performance when practically applied. For athletes who are force-deficient, heavier resistance can be utilized to enhance the development of musculature to produce near-maximal ground reactive forces. For athletes who are power-deficient, lighter loads can be utilized to enhance the application of ground reactive forces at high velocities. Thus, in theory, the previously described model can conceptually be applied to the sport of golf to observe, measure, and address specific features of swing kinematics (e.g., force, power, velocity) that may transfer to improved CHS and overall sporting performance.

Therefore, the purpose of this investigation was to identify specific KPIs that are significantly related to golf club head speed within an elite collegiate golf population. A secondary purpose of this investigation was to examine differences and similarities between males and females for measures of anthropometry, lower-body neuromuscular power, upper-body rotational velocity, and golf performance. Based on the nature of the sport, it was hypothesized that significant relationships between measures of rotational power, velocity, and CHS would be observed. This information could potentially be utilized by multidisciplinary performance teams to identify KPIs as well as develop performance approaches that chiefly aim to improve rotational neuromuscular power abilities that translate to clubhead driver speed ability.

MATERIALS AND METHODS

Experimental Approach to the Problem

In order to evaluate relationships between physical and performance characteristics of elite collegiate male and female golfers, a cross-section study design was used.

Subjects

Eleven female (age=21.2 ± 1.8yrs, ht=163.07 ± 6.86 cm, and wt=67.30 ± 8.39 kg) and ten male (age=21.0 ± 1.8yrs, ht=172.1 ± 8.32cm, and wt=77.1 ± 1.32 kg) NCAA Division I golfers participated in this study. The golfers consisted of elite amateurs playing competitive collegiate golf on teams. The men's team finished the season ranked 5th nationally and the women's team finished the season ranked 6th nationally. Within the last decade, the men's team appeared at the NCAA Championships nine times winning three national championships and the women's team appeared six times finishing once as a runner-up to the national champion. McKay et al. (McKay et al., 2022) classified this cohort of athletes as "Tier 4: Elite/International" which only includes approximately 0.003% to 0.006% of the global population.

Procedures

Anthropometrics

Height

The participant's height was recorded using a stadiometer. The participants removed their shoes and socks and were instructed to stand tall with their feet flat on the ground facing out from the stadiometer and height was measured in inches and converted to centimeters.

Weight

The participant's weight was recorded using a calibrated electronic scale with their shoes and socks off and only wearing shorts and a tee shirt. The subjects were instructed to step onto the scale and hold a standing position while weight was recorded.

Lower-Body Neuromuscular Power

Countermovement vertical jump

The CMJ was utilized to assess the stretch-shortening cycle during the coordinated whole-body locomotion. Participants began the CMJ test by performing a fast countermovement of their lower limbs to the 90-degree position and then jumping as high as possible. Participants were allowed to use a backward arm swing as they flexed their knees to the 90-degree position and forward arm swing as they extended their knees into the jump. For each jump, participants were instructed to land at the same point of takeoff. All measurements were collected with the JustJump Mat® (Probotics Inc., Huntsville, AL, USA) and closely followed valid and reliable methodological approaches utilized within previous research (Kucic et al., 2020). The best attempt of three attempts was utilized for final analyses. To minimize a possible influence of fatigue, each jump was separated by 10-15 seconds of passive rest in alignment with previously reported research methodologies (Cabarkapa et al., 2023a; Cabarkapa et al., 2023b).

Lateral Bound

The lateral bound was utilized to assess the efficient transfer of lower-body neuromuscular power in the transverse plane and has been reported in prior sports performance literature (Cesar et al., 2009). Lateral bounds were performed with the participant standing erect before flexing the knee to approximately 90 degrees with the hands on the hips to reduce upper extremity contribution to lower-extremity power production. Participants remained stabilized in the 90-degree position for 2-seconds prior to performing the jump. Stabilization in the 90-degree position reduced the use of elastic energy in the muscles. The lateral bound was assessed by having the participant position the lateral side of their front foot parallel to a tape line on the floor (simulating the golf address position). The lateral bound was performed with the dominant leg (push off leg) positioned furthest away from the tape line and then participants switched position so that the non-dominant leg was positioned furthest away from the tape line in order to get distance travelled for the dominant (DLB) and non-dominant (NDLB) leg. The participants were instructed that this is a dynamic movement and were allowed to load up and jump outward from the tape line laterally and quarter turn in the air so that both feet landed parallel to each other in order to decrease stress at the knee, each bound was separated by 10-15 seconds of passive rest. The participants were instructed to bound three times, and the best attempt was utilized for final analyses. The bounds were measured in centimeters.

Upper-Body Rotational Velocity

Upper-body rotational power was assessed using a Keiser Functional Trainer machine (Fresno, CA, USA) with the tension on the cable set at 12% (12% BM), 15% (15% BM), and 18% (18% BM) of the participant's body mass. A linear position transducer (Tendo Unit, Tendo Sport, Trencin, Slovak Republic) was attached to the Keiser arm with the tether running parallel to the Keiser cable and both were attached to a belt (Whatsthatstrap, USA) positioned over the shoulder and across the waist of the participant. The participants positioned themselves in the swing address position and were instructed to place their arms across their chest while executing a simulated fast (maximal swing) golf swing. Peak and average velocities at 12%BM (12 PV; 12AV), 15%BM (15PV; 15AV), and 18%BM (18PV; 18AV) were recorded in meters per second using the Tendo Unit during the participant's simulated swing.

Golf Performance

Club head speed (CHS) was measured using a Trackman device (Trackman, Scottsdale, AZ, USA) on the driving range. The participants were instructed to take their "normal" swing that they would take hitting a tee ball with their driver. Three swings were completed, and the highest speed was recorded as their "normal" CHS (N-CHS). The participants were then instructed to hit three additional tee balls with their driver at maximal speed in order to attain a "fast" CHS (F-CHS). Three swings were completed, and the highest speed was recorded as their "fast" CHS. Chest turn, pelvis turn, and x-factor swing kinematics were evaluated during N-CHS conditions by utilizing the SportsBox 3DGolf artificial intelligence smartphone application (Sportsbox.ai, Inc., Bellevue, WA, USA). Each of the metrics of interest are proprietary to the SportsBox company. According to information publicly available on their website (https://help.sportsbox.ai/what-trackers-are-included-with-3d-practice), the chest turn is the angle of rotation of the rib cage around the spine during the swing. The pelvis turn is the angle at which the pelvis turns during the backswing. The chest and pelvis turn angle (or rotation) at the top of the backswing were assessed in degrees for each of the three attempts and the average was utilized for statistical analysis. X-Factor measured the turn angle (or rotation) of the chest with respect to the turn angle (or rotation) of the pelvis and may be an indirect measure of golf specific stretch shortening cycle mechanisms. The X-Factor is negative when the chest is turned more away from the target than the pelvis and positive when the chest is turned more towards the target than the pelvis.

Statistical Analyses

Data was analyzed using IBM SPSS statistics (Version 24.0; IBM Corporation, New York, NY). Descriptive statistics were calculated to summarize results from the dataset. Shapiro-Wilk's test corroborated that the normality assumption was not violated for any dependent variables examined in the present study. A priori power analysis using G*Power software 3.1.9.7 version was conducted to determine the necessary effect size. Based on a desired power of 0.80 at a significance level of 0.05, the calculated effect size was 0.49. Independent samples t-test were calculated to compare mean group differences between female and male participants. The a priori was set at $p < 0.05$. For correlation analysis, the Pearson R was utilized, where the interpretations were as follows: weak correlation: R < 0.40, moderate correlation: R < 0.70, and strong correlation: R > 0.70 (Schober et al., 2018). The present study conformed to the principles outlined in the Declaration of Helsinki and was approved by Institutional Review Board (IRB) of Oklahoma State University (OSU) (OSU IRB-21-395).

RESULTS

Descriptive statistics for each dependent variable are presented in Tables 1-5. As hypothesized, significant differences were observed between sexes for specific measures of lower-body neuromuscular power. However, no significant differences were observed for 12 PV, 12 AV, 15 AV, 18 AV, or rotational kinematic measures ($p > 0.05$) reported in this study.

DISCUSSION

The purpose of this study was to assess rotational load-velocity characteristics within a cohort of elite NCCA Division-I collegiate golfers. The findings indicated that differences in measures of anthropometrics, sagittal and transverse jumping ability, and rotational peak velocity exist between sexes. Furthermore, peak rotational velocities at specific loads relative to an athlete's body mass were discovered to have a significantly moderate positive correlation with fast club head speed. However, no statistically significant differences were observed between female and male collegiate golfers in any measure of rotational average velocity or rotational kinematics, respectively. To our

Table 1. Descriptive statistics, means, and standard deviations (x̄ ± SD), for anthropometrics, vertical and horizontal jump metrics, rotational velocity metrics at 12%, 15%, and 18% body weight, and golf swing metrics.

Measure	Male	Female	*p*	CI
Anthropometrics				
Height (cm)	175.26 ± 8.33*	163.20 ± 6.96	0.002	158.51-167.85
Weight (kg)	78.05 ± 10.80*	67.29 ± 8.39	0.019	61.65-72.92
Body Mass Index (kg/m^2)	25.40 ± 3.85	25.39 ± 2.82	0.991	22.81-27.99
12% Body Mass	9.37 ± 1.30*	8.07 ± 1.01	0.019	7.40-8.75
15% Body Mass	11.71 ± 1.62*	10.09 ± 1.26	0.019	9.25-10.94
18% Body Mass	14.05 ± 1.94*	12.11 ± 1.51	0.019	11.10-13.13
Jump performance				
Countermovement Jump Height (cm)	62.38 ± 6.78*	42.19 ± 4.88	< 0.001	46.43-57.18
Countermovement Jump Flight Time (s)	0.70 ± 0.49*	0.58 ± 0.03	< 0.001	0.61-0.67
Dominant Lateral Bound (cm)	180.09 ± 26.59*	127.23 ± 15.88	< 0.001	138.78-168.02
Non-Dominant Lateral Bound (cm)	183.52 ± 22.96*	119.66 ± 15.54	< 0.001	132.89-167.26
Rotational velocity metrics				
12% Peak Velocity (m/s)	2.54 ± 0.37*	2.15 ± 0.40	0.032	1.89-2.42
12% Average Velocity (m/s)	1.46 ± 0.16	1.30 ± 0.23	0.073	1.14-1.44
15% Peak Velocity (m/s)	2.55 ± 0.37*	2.05 ± 0.39	0.007	1.78-2.31
15% Average Velocity (m/s)	1.48 ± 0.15	1.32 ± 0.24	0.085	1.16-1.48
18% Peak Velocity (m/s)	2.52 ± 0.32*	2.14 ± 0.38	0.023	1.89-2.40
18% Average Velocity (m/s)	1.47 ± 0.17	1.38 ± 0.23	0.333	1.23-1.54
Golf swing metrics				
Clubhead Speed-N (mph)	115.92 ± 4.03*	93.53 ± 5.67	< 0.001	89.72-97.34
Clubhead Speed-F (mph)	120.42 ± 4.70*	95.47 ± 5.57	< 0.001	91.73-99.21
Chest Turn Angle (°)	99.20 ± 3.08	97.27 ± 4.45	0.268	94.28-100.26
Pelvis Turn Angle (°)	45.20 ± 3.76	45.18 ± 11.44	0.996	37.50-52.86
X-Factor Angle (°)	61.10 ± 2.60	60.64 ± 5.39	0.808	57.02-64.26

**indicates significant difference ($p < 0.05$) compared to female golf athletes; CMJ = countermovement jump, LB = lateral bound, Clubhead Speed-N = normal clubhead speed and Clubhead Speed-F = fast clubhead speed.*

knowledge, the current study is the first to identify KPIs by assessing the relationships between club head speed and rotational characteristics by utilizing load-velocity methods within golf populations. Additionally, these findings contribute to the greater body of knowledge by successfully developing and implementing novel measurements that are specific to golfing performance (Annur et al., 2022 and Smith et al., 2010). Altogether, this study successfully identified the relationship between external loads, physical qualities such as rotational velocity, and their relationship to club head speed. These findings may be beneficial for sports performance practitioners seeking alternative methods for evaluating and enhancing athletic performance based on the KPIs club head speed within golf populations.

It was hypothesized that anthropometric measurements would significantly differ between female golf athletes compared to male golf athletes. Findings of the current investigation are in agreement with those previously reported in research within elite collegiate and collegiate golf populations examining measures of height (male; 173.1 ± 0.04 cm and 176.7 ± 5.6 cm, female; 156.4 ± 0.02 cm and 162.6 ± 4.7 cm), body mass (male; 74.6 ± 10.9 kg and 78.6 ± 17.3 kg, female; 59.7 ± 7.3 kg and 60.2 ± 10.4 kg), and body mass index (male; 24.9 ± 3.9 kg/m^2 and 25.1 ± 4.9 kg/m^2, female; 24.4 ± 2.6 kg/m^2 and 22.7 ± 3.0 kg/m^2) (Annur et al., 2022 and Son et al., 2016). These findings provide a meaningful contribution to the field related to athlete health and body composition recommendations for NCAA Division-I male and female golfers. For sport coaches, understanding how an athlete's height, weight, and somatotype based on their relationship to club head speed can potentially assist with identifying or developing an approach for identifying talent based. Although, it should be noted that physical and physiological aspects of performance are but several factors that

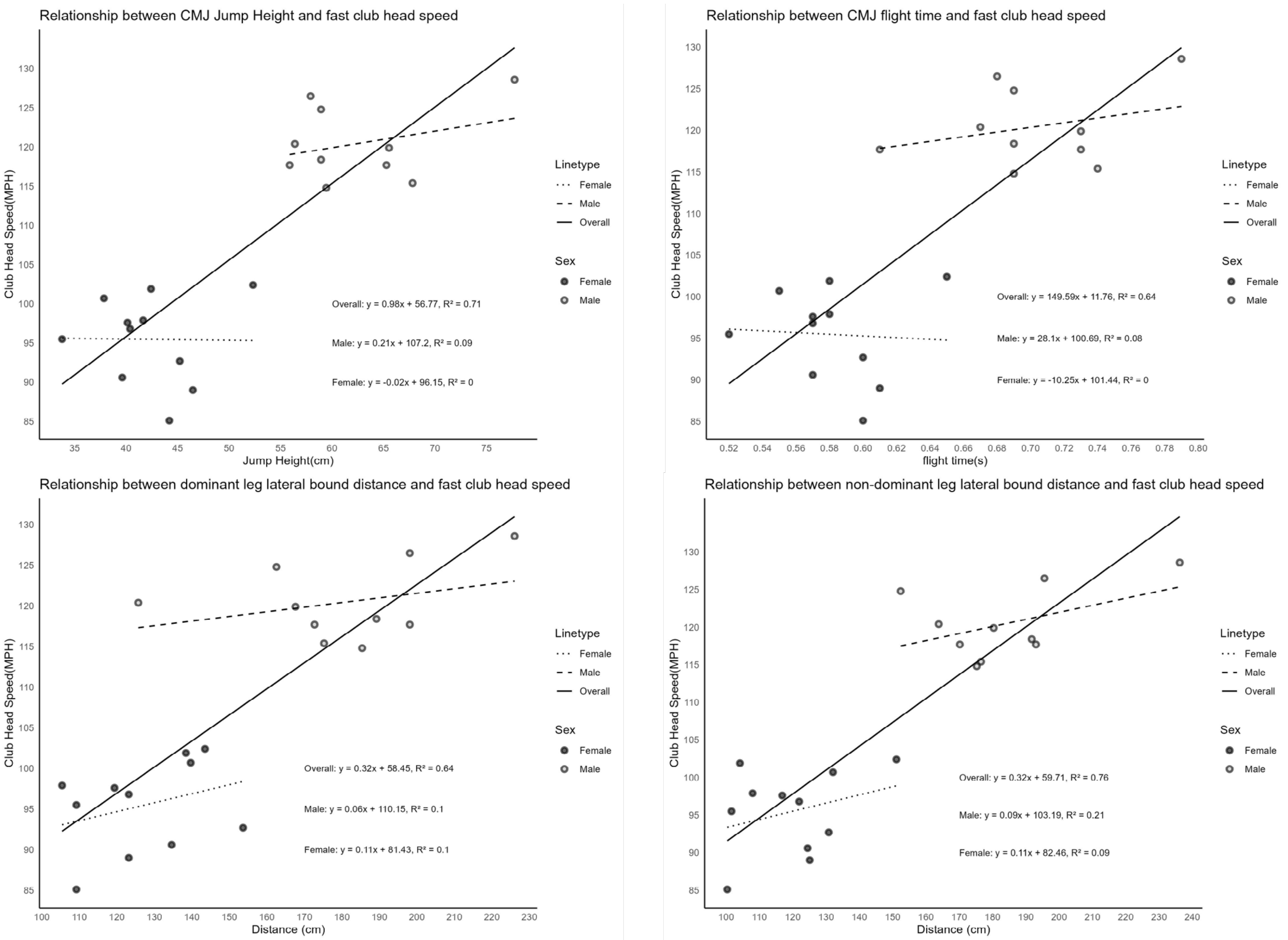

Figure 1. Scatterplots illustrating the relationships between countermovement and lateral bound performance and fast club head speed.

Table 2. Pearson's r correlations between golf shot data and key performance indicators.

Variables		Normal Clubhead Speed	Fast Clubhead Speed
Anthropometry	Height	0.619*	0.657**
	Weight	0.414	0.451*
CMJ	Height	0.825**	0.840**
	Flight Time	0.792**	0.801**
DLB	Distance	0.790**	0.802**
	NDLB	0.876**	0.873**
12% Body mass	Peak Velocity	0.407	0.436*
	Average Velocity	0.334	0.355
15% Body mass	Peak Velocity	0.508*	0.526*
	Average Velocity	0.352	0.365
18% Body mass	Peak Velocity	0.404	0.439*
	Average Velocity	0.199	0.221
Kinematics	B Shoulder Turn	0.166	0.199
	B Pelvic Turn	0.123	0.145
	B X Factor	-0.125	-0.105

**indicates significant correlations (p < 0.05), ** indicates significant difference (p < 0.001)* ultimately contribute to optimal athletic performance and others should be explored (e.g., psychological factors, technical ability, tactical ability, etc.). For sports performance professionals who are tasked with developing talent, these findings can be used to rationalize the development and implementation of strength and conditioning programming aimed at improving body composition for sports performance. In the future, research within golfing populations that explores strength and conditioning programming characteristics (i.e., training frequency, intensity, time, type, volume, rest, and progression) along with measures of physical and physiological performance could advance our understanding of how health, physical fitness, and athletic performance may be related within this population and perhaps may be useful for translation across sport and general populations.

It was hypothesized that lower-body neuromuscular power would significantly differ between female golf athletes compared to male golf athletes. Findings from the current investigation suggested that males jumped significantly higher than females in the CMJ, and further in DLB and NDLB tasks. However, it should be noted that athletes within the current study, both male and female, jumped higher than those who participated in previous studies examining similar populations (male; 37.9 ± 6.8 cm, female; 24.0 ± 6.0 cm and 20.8 ± 3.1 cm) (Robinson et al., 2024 and Annur et al., 2022). Interestingly, the NDLB task was the strongest correlate of club head speed in both normal and fast conditions. This finding is unique as the lateral bound assessment within the golfing population was a novel development by Dr. Douglas B. Smith of the OSU-GRIP staff to better understand KPIs of club head speed and had not been included in prior literature for this demographic. These findings may be utilized by strength and conditioning professionals when developing and implementing training programs for enhancing physical characteristics that transfer to golf performance. For instance, by understanding the lower-body neuromuscular power capabilities of elite level collegiate golfers reported here and previously, performance benchmarks can then be set to 1.) guide training approaches 2.) motivate athletes during resistance training activities and 3.) to enhance physical preparation and performance. However, prior to the design of a narrowly focused training program, the practitioner must have a thorough fundamental understanding of designing an annual training plan, conducting a needs and competition analysis, evaluating athlete health and physical fitness, and long-term athlete development in order to ensure the right means and methods for physical development are selected. As technology advances, future research would benefit from the integration of force plate technology into the assessment of lower-body neuromuscular power during the CMJ task. In addition to understanding performance variables such as jump height and jump velocity, a further understanding of eccentric and concentric neuromuscular force and power could be gleaned, especially as it ultimately relates to enhanced golfing performance.

Lastly, it was hypothesized that load-dependent rotational characteristics and clubhead speed would significantly differ between female golf athletes compared to male golf athletes. Based on the results of this study, this hypothesis was partially supported. Significant differences were observed between sexes for peak upper-body rotational velocity at each load relative to body mass. However, no significant differences were observed between loads for average upper-body rotational velocity. Altogether, these findings may be attributable to differences or similarities in upper-extremity body composition (i.e., total mass, muscle mass, lean body mass, fat mass, etc.), or in golf swing strategies, techniques, and kinematic sequencing between the sexes. Of particular interest to the authors were the similarities between sexes for the measure of average upper-body rotational velocity whereby at the elite collegiate level, female athletes produce similar rotational velocities as their male counterparts. Perhaps this observation was a result of the nature of the measure itself and the average velocity of a highly technical movement, but the authors posit that it is quite possible that this may also be a display of mastery of sporting techniques from the understudied elite female athlete population. However, this exceeded the scope of the current investigation and requires further inquiry with larger sample sizes to better understand why or how this difference exists. To the readers' interest, the findings from this study have produced one other novel discovery pertinent to the development of the rotational athlete. The identification of optimal external loads relative to body mass were positively correlated with club head speed. Peak upper-extremity rotational velocities at relatively lighter and heavier loads (12% and 18% of an athlete's body mass) were positively correlated with fast club head speeds. While peak and average upper-extremity rotational velocities at a relatively moderate load (15% of an athlete's body mass) were positively correlated with normal club head speeds. The discovery of these optimal loads were created in part by techniques used to assess other, more dynamic qualities (i.e., load-velocity profiling for linear sprinting). Therefore, and prior to providing recommendations for using these loading parameters to enhance golf swing performance, the authors would like to encourage sports performance researchers to continue to explore concepts, models, and ideas outside of their field.

The authors recommend utilizing an evidence-based resistance training approach that is designed to improve strength-endurance, neuromuscular strength, and neuromuscular power which may translated to upper-extremity rotational velocity, clubhead speed and overall athletic performance (Johnson, 2025). One such resistance training approach is the ten, five, three model developed by Johnson, 2025 as it is adaptable to sport, sex, and training age. Within this model, exercise categories are organized and programmed based on the physical or physiological characteristic targeted for improvement. For the development of strength-endurance, exercise techniques, and foundational strength, the 10-repetition range is utilized and incorporates foundational movements such as the squat, step, hinge, lunge, push, pull, and carry exercises. For the development of absolute and relative neuromuscular strength, the 5-repetition range is utilized and incorporates multi-joint exercises such as the barbell back squat, front squat, bench press, incline press, overhead press, and deadlift. For the development of neuromuscular power and the stretch-shortening cycle, the 3-repetition range is utilized which incorporates plyometric, ballistic, and Olympic weightlifting exercises. Lastly, and once sufficient neuromuscular strength has been developed, it may be beneficial for the sports performance practitioner to introduce upper-extremity rotational exercises at specific loads similar to those introduced in this manuscript. One such strategy for progressing the loading of this recommendation may follow this order; 1.) 15% of body mass to develop upper-extremity rotational peak and average velocities for normal club head speed, 2.) 18% of body mass to develop upper-extremity rotational peak velocity for fast club head speed emphasizing maximal force expression, and finally 3.) 12% of body mass to develop upper-extremity rotational peak velocity for fast club head speed while emphasizing maximal exercise movement speed with proper form. Sequentially, this approach could be implemented in a block, linear, or undulating periodization fashion for developmental, intermediate, and advanced athletes (see Figure 2.). Careful consideration of training load and volume may be essential to avoid the inhibition of golf swing kinetics.

While the results of this study highlight the importance of profiling athletic qualities such as lower-body neuromuscular power, it is not without limitations. Based on the nature of the collegiate performance setting as well as training and competition schedules, it may be useful to monitor physiological performance variables throughout the duration of a competitive season. Sports performance professionals may also benefit from collaborating to establish normative values for each

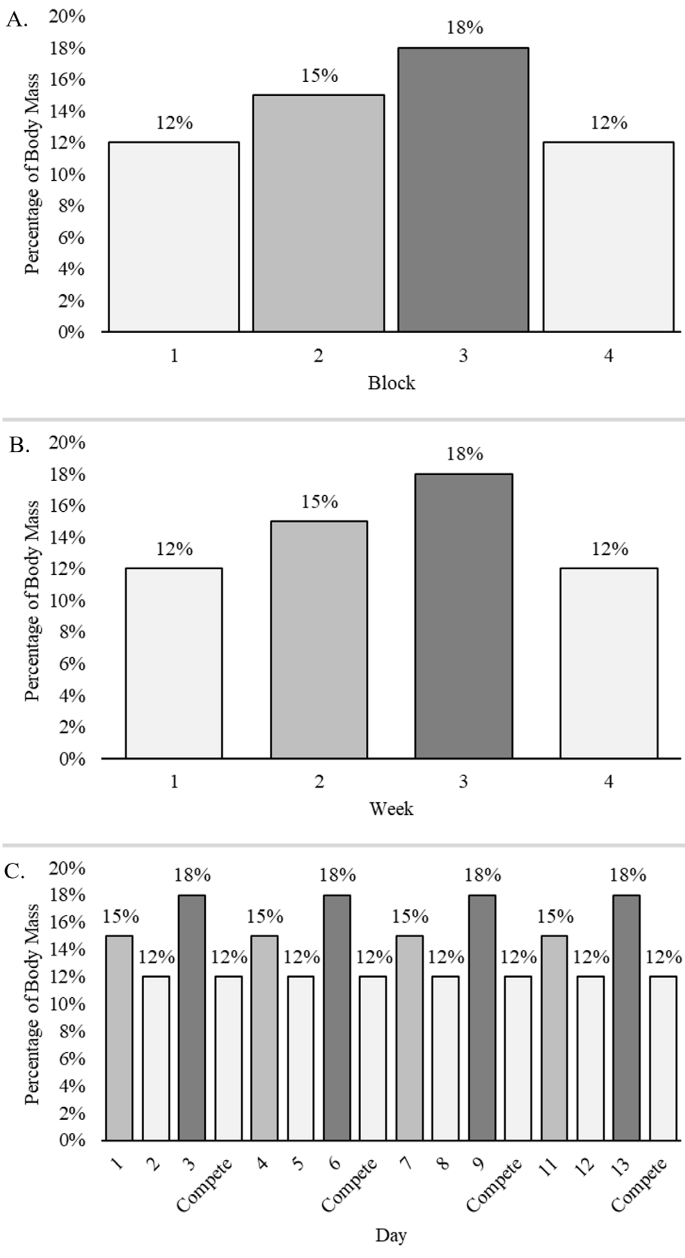

Figure 2. Periodization models for improving upper-body rotational velocity by implementing A.) block periodization for developmental golfers, B.) linear periodization for intermediate golfers, or C.) Undulating periodization for advanced golfers. Training blocks, weeks, and days starting at 12% body mass have been included as an introductory component.

of the variables assessed within this study. Although not explored within this study, researchers may also find it beneficial to examine the relationships between heavier loads relative to body mass and club head speeds. Lastly, longitudinal assessments of physiological performance can also be beneficial to account for resistance training approaches utilized to enhance athletic performance. In the future, stratifying athletes by their resistance training age can contribute to further understanding differences and similarities between measures of athletic performance. Finally, a larger sample size is recommended if a similar statistical analysis approach is to be taken.

To conclude, the findings of the present study observed significant differences in measures of anthropometry, sagittal and transverse lower-body jumping ability, and rotational peak velocity between sexes. Furthermore, peak rotational velocities at specific loads relative to an athlete's body mass were discovered to have a significantly moderate positive correlation with fast club head speed, which we believe to be a novel discovery regarding meaningful KPIs within golf. To our knowledge, the current study is the first to assess the relationships between club head speed and rotational characteristics by utilizing load-velocity methods within collegiate golfers.

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CONFLICTS OF INTEREST

The authors report no conflict of interest.

FUNDING

This study received no specific funding in order to be completed.

ETHICAL APPROVAL

The present study conformed to the principles outlined in the Declaration of Helsinki and was approved by Institutional Review Board (IRB) of Oklahoma State University (OSU) (OSU IRB-21-395).

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REFERENCES

1. Bishop, C., Ehlert, A., Wells, J., Brearley, S., Brennan, A., & Coughlan, D. (2022). Strength and conditioning for golf athletes: biomechanics, injury risk, physical requirements, and recommendations for testing and training. Professional Strength and Conditioning, (64), 7-18.
2. Brennan, A., Murray, A., Coughlan, D., Wells, J., Xu, J., Turner, A., ... & Bishop, C. (2024a). Associations and within-group differences in physical characteristics and golf performance data in high-level amateur players. Applied Sciences, 14(5), 1854.
3. Brennan, A., Murray, A., Mountjoy, M., Hellstrom, J., Coughlan, D., Wells, J., ... & Bishop, C. (2024b). Associations between physical characteristics and golf clubhead speed: A systematic review with meta-analysis. Sports Medicine, 1-25.
4. Cahill, M. J., Oliver, J. L., Cronin, J. B., Clark, K. P., Cross, M. R., & Lloyd, R. S. (2019). Sled-pull load–velocity profiling and implications for sprint training prescription in young male athletes. Sports, 7(5), 119.
5. Kotani, Y., Lake, J., Guppy, S. N., Poon, W., Nosaka, K., Hori, N., & Haff, G. G. (2022). Reliability of the squat jump force-velocity and load-velocity profiles. The Journal of Strength & Conditioning Research, 36(11), 3000-3007.
6. Kukić, F., Todorović, N., Čvorović, A., Johnson, Q., & Dawes, J. J. (2020). Association of improvements in squat jump with improvements in countermovement jump without and with arm swing. Serbian Journal of Sport Sciences, 1(3), 29-35.
7. Loturco, I., McGuigan, M. R., Pereira, L. A., & Pareja-Blanco, F. (2023). The load-velocity relationship in the jump squat exercise. Biology of Sport, 40(2), 611.
8. Smith, M.F (2010). The role of physiology in the development of golf performance. Sports Med 40, 635–655.
9. Anderson E., Lockie R.G., & Dawes J.J. (2018). Relationship of absolute power and relative lower-body strength to predictors of athletic performance in collegiate women soccer players. Sports 6(4), 106.
10. Lockie R.G., Dawes J.J., & Jones M.T. (2018). Relationships between linear speed and lower-body power with change-of direction speed in National Collegiate Athletic Association Divisions I and II women soccer athletes. Sports 6(2), 30.
11. McFarland I.T., Dawes J.J., Elder C.L., & Lockie R.G. (2016). Relationship of two vertical jumping test to sprint and change of direction speed among male and female collegiate soccer players. Sports 4(1), 11.

12. Stassi R.H., Dardouri W., Yahmed M.H., Gmada N., Mahfoudhi M.E., & Gharbi Z. (2009). Relative and absolute reliability of a modified agility t-test and its relationship with vertical jump and straight sprint. The Journal of Strength Conditioning Research 23(6), 1644-1651.
13. Read, P. J., & Lloyd, R. S. (2014). Strength and conditioning considerations for golf. Strength & Conditioning Journal, 36(5), 24-33.
14. Read, P. J., Lloyd, R. S., Croix, M. D. S., & Oliver, J. L. (2013). Relationships between field-based measures of strength and power and golf club head speed. The Journal of Strength & Conditioning Research, 27(10), 2708-2713.
15. Robinson, L., Murray, A., Coughlan, D., Mountjoy, M., Hembrough, R., Glover, D., Scott, F., Turner, A., & Bishop, C. (2024). Relationships and within-group differences in physical attributes and golf performance in elite amateur female players. Life (Basel, Switzerland), 14(6), 674. https://doi.org/10.3390/life14060674
16. Wells, J. E., Mitchell, A. C., Charalambous, L. H., & Fletcher, I. M. (2018). Relationships between highly skilled golfers' clubhead velocity and force producing capabilities during vertical jumps and an isometric mid-thigh pull. Journal of Sports Sciences, 36(16), 1847-1851.
17. Hellstrom J. (2008). The relation between physical tests, measures and club head speed in elite golfers. International Journal of Sports Science & Coaching 3(1_suppl), 85–92.
18. Annur, M. S. S., Adnan, M. A., Mohamed, M. N., Radzi, N. A. A. M., Kasim, N. A. A., Ismail, S. I., & Hasan, H. (2022). Relationship between selected physical fitness indicators and golf performances among elite university golfers. Journal of Physical Education and Sport, 22(10), 2420-2426.
19. Schober P, Boer C, Schwarte LA. Correlation Coefficients: Appropriate Use and Interpretation. Anesthesia & Analgesia 126: 1763-1768, 2018.
20. Son, S., Han, K., & So, W. Y. (2016). The relationships of waist and mid-thigh circumference with performance of college golfers. Journal of Physical Therapy Science, 28(3), 718-721.
21. McKay, A. K., Stellingwerff, T., Smith, E. S., Martin, D. T., Mujika, I., Goosey-Tolfrey, V. L., Sheppard, J., & Burke, L. M. (2022). Defining training and performance caliber: A participant classification framework. International Journal of Sports Physiology and Performance, 17(2), 317-331. Retrieved Oct 9, 2024, from https://doi.org/10.1123/ijspp.2021-045.
22. Cabarkapa, D., Cabarkapa, D. V., Aleksic, J., Philipp, N. M., Scott, A. A., Johnson, Q. R., & Fry, A. C. (2023). Differences in countermovement vertical jump force-time metrics between starting and non-starting professional male basketball players. Frontiers in Sports and Active Living, 5, 1327379.
23. Cabarkapa, D., Cabarkapa, D. V., Philipp, N. M., Knezevic, O. M., Mirkov, D. M., & Fry, A. C. (2023). Pre-post practice changes in countermovement vertical jump force-time metrics in professional male basketball players. The Journal of Strength & Conditioning Research, 37(11), e609-e612.
24. Meylan, C., McMaster, T., Cronin, J., Mohammad, N. I., Rogers, C., & DeKlerk, M. (2009). Single-leg lateral, horizontal, and vertical jump assessment: Reliability, interrelationships, and ability to predict sprint and change-of-direction performance. The Journal of Strength & Conditioning Research, 23(4), 1140-1147.
25. Johnson, Q. R. (2025). Part I: Development and implementation of the ten, five, three (TFT) model for resistance training. Muscles, 4(2), 14.