Physiological Correlates of Golf Performance

Greg D. Wells,[1] Maryam Elmi,[1] and Scott Thomas[2]

[1]*Department of Physiology and Experimental Medicine, The Hospital for Sick Children; and* [2]*Faculty of Physical and Health Education, The University of Toronto, Toronto, Ontario, Canada*

Abstract

Wells, GD, Elmi, M, and Thomas, S. Physiological correlates of golf performance. *J Strength Cond Res* 23(3): 741–750, 2009—Golf is now a sport where physical training is an integral component of elite players' practice and contributes to the ability to play at a high level consistently and without injury. Relationships between physical conditioning and golf performance have not been reported. Therefore, the objective of this research was to identify physiological correlates of golf performance in elite golfers under laboratory (ball speed and distance) and tournament conditions (average score, greens in regulation, short game measures, and putting accuracy).

The correlation analysis revealed significant associations between mass, height, body mass index, sit height, arm length, and predicted $\dot{V}O_{2max}$ and golf measures. Significant correlations were noted between anterior abdominal muscle endurance and driver carry distance ($r = 0.38$; $P = 0.04$) and average putt distance after a chip shot ($r = -0.44$; $P = 0.03$), between dominant side abdominal muscle endurance and average putt distance after a chip shot ($r = -0.43$; $P = 0.03$), and between nondominant-side abdominal muscle endurance and average putt distance after a sand shot ($r = -0.59$; $P = 0.001$). Further correlations were found among sit and reach and driver carry distance ($r = -0.36$; $P = 0.04$), 5-iron ball speed ($r = -0.41$; $P = 0.02$), 5-iron carry distance ($r = -0.44$; $P = 0.01$), and score ($r = 0.43$; $P = 0.03$). Correlation analysis revealed significant associations among peripheral muscle test results, golf driver results, 5-iron ball measures, score, and putting efficacy. These results may be important for developing training programs based on sound physiological rationale and for the development of talent identification programs. Results suggest that core strength and stability, flexibility, balance, and peripheral muscle strength are correlated with golf performance and should be included in golf training programs.

Address correspondence to Greg D. Wells, greg.wells@utoronto.ca.

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Introduction

Golf is a very demanding physical game, not only in terms of precision and complexity of the golf swing movement, but also in terms of creating explosive power through a wide range of motion. Researchers have described the golf swing as a complex movement of the whole body that transfers power to a golf ball to propel the ball great distances with accuracy (15). For example, a typical male player will maximally recruit 30 lbs of muscle to generate 4 horsepower during a golf swing using nearly every joint and limb in the body (3), a very high power output that translates into 900 kg of force being applied to the ball in little more than half a millisecond at impact. Typical club head speeds (the velocity at which a golf club impacts with a golf ball) during a golf swing can exceed 160 $km \cdot hour^{-1}$, and it takes only 0.2 seconds for the golfer to accelerate the club to this speed (3). This is done 30–40 times per round. Furthermore, elite golfers can produce these movements while maintaining consistent clubface alignment within 2 degrees from shot to shot. The cardiovascular demands of walking the golf course (using a pull cart for clubs) for normal healthy individuals has been reported to be approximately 8.2 ± 0.2 metabolic equivalents per 18 holes (5) and requires approximately 46 ± 2.6% of a golfers functional capacity on a flat course or 50–85% on a hilly course (5).

Recently, the sport of golf has been revolutionized by the performances of players like Tiger Woods and Annika Sorenstam. One of the factors that helped these players reach their #1 world ranking is their commitment to physical preparation, including balance, flexibility, posture, core stability, strength, power, and cardiovascular training. The new breed of elite player is leaner, more muscular, and more flexible than players in the previous generation. Golf players have also discovered the importance of physical preparation in preventing and recovering from injuries (9), a topic that has recently been reviewed by McHardy et al. (16). Golf is now a sport where physical training is an integral component of elite players' practice regimen and contributes to the ability to play at a high level consistently and without injury (16).

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In a recent review of the biomechanics of the golf swing (11), the authors suggested that physical conditioning will help recruit the muscles in the correct sequence and to the optimum effect. This suggestion has been supported by the results of a recent study that investigated the effects of an 11-week strength, power, and flexibility training program on intercollegiate golfers that resulted in a significant increase in club head speed and driving distance (4). In addition, earlier reports (7,10,14) also demonstrated a significant increase in club head speed and driving distance after weights and plyometrics training programs.

Studies on the effect of training on golf performance have not been reported for an elite cohort, with studies reporting the effect of training at the university level (4) or on recreational subjects (14), for example. Further, the training programs that have been investigated used a combination of strength, power, plyometrics, and flexibility training. Relationships between elements of conditioning (balance, flexibility, core strength, upper- and lower-body strength and power, and cardiovascular conditioning) and golf performance have not been reported. Differences between the physiological characteristics of male and female golfers and how these characteristics impact golf performance have also not been reported. Given the body of research demonstrating the positive effect of physical training on many different sport activities, it was hypothesized that there would be positive correlations between physiological performance measures and golf performance measures. Therefore, the objective of the current research was to identify statistically significant physiological correlates of golf performance in elite amateur golfers.

The physiological capacities that were evaluated were: (a) balance, (b) flexibility, (c) abdominal muscle performance, (d) peripheral muscle performance, and (e) cardiovascular function. The golf variables that were evaluated were driver and 5-iron ball speed and distance, total score, greens in regulation, measures of short game, sand shot making ability, and putting efficiency. The primary hypothesis of this study was that there would be significant positive correlations between measures of physiological capacities and driver and 5-iron ball speed and distance and significant negative correlations between score, greens in regulation, and short game, sand, and putting measures. The rationale for this hypothesis is that physiological capacities might improve the ability of golfers to perform golf skills at a higher level of proficiency. The secondary hypothesis was that there would be significant differences between the results of the physiological assessments between male and female players, and the rationale for this hypothesis is that there may be differences in how physiological characteristics of male and female players influence their ability to execute certain sport skills.

Methods

Experimental Approach to the Problem

A correlation study design was used to answer the primary research question to determine the correlation between physiological characteristics of elite golfers (balance, flexibility, core strength, peripheral strength and power, and cardiovascular function) and golf performance under laboratory conditions (ball speed [velocity] and ball distance [displacement] achieved using both a driver and a fairway iron) and under tournament conditions (average score, greens in regulation, short game measures, and putting accuracy). Correlation analysis was chosen as the study design because we were interested in determining the strength and direction of the relationship between physical characteristics of golfers and their game performance. We assigned the physiological measures as independent and the golf performance measures as the dependent variables to establish physiological characteristics as possible predictor variables for golf performance. Velocity and displacement were both evaluated because the shot distance is affected by not only the ball speed immediately after impact, but also ball spin and trajectory. Secondary comparative analyses were performed between male and female groups.

Subjects

With approval from the Human Ethics Committee at the University of Toronto (Protocol reference number 20175) and written informed consent, we recruited 24 healthy Canadian National Golf Team members (9 women and 15 men) to participate in the study. They had no declared health problems and had previously completed all tests reported herein as part of their regular sport training regimen. All participants had been involved with competitive golf training for at least 5 years before the beginning of the study and were actively involved with golf training and performance at the time of the study. The participants were the best amateur golfers in Canada, and several were actively competing in the National Collegiate Athletic Association university sport system during the academic year. Six members of the cohort represented Canada at the World Amateur Golf Championships.

Procedures

Descriptive data were collected for all subjects, including sex, date of birth, height, body mass, and history of competitive golf statistics including current handicap (a rating of golf performance). Experimental golf data were collected (a) during a testing session at a fitness center for physiological variables, (b) during a separate testing session at an approved Royal Canadian Golf Association testing facility (Titleist Fitting Centre, Toronto, Canada) during the competitive golf season, and (c) from data entered by the players to track their tournament golf performance in an online database (www.shot-by-shot.com). Physiological data were collected by 2 trained kinesiologists and a Ph.D. level exercise physiologist. Before testing, the players were led through a brief standardized warm-up that consisted of light running and stretching for approximately 10 minutes. Physical tests were conducted in a standard order to minimize fatigue, and at least 5 minutes of recovery was provided between tests.

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Physical tests were conducted in the morning and golf tests in the afternoon at least 2 hours after the completion of the physical tests. The physical performance testing was conducted at a training camp held near the beginning of the competitive season in June. Driver and 5-iron performance data were collected during the same camp. The tournament performance data were collected from tournaments held during the same season from June to August.

Anthropometric Protocol

The following variables were collected according to the methods published in Wells et al. (18): Standing and sitting height to the nearest 0.2 m was assessed by using a Health-O-Meter weighing scale (Health-O-Meter 400S; Sunbeam Products Inc., Boca Raton, Fla) with a vertical measuring rod. Mass was assessed to the nearest 0.5 kg with the same Health-O-Meter scale. Limb length variables included (a) total arm length, measured as the length from the greater tuberosity of the humerus to the ulnar styloid with the elbow fully extended, and (b) total leg length, with the participant in standing position, measured as the length from the greater trochanter of the femur to the level of the medial malleolus on the lateral side of the leg.

Flexibility Protocol

The sit-and-reach test of hamstring, hip, and lower back flexibility was used to assess general flexibility, as described by Church et al. (2). Sit and reach was measured while the subjects sat with legs extended and together, knees locked, and toes pointed upward. The athlete then reached forward while exhaling with both hands together and stretched out as far as possible along the sit and reach box. The reach was held for at least 2 seconds. This was repeated for the dominant leg and nondominant leg separately, with the opposing leg held with a 90-degree bend at the knee and foot placed against the inside of the test leg. The measurement was taken as the distance reached beyond the heel to the nearest 0.5 cm. The test was repeated twice with the highest value taken as the score.

Balance Protocol

The athletes were instructed to stand on one foot and to place the foot of the other leg against the lower part of the support leg just below the knee. Then, the hands were placed on the hips. The test began when the athlete raised their heel of the support foot from the floor and were instructed to maintain their balance for as long as possible. The test ended when the athlete replaced their heel to the floor or removed their hands from their hips. The test was performed for both right and left legs. The result was the time in seconds, and the best time of 3 attempts was taken as the result. Test-retest reliability (intraclass correlation coefficient) for the balance protocol was determined to be $r = 0.81$; $P = 0.0001$; $n = 17$.

Abdominal Muscle Performance Protocol

The participants began this test lying prone and placed their hands and elbows on the ground (Figure 1). The test began when then they raised their body off the ground using their hands and toes as pivot points. The participants were required to maintain their body in a straight line and in a neutral position. The result was the maximum amount of time that the position was held without movement (i.e., the hips are raised, then lowered). The test ended when the subject (a) returned their body to the ground, (b) moved their core body in any way (reshifting or repositioning), or (c) allowed their hips or head to sag toward the ground. The result was time in seconds. The abdominal muscle performance test was performed in 3 positions: front, dominant side (Figure 2), and nondominant side. Test-retest reliability (intraclass correlation coefficient) for the abdominal muscle protocol was determined to be $r = 0.48$; $P = 0.058$; $n = 16$.

Figure 1. Demonstration of the positioning required during the anterior abdominal muscle endurance test.

Peripheral Muscle Performance Protocol

Upper-body and lower-body muscle performance were assessed using general tests of strength and power. Leg power

Figure 2. Demonstration of the positioning required during the side abdominal muscle endurance test.

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was assessed by vertical jump; the result was recorded as the difference between reach and jump heights in centimeters. Vertical jump was performed (a) jumping with both legs, (b) jumping with the right leg only, and (c) jumping with the left leg only. Three attempts were performed for each of both right and left leg jumps, with the result taken as the average of the best 2 jumps in each condition. Arm strength was assessed using a handgrip dynamometer in kilograms with the participant in a standing position and maintaining a straight arm. These methods have been described previously (18). In addition to the vertical jump and hand grip tests, participants were assessed on upper-body muscular endurance by measuring the number of push-ups and pull-ups in 60 seconds. The push-up protocol was as follows: The starting position was to have the athlete lie on their stomach with the arms positioned at 90-degree elbow flexion and hands facing forward. The athlete then pushed up by straightening the elbows and using the toes as a pivot point. The body was required to be kept in a straight line. The athletes then lowered themselves until their elbows formed a 90-degree angle. The result was the maximum number of repetitions the athlete performed in 60 seconds. Repetitions that did not conform to the protocol were not counted. Test-retest reliability (intraclass correlation coefficient) for the push-up protocol was determined to be $r = 0.84$; $P = 0.0001$; $n = 14$.

The pull-up protocol was as follows: The athletes started by lying on their back with the shoulders directly below a bar that was set at a height 1–2 in. beyond their reach. An elastic band was suspended across the uprights parallel to and approximately 7–8 in. below the bar to serve as a marker for the participants (Figure 3). In the start position (down), the participants' hips were off the floor, the arms and legs were straight, and only the heels were in contact with the floor. An underhand grip (palms towards the feet) was used, and thumbs were placed around the bar. A pull-up was completed when the elbows were contracted to a 90-degree arm bend. The result was the maximum number of repetitions in 60 seconds, keeping the hips and knees extended through each attempt. The participants were allowed to rest between pull-ups but were not allowed to touch the ground. Test-retest reliability (intraclass correlation coefficient) for the pull-up protocol was determined to be $r = 0.74$; $P = 0.0016$, $n = 15$.

Cardiovascular Performance Test Protocol

The Leger multistage run test was used to measure cardiovascular performance and conditioning. Participants were required to run at gradually increasing speeds between lines separated by 20 m. This test was described by Leger et al. (13) and has been validated as a predictor of maximal aerobic capacity (12). The regression equations developed by Stickland et al. (17) for the prediction of maximal aerobic power ($\dot{V}O_{2max}$) from the results of the Leger test were used to obtain predicted $\dot{V}O_{2max}$ values for the participants. The regression equations that were used to predict $\dot{V}O_{2max}$ were $Y = 2.75X + 28.8$ ($r^2 = 0.77$; $SEE = 4.07$ ml·kg^{-1}·min^{-1}) for men and $Y = 2.85X + 25.1$ ($r^2 = 0.66$; $SEE = 3.64$ ml·kg^{-1}·min^{-1}) for women, where X equals the last half-stage of the test that had been completed.

Golf Performance Assessment

Participants performed the golf testing after a short stretching protocol and approximately 20–30 shots of gradually increasing intensity at a driving range next to the test facility. The test was performed using a calibrated assessment apparatus (Titleist Launch Monitor [TLM]; Titleist Inc., Fairhaven Mass). This apparatus uses a system of digital cameras, high-speed strobes, and image analysis to record and analyze the split-second event when the golf ball and club collide to produce a golf shot. By interpreting the images obtained at impact, the TLM is able to calculate the launch conditions imparted to a golf ball at impact. Launch conditions were defined as the golf ball's initial trajectory, spin, and velocity, which together dictate the subsequent distance travelled by the ball. The golf performance variables that were recorded included (a) ball speed (velocity) and (b) carry distance (displacement). These were assessed for both a driver and a fairway iron (5-iron) because they are representative of the 2 major types of clubs used in golf (woods and fairway irons). The results were the average of 5 shots taken with each of the driver and 5-iron. Participants were allowed to perform their individual preshot routine before each shot.

Additionally, the participants tracked their golf performance statistics during national team sponsored tournaments and entered these into an online database (www.shot-by-shot.com). These measures included mean score, mean number of greens reached in regulation play, average putt distance after a chip shot (as a measure of short game ability), average putt distance after sand shot (as a second measure of short game ability), and the number of putts taken per competitive round. Club selection during tournaments was the responsibility of the player and was in conformation with the rules of golf.

Statistical Analyses

Results were expressed as mean ± *SD.* The statistical analyses were performed using Sigma Stat 3.0 Software (SPSS Inc., Chicago, Ill). Descriptive statistics were performed for all variables. Differences between men and women were evaluated by two-tailed *t*-test. If differences were detected between men and women for a specific variable, the subsequent correlation analysis was then also performed on the results grouped by sex. Correlation analysis was performed for all variables using a Pearson Product Moment Correlation test. Statistical significance was considered to be $P \leq 0.05$.

Results

Significant correlations were observed between physiological variables and golf performance measures. Significant

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Figure 3. Demonstration of the starting position during the pull-up test protocol.

differences between the male and female participants were also observed. These are presented in detail as follows.

Descriptive Characteristics and Anthropometry Test Results

The descriptive characteristics of the participants are shown in Table 1. Significant differences between male and female participants are also indicated in Table 1. Correlation analysis revealed significant associations between mass, height, body mass index, sit height, arm length, and predicted $\dot{V}O_{2max}$ variables and golf performance measures for grouped results. There were fewer significant correlations when the data were analyzed by sex, although several relationships were observed. More specifically, there was a significant negative correlation between sitting height and average putt distance after a sand shot for women ($r = -0.8$; $P = 0.0001$), and the following correlations were observed for male subjects: average putt distance after a sand shot and mass ($r = 0.61$; $P = 0.03$), average putt distance after a sand shot and body mass index ($r = 0.59$; $P = 0.04$), driver ball speed and height ($r = 0.48$; $P = 0.05$), driver ball speed and arm length ($r = 0.61$; $P = 0.01$), driver carry distance and arm length ($r = 0.62$; $P = 0.01$), and greens in regulation and arm length ($r = 0.69$; $P = 0.01$). The detailed results of the correlation analysis are presented in Table 2.

Abdominal Muscle Performance Test Results

Nearly significant differences were noted between men and women on the national team for anterior abdominal muscle performance ($P = 0.14$) or dominant-side abdominal muscle performance ($P = 0.07$) but were significantly different of nondominant-side abdominal muscle performance ($P = 0.02$). The results of the abdominal muscle performance tests are reported in Table 3.

Correlation analysis revealed significant associations between anterior and side abdominal muscle performance and golf performance for grouped results for women and men. For grouped results, significant correlations were noted between anterior abdominal muscle endurance and driver carry distance ($r = 0.38$; $P = 0.04$) and average putt distance after a chip shot ($r = -0.44$; $P = 0.03$), between dominant-side abdominal muscle endurance and average putt distance after a chip shot ($r = -0.43$; $P = 0.03$), and between nondominant-side abdominal muscle endurance and average putt distance after a sand shot ($r = -0.59$; $P = 0.001$). When analyzed by sex, anterior abdominal muscle performance was correlated with average putt distance after a sand shot ($r = -0.59$; $P = 0.04$) for men. Dominant-side abdominal muscle endurance was correlated with average putt distance after chip shots ($r = -0.56$; $P = 0.05$) and sand shots ($r = -0.64$; $P = 0.02$) for men and with driver carry distance ($r = 0.55$; $P = 0.03$), 5-iron ball speed ($r = 0.59$; $P = 0.02$), 5-iron carry distance ($r = 0.56$; $P = 0.03$), and average putt distance after sand shots ($r = -0.62$; $P = 0.03$) for women. Nondominant-side abdominal muscle endurance was correlated with average putt distance after a chip shot ($r = -0.56$; $P = 0.05$) and average putt distance and after a sand shot ($r = -0.62$; $P = 0.03$) for men and average putt distance after sand shots for women ($r = 0.89$; $P = 0.0001$).

TABLE 1. Summary of the descriptive characteristics of the participants ($n = 9$ women and 15 men).

Variable	Combined (mean ± *SD*)	Men (mean ± *SD*)	Women (mean ± *SD*)	M vs. W
Age (y)	(22.7 ± 5.1)	(23.2 ± 3.2)	(22.1 ± 6.6)	$p = 0.68$
Mass (kg)	(70 ± 11.4)	(77 ± 7.8)	(62 ± 9.5)	$p = 0.01$
Height (cm)	(175.9 ± 8.3)	(181.2 ± 6.2)	(170.3 ± 6.4)	$p = 0.0008$
Body mass index (index)	(22.4 ± 2.9)	(23.4 ± 2.2)	(21.4 ± 3.3)	$p = 0.26$
Sitting height (cm)	(89.6 ± 4.3)	(92.6 ± 2.9)	(86.3 ± 2.9)	$p = 0.0001$
Arm length (cm)	(79.9 ± 5.1)	(83.1 ± 3.3)	(76.4 ± 4.2)	$p = 0.0006$
Leg length (cm)	(87.2 ± 5.8)	(89.8 ± 3.7)	(85.2 ± 7)	$p = 0.38$
$\dot{V}O_{2max}$predicted (ml·kg^{-1}·min^{-1})	(50.6 ± 5.8)	(54.8 ± 3.4)	(46.2 ± 4.4)	$p = 0.000001$

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TABLE 2. Correlation analysis results: descriptive variables vs. golf performance ($n = 9$ women and 15 men).

Variable		Age (y)	Mass (kg)	Height (cm)	Body mass index (index)	Sit height (cm)	Arm length (cm)	Leg length (cm)
Driver ball speed (km·h^{-1})	correlation	0.03	0.60	0.70	0.24	0.77	0.71	0.34
	p- value	0.87	0.0002	<0.0001	0.17	<0.0001	<0.0001	0.05
Driver carry distance (m)	correlation	0.05	0.56	0.71	0.19	0.76	0.71	0.38
	p- value	0.78	0.0007	<0.0001	0.29	<0.0001	<0.0001	0.03
5-Iron ball speed (km·h^{-1})	correlation	0.10	0.67	0.69	0.34	0.73	0.67	0.35
	p- value	0.58	<0.0001	<0.0001	0.05	<0.0001	<0.0001	0.05
5-Iron carry distance (m)	correlation	0.11	0.67	0.68	0.35	0.72	0.66	0.36
	p- value	0.53	<0.0001	<0.0001	0.05	<0.0001	<0.0001	0.04
Score (total # shots per round)	correlation	−0.03	−0.48	−0.54	−0.19	−0.51	−0.55	−0.32
	p- value	0.89	0.01	0.004	0.36	0.01	0.004	0.11
Greens in regulation (number per round)	correlation	−0.02	0.08	0.09	0.03	0.06	0.14	0.20
	p- value	0.91	0.68	0.66	0.89	0.76	0.50	0.32
Average putt distance after chip shot	correlation	0.14	−0.14	−0.21	−0.02	−0.24	−0.13	0.00
	p- value	0.49	0.49	0.32	0.92	0.24	0.52	0.99
Average putt distance after sand shot	correlation	−0.08	−0.28	−0.22	−0.21	−0.53	−0.40	0.07
	p- value	0.70	0.16	0.27	0.30	0.01	0.04	0.73
Putts (number per round)	correlation	0.06	−0.33	−0.42	−0.10	−0.51	−0.39	0.02
	p- value	0.78	0.10	0.03	0.63	0.01	0.05	0.94

Flexibility and Balance Test Results

There were no significant differences between women and men in the sit and reach flexibility tests or for the dominant and nondominant leg balance tests, therefore only grouped correlation results are reported for these variables. The results of the flexibility and balance tests are reported in Table 3.

Correlation analysis revealed significant associations between sit and reach test results and golf performance for grouped results. The observed correlations were between sit and reach (both legs) and driver carry distance ($r = -0.36$; $P = 0.04$), 5-iron ball speed ($r = -0.41$; $P = 0.02$), 5-iron carry distance ($r = -0.44$; $P = 0.01$), and score ($r = 0.43$; $P = 0.03$). Similar results were observed for the correlations between dominant leg flexibility and driver carry distance ($r = -0.35$; $P = 0.05$), 5-iron carry distance ($r = -0.34$; $P = 0.05$), and score ($r = 0.46$; $P = 0.02$) and between nondominant leg flexibility and driver ball speed ($r = -0.35$; $P = 0.04$), driver carry distance ($r = -0.41$; $P = 0.02$), 5-iron ball speed ($r = -0.38$; $P = 0.03$), 5-iron carry distance ($r = -0.40$; $P = 0.02$), and score ($r = 0.47$; $P = 0.02$).

The result of the balance testing demonstrated a significant relationship between grouped results and dominant leg balance and greens in regulation ($r = -0.43$; $P = 0.04$) and

TABLE 3. Results summary: abdominal muscle, flexibility, and balance variables ($n = 9$ women and 15 men).

Variable	Combined (mean ± *SD*)	Men (mean ± *SD*)	Women (mean ± *SD*)	M vs. W
Anterior abdominal muscle endurance (s)	(153.3 ± 51.2)	(170.9 ± 54.8)	(136.8 ± 42.8)	$p = 014$
Abdominal muscle endurance dominant side (s)	(81.1 ± 25.7)	(84.1 ± 28.5)	(77.7 ± 22.7)	$p = 0.07$
Abdominal muscle endurance nondominant side (s)	(88.6 ± 30.6)	(92.1 ± 25.2)	(84.9 ± 35.9)	$p = 0.02$
Sit and reach (cm)	(20.1 ± 6.2)	(17.5 ± 4.8)	(22.9 ± 6.4)	$p = 0.81$
Sit and reach dominant side (cm)	(24.5 ± 8.9)	(21.3 ± 6.6)	(27.9 ± 9.8)	$p = 0.84$
Sit and reach nondominant side (cm)	(24.3 ± 8.9)	(20.6 ± 6.6)	(28.2 ± 9.6)	$p = 0.81$
Static balance dominant side (s)	(31.6 ± 18.4)	(31.2 ± 14.5)	(32 ± 22.1)	$p = 0.06$
Static balance nondominant side (s)	(33.1 ± 17.2)	(33.2 ± 16.1)	(33 ± 19)	$p = 0.51$

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TABLE 4. Results summary: strength and power variables (n = 9 women and 15 men).

Variable	Combined (mean ± *SD*)	Men (mean ± *SD*)	Women (mean ± *SD*)	M vs. W
Vertical jump (cm)	(41.4 ± 16.8)	(48.9 ± 15.4)	(33.4 ± 14.7)	$p = 0.01$
Dominant leg vertical jump (cm)	(26.4 ± 8.5)	(31.3 ± 6.4)	(21.4 ± 7.5)	$p = 0.03$
Nondominant leg vertical jump (cm)	(25.3 ± 8.8)	(31 ± 7.2)	(19.3 ± 5.8)	$p = 0.002$
Pull-up (# in 60 s)	(19.8 ± 9.8)	(26.4 ± 7.6)	(12.3 ± 5.7)	$p = 0.0001$
Push up (# in 60 s)	(32 ± 15.8)	(40.6 ± 16.4)	(22.2 ± 7.1)	$p = 0.00001$
Dominant arm grip strength (N)	(46.2 ± 11.9)	(54.1 ± 9.4)	(37.9 ± 7.9)	$p = 0.02$
Nondominant arm grip strength (N)	(45.8 ± 12.2)	(55.1 ± 8.5)	(35.9 ± 6.2)	$p = 0.002$

between nondominant leg balance and average putting distance after a chip shot ($r = 0.50$; $P = 0.01$).

Peripheral Muscle Test Results

There were significant differences between women and men for vertical jump, number of pull-ups in 60 seconds, number of push-ups in 60 seconds, and grip strength. The results of the peripheral muscle performance tests are reported in Table 4. Correlation analysis revealed significant associations between peripheral muscle test results and golf driver results, 5-iron ball measures, score, and putting efficacy for grouped results. The detailed results of this correlation analysis are presented in Table 5. The analysis of the female participants' results revealed trends and significant correlations between peripheral muscle performance tests and golf performance for dominant leg vertical jump and driver ball speed ($r = 0.57$; $P = 0.02$) and driver distance ($r = 0.61$; $P = 0.01$), pull-up (5-iron ball speed [$r = 0.54$; $P = 0.04$]), 5-iron distance ($r = 0.58$; $P = 0.02$), and sand shots ($r = 0.69$; $P = 0.01$) and dominant arm grip strength (putting [$r = 0.61$; $P = 0.03$]). Results from the analysis of the male participants indicate significant correlations between vertical jump and driver ball speed ($r = 0.50$; $P = 0.04$), driver distance ($r = 0.62$; $P = 0.01$), greens in regulation ($r = 0.66$; $P = 0.01$), and sand shot performance ($r = 0.50$; $P = 0.08$ trend only), between pull-up

TABLE 5. correlation results–muscle strength and power performance variables vs. golf performance (n = 9 women and 15 men).

Variable		Vertical jump (cm)	Dominant leg vertical jump (cm)	Non-dominant leg vertical jump (cm)	Pull up (#·60 sec^{-1})	Push up (#·60 sec^{-1})	Dominent arm grip strength (N)	Non-dominant arm grip strenght (N)
Driver ball speed	correlation	0.59	0.73	0.77	0.80	0.66	0.78	0.82
(Km·hr^{-1})	*p*-value	0.0003	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Driver carry	correlation	0.60	0.75	0.78	0.79	0.67	0.77	0.81
distance (m)	*p*-value	0.0002	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
5-Iron ball speed	correlation	0.50	0.66	0.70	0.78	0.57	0.78	0.85
(Km·hr^{-1})	*p*-value	0.003	<0.0001	<0.0001	<0.0001	<0.0006	<0.0001	<0.0001
5-Iron carry	correlation	0.48	0.64	0.69	0.76	0.55	0.78	0.85
distance (m)	*p*-value	0.01	<0.0001	<0.0001	<0.0001	0.001	<0.0001	<0.0001
Score (total #	correlation	−0.59	−0.64	−0.69	−0.64	−0.49	−0.68	−0.71
shots / round)	*p*-value	0.002	0.0005	<0.0001	0.0006	0.01	0.0001	<0.0001
Greens in	correlation	0.50	0.32	0.29	0.23	0.16	0.31	0.21
regulation (# / round)	*p*-value	0.01	0.12	0.14	0.26	0.46	0.12	0.30
Ave putt distance	correlation	−0.07	−0.21	−0.26	−0.45	−0.31	−0.23	−0.36
after chip shot	*p*-value	0.74	0.30	0.019	0.03	0.13	0.26	0.07
Ave putt distance	correlation	−0.31	−0.32	−0.29	0.05	−0.13	−0.33	−0.25
after sand shot	*p*-value	0.12	0.12	0.15	0.81	0.55	0.10	0.22
Putts (# / round)	correlation	−0.11	−0.24	−0.33	−0.41	−0.39	−0.31	−0.44
	p-value	0.60	0.24	0.10	0.04	0.05	0.13	0.02

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Table 6. Golf performance test results ($n = 9$ women and 15 men).

Variable	Combined (mean ± *SD*)	Men (mean ± *SD*)	Women (mean ± *SD*)	M vs. Q
Driver ball speed ($km \cdot h^{-1}$)	(244.8 ± 28.4)	(269.9 ± 12)	(218.2 ± 10)	$p < 0.0001$
Driver carry distance (m)	(223.9 ± 31.2)	(251.5 ± 10.3)	(194.6 ± 13.5)	$p < 0.0001$
5-Iron ball speed ($km \cdot h^{-1}$)	(197.8 ± 18.4)	(214.3 ± 6.9)	(180.3 ± 5.9)	$p < 0.0001$
5-Iron carry distance (m)	(165.6 ± 18.1)	(181.8 ± 6.5)	(148.5 ± 6.6)	$p < 0.0001$
Score (# shots per round)	(73.2 ± 2.4)	(71.3 ± 1.4)	(75 ± 1.5)	$p < 0.0001$
Greens in regulation (*n*)	(12 ± 1.5)	(12.1 ± 1.4)	(11.9 ± 1.6)	$p = 0.8$
Average putt distance after chip shot (ft.)	(8.4 ± 1.7)	(7.6 ± 1.7)	(9.2 ± 1.3)	$p = 0.01$
Average putt distance after sand shot (ft.)	(14 ± 11.6)	(11 ± 3.2)	(17 ± 15.8)	$p = 0.2$
Putts (# putts per round)	(30.8 ± 1.8)	(29.5 ± 1.3)	(32 ± 1.3)	$p < 0.0001$

and driver ball speed ($r = 0.55$; $P = 0.02$), driver distance ($r = 0.53$; $P = 0.03$), between push-up and driver ball speed ($r = 0.48$; $P = 0.05$) and driver distance ($r = 0.61$; $P = 0.01$), and between grip strength (dominant and nondominant hand) and driver ball speed ($r = 0.65$; $P = 0.01$), driver distance ($r = 0.64$; $P = 0.01$), 5-iron ball speed ($r = 0.60$; $P = 0.01$), and 5-iron distance ($r = 0.60$; $P = 0.01$).

Golf Performance Test Results

There were significant differences between women and men for all golf performance test results except greens in regulation and putting distance after sand shots. The results of the golf performance tests are reported in Table 6.

Correlation analysis within golf performance measures was not performed because the primary objective of this research was to determine the relationship between physiological performance and golf performance.

Discussion

The purpose of this study was to establish relationships between measures of physiological capacity and measures of golf performance. The physiological tests were selected to provide a general assessment of fitness in broad categories including anthropometric characteristics, cardiovascular fitness, flexibility, balance, abdominal muscle performance, and upper- and lower-body peripheral muscle performance. Significant correlations between the measured physiological variables and golf performance were noted in all areas.

The analysis of the descriptive test results revealed anthropometric differences between the male and female participants, as was expected. These differences are consistent with reports on other athletic groups (18). The significant correlations between anthropometric measures such as height, sitting height, and arm length and measures of golf performance are expected. This suggests that athletes with longer levers are able to generate more force at impact than athletes with shorter levers. This may be important for the development of talent identification programs because height and limb length are largely determined by genetic factors. Anthropometry seemed to be more strongly correlated with driver and 5-iron performance, as well as score, and less so with short-game measures, such as greens in regulation and putting distance after chip shots, although height and limb lengths seemed to be correlated with putting efficacy. Although the importance of driving distance has been decreasing in recent years, distance remains a significant determinant of golf performance for both men and women golfers (19).

The result of the Leger multistage run test, which was used to predict relative aerobic capacity in this group, was also significantly correlated with measures of golf performance. This was an unexpected finding, given that aerobic capacity is not normally associated with golf performance. We suggest that the athletes that are the most actively involved in training for their sport are also those that possess the greatest aerobic capacity, and the Leger test results are a reflection of this general athletic ability rather than a reflection of the importance of aerobic capacity in generating power in the golf swing. This hypothesis is supported by recent research by Burgomaster et al. (1), who reported that anaerobic training imparted significant improvements in aerobic capacity, which suggests that there may be interesting benefits of cross training in this population. It should also be stated that research has demonstrated that aerobic training has negative impacts on power development (recently reviewed in Elliott et al. (6)); therefore, any aerobic training undertaken by golfers should likely be accompanied by maintenance strength and power training. Interestingly, our results also suggested a relationship between aerobic capacity and total score short game (chip shot efficacy) and putting average, suggesting that during the course of a season, those golfers with the best aerobic conditioning are those that have better outcomes in these areas.

The analysis of the results of the abdominal muscle testing revealed significant correlations between golf performance

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and driver and 5-iron distance. Interestingly, the association is significant between dominant-side abdominal strength and drive distance in the female golfers, but not in men, possibly suggesting that the taller men who were required to hold the abdominal strength test may have had difficulty given the longer lever points between the hands and feet, thus negatively impacting the results. Another possibility is that the chosen abdominal test is more reflective of muscle endurance rather than muscle power, the latter being more important for the golf swing. The finding that abdominal muscle strength on the dominant side of the body is correlated with drive distance in women suggests that stronger internal and external oblique muscles on the dominant side of the body may help female golfers improve golf swing power and thus drive distance. There also seemed to be correlations between putting distance after sand and chip shots for both men and women, suggesting that core strength and stability may be important for short game effectiveness.

The sit and reach test was used as a measure of general flexibility. The advantages and limitations of this test are reviewed in Gore (8). The analysis of the grouped results of this test revealed several significant correlations, although the correlations between flexibility and driver/5-iron distance were negative, suggesting that greater flexibility, as assessed by this test, is related to shorter distance; however, there was a positive association between sit and reach results and scoring average. A greater range of flexibility assessments is likely required to determine the exact relationships between the flexibility of different components of the body and various aspects of golf performance.

The analysis of balance test revealed a significant relationship between dominant and nondominant leg balance and greens in regulation and average putt distance after a chip shot. Therefore, balance seems to be related to the ability to execute shots from the fairway or rough as a golfer is approaching the green. This is expected given the weight shift that occurs during the backswing, resulting in the golfer balancing primarily on the dominant leg, and the fact that golfers are balanced primarily on the dominant leg during the initiation of the downswing. Fairways and rough are not always stable and may have uneven ground; therefore, balance would be expected to contribute to this area of golf performance.

The results of the peripheral muscle testing suggest that leg power (vertical jump), upper body strength (push and pull ups), and arm strength (grip strength), were all correlated with golf performance measures, although the strongest correlations were with measures of distance and total score. When the results were analyzed by sex, significant correlations were observed for vertical jump with both legs and the individual legs for men but only for the dominant leg vertical jump for women. This suggests that leg power is of critical importance for male golfers for developing power during the golf swing, but perhaps that power for female golfers may be derived differently. In general, upper-body strength (pull-ups and push-ups) was correlated with drive distance for men and with 5-iron distance and sand shot effectiveness in women. Forearm strength was correlated with measures of distance in the male group, but only with putting in the female group, suggesting very different recruitment patterns may be happening for the different sexes during different aspects of the game.

This research presents a report on correlations between general physiological fitness variables and measures of golf performance. Significant correlations were observed, as were different trends for men and women participants. Previous research has suggested that there are difference responses to training between male and female golfers (4), therefore sex differences in physiological correlations and trainability should be considered carefully by coaches and researchers. This research provides a foundation for the development of golf-specific training programs, as well as information that can be used for the development of talent-identification programs. The research design of this study was to determine correlations, which must be interpreted with caution because correlation does not imply causality. Therefore, we suggest that the results of the current research only be used to identify and understand general relationships between variables.

Practical Applications

Golf is a very demanding physical game, not only in terms of precision and complexity of the golf swing movement, but also in terms of creating explosive power through a wide range of motion. Recently, the sport of golf has been revolutionized by players who have committed to optimal physical preparation, including balance, flexibility, posture, core stability, strength, power, and cardiovascular training. Relationships between elements of conditioning (balance, flexibility, core strength, upper- and lower-body strength and power, and cardiovascular conditioning) and golf performance have not been reported. Therefore, the objective of the current research was to identify statistically significant physiological correlates of golf performance in elite amateur golfers.

A correlation study design was used to answer the primary research question to determine the correlation between physiological characteristics of elite golfers (balance, flexibility, core strength, peripheral strength and power, and cardiovascular function) and golf performance under laboratory conditions (ball speed [velocity] and ball distance [displacement] achieved using both a driver and a fairway iron) and under tournament conditions (average score, greens in regulation, short-game measures, and putting accuracy).

The physiological tests were selected to provide a general assessment of fitness in broad categories, including anthropometric characteristics, cardiovascular fitness, flexibility, balance, abdominal muscle performance, and upper- and lower-body peripheral muscle performance. Significant correlations between the measured physiological variables

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and golf performance were noted. Significant correlations between anthropometric measures, such as height, sitting height, and arm length and driver and 5-iron performance, as well as score, were noted. This may be important for the development of talent identification programs because height and limb length are largely determined by genetic factors. Interestingly, our results also suggested a relationship between aerobic capacity and total score short game (chip shot efficacy) and putting average, suggesting that during the course of a season, those golfers with the best aerobic conditioning are those that have better outcomes in these areas. There seemed to be correlations between putting distance after sand and chip shots for both men and women, suggesting that core strength and stability may be important for short-game effectiveness, in addition to driver and 5-iron distance, which were also significantly correlated to core strength. There was a positive association between sit and reach results and scoring average, suggesting that flexibility may be important for golfers. Balance seems to be related to the ability to execute shots from the fairway or rough as a golfer is approaching the green. The results of the peripheral muscle testing suggest that leg power (vertical jump), upper-body strength (push-ups and pull-ups), and arm strength (grip strength) were all correlated with golf performance measures, although the strongest correlations were with measures of distance and total score.

This research presents a rationale for the inclusion of balance, flexibility, core strength, upper- and lower-body strength and power, and cardiovascular conditioning in golf training programs.

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