Correlations of force, velocity and power in a golf specific rotational test and total driving in young elite golfers

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Bachelor’s Thesis In Exercise Biomedicine

Halmstad 2017-05-23
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2017-05-23
Bachelors thesis 15 credits in Exercise Biomedicine
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Abstract

**Background:** Power and an increase in rotational velocity should be a primary focus in a golfer’s strength and conditioning program. Total driving, a driving performance value combining distance and accuracy, has a powerful relationship with a golfer’s performance. Despite this knowledge, most golf studies have focused on club head speed and driver distance. In addition, the studies looking at power (W), velocity (m/s) and force (N) in a golf specific rotational test are few. Looking at these specific numbers is important in optimizing training efficiency and golf performance. Also, there are differences in the swing characteristics of male and female golfers. Men have a greater muscle tension during the golf swing. There is a 15% difference in driving distance between men and women of the same world ranking. **Aim:** The aim was to study the correlation between power, velocity and force in a golf specific rotational test, and total driving in golf. **Method:** Twenty-four young elite golfers; 14 men and 10 women with a hcp ≤ 5 took part in the present study. The correlation between two tests; a golf specific rotational test (peak power, peak force and peak velocity) and a total driving tests was studied. The data, which was normally distributed, was studied with Pearson’s test for correlations (r). **Result:** In the present study 8/9 correlations were poor (r -0.17 – 0.45). Peak power and total driving for women showed a moderate correlation r=0.59 (r² =0.35). All correlations measured were stronger for the women only group than the men only group. **Conclusion:** There seems to be a moderate correlation between peak power and total driving for women, suggesting that peak power might influence total driving. Other variables correlated poorly. Future work should consider studying the correlation between golf specific rotational tests and total driving calculated from tournament rounds.
Abstrakt

**Bakgrund:** Power och att öka rotationshastighet bör prioriteras högt i en golfares fysiska träningsprogram. Total driving, ett mätvärde för driverprestation som innefattar både slaglängd och precision, har ett starkt samband med en golfares prestation. Trots denna kunskap har de flesta tidigare golfstudier fokuserat på klubbhastighet och slaglängd. Utöver detta har få studier tittat på kraft (N), hastighet (m/s) och power (W) i golfspecifika rotationstest. Dessa värden är av vikt när målsättningen är att optimera träningseffektivitet och golfprestation. Män och kvinnors golfteknik skiljer sig, bland annat har man sett att män har en större spänning i muskulaturen. Det finns även en skillnad i slaglängd, där en man slår 15% längre än en kvinna med samma världsrängning. **Metod:** 24 unga elitgolfare; 14 killar och 10 tjejer med hcp ≤ 5 var med i denna studie. Studien undersökte korrelationen mellan två tester; ett golf specifikt rotationstest (peak power, peak force and peak velocity) och ett total driving test. Ett Pearson`s test (r) användes sedan för att räkna ut korrelationerna eftersom datan var normalfördelad. **Resultat:** För 8/9 korrelationer var resultatet svagt (r -0,17 – 0,45). Peak power värden hade en måttlig korrelation med total driving för kvinnor r= 0,59 (r^2 =0,35). Alla korrelationer som mättas var starkare för gruppen med kvinnor än för gruppen med män. **Slutsats:** Det verkar finnas en måttlig korrelation mellan peak power och total driving för tjejer. Detta betyder att peak power skulle kunna påverka total driving. Resterande variabler visade på svaga korrelationer. Framtida studier borde undersöka korrelationerna mellan ett golfspecifikt rotationstest och total driving uträknat från tävlingsspel.
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**Background**

In golf as in all sports, men and women who compete at world-class level face extremely tough competition. To cope with this, it is important for athletes and their coaches to gather accurate information about tasks of their sports so they can prioritize the right skills in practice (Hellström, 2009). Recent scientific work has aimed to improve knowledge about both technique, performance and the physical demands golf (Cross, 2016). Previous research has showed that power and the ability to quickly apply force during the golf swing are of high importance for golfers, and an increased rotational velocity should be a primary focus for golf specific strength and conditioning training (Schofield, 2015). These variables particularly affect the golfer’s ability to hit the ball far (Leary, Statler, Hopkins, Fitzwater, Kesling, Lyon, . . . Haff, 2012). Hitting the tee shot with preferred accuracy and length can open up for an easier second shot (Hellström, Nillson & Isberg, 2014). One way to measure this part of golf performance is to calculate total driving (TD). Total driving is the combination of driving distance and driving accuracy and it has a powerful relationship with a golfer’s performance (Engelhart, 2002).

Despite this knowledge, few have studied the relationship between peak force (PF), peak velocity (PV) and peak power (PP) production in golf specific rotational exercises and how those variables correlate with length and accuracy of a golf shot. Previously, club head speed (CHS) and shot distance have been the most frequent subjects of golf research.

**Force – velocity relationships and power**

Knowing how to create maximal power, which is the combination of force and velocity, is important when you want to develop explosive capabilities at an individual level (Cross, 2016). It is also important for an individual to know his or her own force and velocity characteristics and to what extent these two variables contribute to power. To be able to train in optimal power conditions is theorized to improve performance (Cross, 2016). In addition to power, the individual force-velocity (F-v) mechanical profile, specifically the F-v imbalance (FVimb) seem to affect ballistic performances like the golf swing. FVimb is defined as the difference between the athletes actual and optimal F-v profile. Each individual has an optimal F-v profile for maximum performance in a specific ballistic movement. A study of 84 subjects have shown clearly beneficial results from a training program focused on improving FVimb.
This study showed that by improving FVimb, performance in jumping can be increased even though maximal power did not change (Jimenez-Reyes, Samozino, Brughelli & Morin, 2017).

Physical conditioning for golfers

Physical conditioning has grown more important for golfers. Players have started to hit the ball further and the primary function of the full golf swing has become to hit the ball as far as possible with control, consistency and accuracy (Gordon, Moir, Davis, Witmer & Cummings, 2009). Muscles adapt specifically to the training regime performed (Malisoux et. al, 2006;2005). Exercises and tests should consequently be specific to the sport in question and include similar muscles and energy systems (Morrison, Chaconas, 2014). Rotational tests (medicine ball throws and trunk rotations) similar to golf specific rotational performance have been studied. Andre, Fry, Heyrman, Hudy, Holt, Roberts, … Gallagher (2012), showed high test-retest reliability (ICC>0.9) for a seated rotational test in a cable machine at three different loads and Algotsson (2016), showed a high test-retest reliability (ICC 0.92) when testing a standing rotation in Quantum 1080.

High CHS and driving distance is important to be able to combat golf courses that are made continuously longer and more difficult. Despite knowledge that training regimes should be specific to the sport, a majority of physical conditioning programs for golfers are hypertrophy related (Schofield, 2015). The strength in golf specific rotational exercises correlate well to CHS (Keogh, et. al., 2009). Power training is a valid method to increase CHS in golfers, and increased rotational velocity should be a primary focus for golf specific strength and conditioning training (Schofield, 2015). The ability to quickly apply force during the golf swing is of high importance partly because of the short time span available for force production. For elite golfers, that time span is as short as 200 to 300 milliseconds with the average downswing at approximately 230 milliseconds (Leary et.al, 2012).

High speed explosive movements, like the golf swing, demand high intensity work and the muscles will need energy fast. Adenosine triphosphate (ATP) and creatine phosphate (PCr) are the two main sources of energy used in this type of activities. Type-II muscle are best suited for high speed movements considering they generate energy and are activated faster than other types. The amount of ATP and PCr an athlete can store and what muscle fibre type is most common in their muscles partly depends on their type of training. Short and intense
strength training can increase the ability to store ATP and PCr (McArdle, Katch & Katch 2010).

Golf swing characteristics of skilled golfers

The golf swing is a complex movement and there is no right way to swing a golf club. However, certain movement patterns are characteristic in skilled golfers. These golfers start their golf swing by simultaneously rotating the upper torso, upper extremities (arms, wrists and hands) and golf club away from the set-up position (Myers, Lephart, Tsai, Sell, Smoliga & Jolly, 2008). The transition to the down swing is when all segments of the body change direction back towards the ball (Callaway, Glaws, Mitchell, Scerbo, Voight, & Sells, 2012). It is initiated by the leg muscles starting to rotate the pelvis, followed by upper torso rotation and movement of arms, wrists, hands and the golf club (Myers et. al., 2008). This movement pattern is in literature called proximal to distal sequencing or kinematic sequence. Proximal to distal sequencing is also seen in other sports including rotational movements as baseball, tennis and soccer. Timing the kinematic sequence wrongly can lead to loss of energy, which in turn leads to a lower CHS, power, accuracy and consistency (Callaway et. al., 2012). CHS is defined as the linear velocity of the golf club’s grip and the shaft’s angular velocity multiplied with the length of the shaft (Hellström, 2009). CHS is usually measured for the “driver” which is the biggest and longest club in a golfer’s bag. The driver is the golf club that is supposed to make the ball fly the furthest.

Skilled golfers are also more able to create an accurate and consistent muscle activation, shot by shot (Hellström, 2009). Relatively high to very high activation (measured with electromyography, EMG) has been detected for the golf swing in; hip and knee extensors, hip abductors and adductors, spinal extensors, and shoulder external rotators such as m. Subscapularis, m. Latissimus dorsi and m. Pectoralis major (Keogh, Marnewick, Maulder, Nortje, Hume & Bradshaw, 2009). Lastly, golfers at an elite level need more than an efficient technique. Other crucial skills in golf can be tactical, perceptual, physical and psychological (Robertson, Burnett & Newton, 2013).

The x-factor and stretch-shortening cycle

In the transition from back swing to down swing there is an angular displacement of the pelvis and shoulders called the x-factor. A big x-factor is common for professional golfers. X-factor
stretch is when the pelvis rotates towards the target before the shoulders, increasing the x-factor angle (Myers et. al., 2008). The value of the x-factor stretch comes from the number of angular degrees’ shoulders and hips separate in the start of the downswing. The x-factor stretch can be explained as upper body and pelvis acting like a spring or coil, using the stretch-shortening cycle (SSC) to create a centrifugal force and increase the CHS and distance of a golf shot. The energy created in the proximal parts of the body increases when progressing to more distal parts, peaking in the wrists and the face of the golf club. Most professional golfers use this coiling pattern in their swing. Comparing less skilled and skilled golfers showed that the x-factor stretch, but not x-factor was significantly larger in skilled golfers (Callaway et. al., 2012).

SSC is described as a natural muscle function. Walking, running and jumping are all movements in which the SSC is present (Malisoux, Francaux, Nielens & Theisen, 2006;2005). SSC occurs when muscles and tendons extract in the eccentric phase of a movement before contracting in the concentric phase i.e. a counter movement jump. This extraction or stretch creates elastic energy that builds up in the muscle and by reflex contributes to strengthening the contraction and producing more force and power in the concentric phase (McArdle, Katch & Katch, 2010). This also occurs if a passively stretched muscle is abruptly activated. Physiologically the process involving elastic energy appears in the cross-bridges between the actin and myosin filaments. It is argued that the heads of the myosin filaments are rotated backwards in the stretch phase, opposite of their most common movement. This position increases the potential energy. With the cross-bridge lifetime being 15ms-120ms it is crucial that the transition phase of SSC movements is short, to be able to utilize the elastic energy during the concentric phase (Komi, 1984).

The efficiency of SSC can be increased with plyometric- and strength- training (McArdle, Katch & Katch, 2010) and it is well known that SSC exercise training can improve jumping ability and other high power movements (Malisoux et. al, 2006;2005). The effect of the eccentric stretch in SSC can be enhanced by increasing intensity (Ishikawa & Komi, 2004;2003). Most of the training effects can be seen as neuromuscular adaptions in activity patterns of agonist and antagonist muscles or in recruitment strategies of motor units. All in all, SSC training is a training paradigm useful for improvement of single-fiber force, contraction velocity and power (Malisoux et. al, 2006;2005).
Total driving
Little is known about how different physical and technical parameters can improve a golf player’s accuracy at both maximal and sub-maximal CHS (Hellström, 2008). Both driving accuracy and driving distance are of importance for golfers. A combination of these, Total Driving (TD), is significantly related to golf performance or money won (Engelhart, 2002). TD is the product of driving accuracy (percent of fairways hit) and driving distance (yards or meters) (Wisemann & Chatterjee, 2006). The fairway is the area where the golf ball is supposed to end up. Joyce, Burnett, Cochrane & Reyes (2016) estimated the width of a fairway to 37m or approximately 41 yards. There is a need for studies on an individual level and how physique and execution relate to a consecutive ball impact and accuracy of the golf shots (Hellström, 2008).

Golf specific physical tests
Studies have earlier examined the correlation of golf parameters with results in various exercises such as medicine ball throws, vertical jumps and sitting rotations (Torres-Ronda, Sánchez-Medina, & González-Badillo, 2011). The strength measured in golf specific rotational exercises seem to correlate highly with CHS (Keogh, et. al., 2009). To include golf specific rotational exercises in strength and conditioning programs for golfers is important if one is looking to increase CHS (Keogh, et. al., 2009; Leary et. al., 2012). An eight-week study has been performed to investigate the effects of a golf specific exercise programme for recreational golfers. After eight weeks researchers could see an improvement in golf swing kinematics, attributed to motor learning effects and improvements in physical characteristics specific to golf (Callaway, et. al., 2012).

Gender differences from a physiological perspective
The amount of force a muscle can generate depends on the placement of the levers it is attached to and the formation of the muscle itself. A comparison of muscle cross sectional area (MSCA) and arm flexor strength of men and women indicates that a larger MSCA facilitates generation of a larger absolute force. This relationship shows the likeness in force generating ability of same size muscle men and women. Looking at men and women with similar amount of fat free mass, the relationship stands. It is when examining absolute force, the gender difference becomes apparent, measuring 50% difference in upper-body strength and 30% in lower-body strength. However, exceptions can appear for women with years of
strength-training experience (McArdle, et. al., 2010). Lastly, a greater musculotendinous stiffness has been proven in men compared to women. This facilitates a bigger buffer of strain energy making it possible for men to utilize elastic energy more effectively (Brown, Nevill, Monk, Otto, Selbie & Wallace, 2011).

**Gender differences in golf**

There are several differences between male and female golf. The most apparent difference is that courses are set up shorter for women (Zheng, Barrentine, Fleisig & Andrews, 2008). It is also well known that swing characteristics of male and female golfers differ at several variables (Egret, Nicolle, Dujardin, Weber & Chollet, 2006; Zheng, Barrentine, Fleisig & Andrews, 2008; Horan, Evans, Morris & Kavanagh, 2010). Female golfers rotate their hips and shoulders more (Egret, Nicolle, Dujardin, Weber & Chollet, 2006). Male golfers have a bigger trunk forward tilt at ball impact and a higher angular velocity of wrists. Average driving distance, in 2007, was 15% shorter for women than men with same world ranking (Zheng et.al., 2008). This male advantage in distance is mainly due to higher CHS thanks to more powerful physical characteristics (Horan, Evans, Morris & Kavanagh, 2010).

**Aim**

Taken together there is a need to study force, velocity and power in golf specific rotational tests and to study tests for accuracy in golf. The aim was to study the correlation between force, velocity and power, in a whole-body golf specific rotational test and total driving (TD) for the whole group and for men and women separately.

Research questions:

- What is the strength of the correlation between peak force in a golf specific rotational test and TD, in the total sample and in men and women separately?
- What is the strength of the correlation between peak velocity in a golf specific rotational test and TD, in the total sample and in men and women separately?
- What is the strength of the correlation between peak power in a golf specific rotational test and TD, in the total sample and in men and women separately?
Methods
The present study was an observational and cross-sectional study of a single group, consisting of two different measurements; (1) measuring force, velocity and power in a golf specific rotational test (GSRT), (2) total driving (TD).

Subjects
The subjects were young elite golfers, mean handicap -1.1(±2.6) and mean age 20 (±2) years of age. Inclusion criterion were that the golfers went to Scandinavian College of Sports or Aspero Gymnasiet in Halmstad and had a hcp ≤ 5. Subjects were recruited through their coaches’ recommendations and via facebook conversation with the test leaders. The invited number of golfers was 31 men and women. Exclusion criteria were that the golfers could not be injured or in pain at the time of the tests and when the tests took place. Twenty-four golfers (14 men and 10 women) agreed to participate, passed the inclusion and exclusion criterion and performed the two tests.

Equipment
1080 Quantum
For the GSRT, Quantum computerized robotic engine system (1080 Quantum synchro, 1080 Motion AB, Lidingö, Sweden) was used. It is a machine that can measure both the concentric and eccentric phase of the same move. Maximum load for the machine is 175kg and maximum speed 8 m/s. 1080 Quantum is a relatively new tool for testing and construction started as recently as in 2005. It has an adjustable lever with a five-meter cable making it possible to test vertical, diagonal and horizontal movement. With 1080 Quantum it is possible to determine the maximum speed of the line going in and out from the machine (1080motion.com).

Trackman 3e
Trackman 3e (trackman.com) is a single radar unit, often referred to as a launch monitor. It uses radar and video to measure different parameters of the head of the golf club and the golf ball. It’s technique is world dominant and also used in baseball and tennis (trackmangolf.com). With Trackman 3e we were able to determine both the length and the accuracy of the golfers’ drives for TD. Sweeney, Alderson, Mills, & Elliott (2009) compared
a launch monitor of similar technique, to a “benchmark” high speed 3D system measuring launch angle, side angle and velocity of the golf ball. The test indicated a good level of agreement.

**Golf equipment**

Each golfer used their own driver club, new Titleist pro v1x golf balls (titleist.com) for the total driving test and tees of preferred length provided by the test leaders.

**Testing procedures**

This study consisted of two tests; one whole-body golf specific rotational test and one total driving test. The two tests were performed separately at different days at Halmstad högskola.

**Total driving test**

The total driving test determined each golfer’s TD value. TD was calculated by multiplying the average carry yardage (measurement to where the ball lands) for the drives, by the percentage of fairway hits. If average driving yardage was 300 and percentage of fairway hits 70%, the calculation (300 x 0.7) gives a TD of 210.

The 24 golfers were divided into groups depending on their practice- or school schedule. Before the test everyone did a mandatory warm up instructed to be similar to their usual golf warm up. This was instructed to include upper and lower body stretches followed by their own golf warm up as they would do it before a tournament.

The test itself consisted of 10 drives (similar amount of drives to a round of golf), hit one shot at the time in the gymnasium at Halmstad Högskola. The golfers hit from an astro turf mat placed approximately 15 meters from a net, all golfers were instructed to tee the ball at their usual preferred height. The stance width from this test was noted and later used as a standardization for the GSRT. The mandatory wait (3-5 minutes) between every shot, while the other group members hit their drives, functioned as a standardization to make the test more similar to a regular round of golf. After each shot the golfers were told the distance and dispersion of the shot in meters, calculated by the Trackman. The average distance from the ten drives in yards was then multiplied by the percentage of fairway hits.
**Whole body golf specific rotational test**

The GSRT consisted of three maximal repetitions at five different loads with the 1080 Quantum. The loads were 2kg, 6kg, 10kg, 14kg and 18kg based on discussion and earlier experiences. Out of these fifteen repetitions, the one with the highest power value (peak power) was chosen for analysis. Concentric speed limit for 1080 Quantum was set at 8 m/s and eccentric speed limit at a constant 1 m/s. The adjustable lever was set at the highest point possible and subjects were asked to stand with their medial foot one meter from the lever.

Before the test all golfers did a warm up consisting of five minutes on a training bike, followed by different upper- and lower body stretches (Keogh, et. al., 2009). Consistency was secured through performing all test at the same time of the day (Keogh, et. al., 2009).

Minimum rest between sets was two minutes, to secure full recovery. The load and the attempt where the athletes managed the peak power (PP) was singled out and PP, peak force (PF) and peak velocity (PV) for that attempt were noted. The 24 golfers performed the test on different dates in close proximity to their golf test. Both tests took place at Halmstad University. The GSRT was performed in a secure, laboratory environment at Halmstad högskola. In advance of the actual test all golfers got to practice the GSRT at 10kg to get familiar with the equipment (1080 Quantum) and the GSRT.

Test-retest reliability has been studied for GSRT (then called a golf relevant rotational movement) at five different loads (2kg, 6kg, 10kg, 14kg, 18kg) for the values PP, PV and PF. Construct validity was also studied and found acceptable. All variables for all five loads, apart from PP with 2kg showed good reliability, ICC 0.84-0.97 (Parker, personal communication, 2017).

**Standardization of the golf specific rotational test**

With the aim for the test to be golf specific and similar to the technique of a golf swing, set up (figure 1) was adapted thereafter. Each subject’s preferred stance was marked with tape before testing, used for all repetitions and they were told to stand with a posture similar to their golf set up. Feet, knees, hips and shoulders were lined up on a horizontal line following the angle of the lever. For right handed golfers, the right shoulder faced the machine. They were also told to grip the handle with both hands.
For the “back swing”, or the rotation from left to right for right handed golfers, Quantum 1080 was set at a constant contraction speed of (1 m/s) for all golfers. For the repetition to be approved there could not be any slack in the cable in the back swing and the feet had to be placed firmly on the ground. The slow speed prevented a quick backswing and made the test all about creating velocity, force and power in the downswing. The golfers were instructed to perform a golf like back swing and with minimum rotation being, for right handed golfers, were the left arm is parallel to the floor (figure 2).
The golfers were instructed to rotate as forcefully as possible through the down swing and to move the handle as fast as they could. For the movement to be accepted the handle had to be rotated past the distal knee (figure 3). Each subject was recommended to try to finish the movement like a golf swing. If the golfers moved the placement of their feet during a repetition, that repetition was annulled.

![Figure 3: Finish position](image)

**Social Considerations**

Few physical tests for golf have evaluated force and velocity profiles or force and velocity imbalance. These two variables seem important when it comes to improving power and ballistic movements like the golf swing. Studying and developing a GSRT that can accurately measure force- and velocity-imbalance would be of great help for golfers that seek to improve their driver performance or club head speed.

Following an exercise program mimicking the golf swing might improve proximal to distal sequencing (Callaway et. al., 2012). Test subjects get experience in performing maximal tests and also gain knowledge about parameters important in developing their golf game. Since there have not been many studies like this one before it is possible that could be of help for future coaches and players.
Ethical considerations

The study was performed in unison with the Helsinki Declaration and national guidelines for ethical principles in studies including humans. All the subjects were informed, both orally and in writing, that they did not have any obligations and that they could decide to quit the tests at any time. They were told that they could ask questions at any time and they had test leaders to show them the proper way to do the tests. There was a slight risk of injury since the GSRT are tests of maximal effort. However, this was not bigger than for their usual training and all golfers also did a proper warm up. The golfers signed a letter of consent saying they had been informed about the benefits and risks of the study and that they had gotten all information they needed. The data was saved at a USB-memory stick and stored at Halmstad University. This means that only the test leaders had access to the data.

Statistics

Data from the two tests was analyzed with IBM Statistical package for social sciences (SPSS) Statistics for Windows, version 24.0 (IBM, Armonk, USA). Shapiro-Wilk’s test for normality was used to see if the variables were normally distributed and if parametric or non-parametric statistics was to be used for calculations. All four variables were normally distributed (p>0.05) and therefore Pearson’s correlation coefficient (r) was chosen. Three different correlations were performed; PF – TD, PV – TD and PP - TD. Finally, the groups were split into male and female to study the same correlations. Descriptive variables (PF, PV, PP and TD) are presented with mean ±SD.

Reference values for strength of the correlation coefficient were; excellent (≥ 0.90), good (0.75-0.89), moderate (0.50-0.74), and poor (<0.50) (Mentiplay, Perraton, Adair, Pua, Williams, McGaw & Clark, 2015).
Results

The group who participated in the study consisted of 14 men and 10 women. All subjects performed the GSRT as well as the TD test. Fourteen subjects reached peak power at 6kg resistance and ten subjects reached peak power at 2kg resistance. Values for peak power ranged from 713W - 2014W with a mean of 1262W (SD±410), and for peak velocity from 3.6 m/s – 7.3 m/s with a mean of 5.5 m/s (SD±0.8). Values for peak force ranged from 165N - 389N with a mean of 273N (SD±69), and values for TD reached from 42.4 – 197.6 with a mean of 128.2, see table 1.

Table 1. Descriptive values for peak power, peak velocity, peak force and total driving for all subjects (n= 24).

<table>
<thead>
<tr>
<th></th>
<th>Whole group mean (±SD) N=24</th>
<th>Women mean (±SD) N=10</th>
<th>Men mean (±SD) N=14</th>
</tr>
</thead>
<tbody>
<tr>
<td>Peak power (W)</td>
<td>1261.8 (410.1)</td>
<td>885.0 (156.4)</td>
<td>1530.9 (305.8)</td>
</tr>
<tr>
<td>Peak velocity (m/s)</td>
<td>5.5 (0.8)</td>
<td>5.1 (0.7)</td>
<td>5.7 (0.7)</td>
</tr>
<tr>
<td>Peak force (N)</td>
<td>273.0 (68.8)</td>
<td>217.8 (43.4)</td>
<td>312.4 (55.2)</td>
</tr>
<tr>
<td>Total driving</td>
<td>128.2 (48.1)</td>
<td>120.5 (38.3)</td>
<td>133.7 (54.9)</td>
</tr>
</tbody>
</table>

Correlations between peak power and total driving

The strength of the correlation between peak power and total driving for the whole group was poor (r=0.23, p=0.29) as seen in figure 4. For women, the correlation was moderate (r=0.59, p=0.07) (figure 5) and for men poor (r=0.10, p=0.74) (figure 6). Values from all correlations can be seen in table 2. The moderate correlation for women (r=0.59, r²=0.35) means that the peak power value in GSRT explains 35% of the TD score.
Figure 4. Correlation between peak power (W) in GSRT (golf specific rotational test) and total driving for the whole group \((r=0.23, p=0.23)\), \(n=24\).

Figure 5. Correlation between peak power (W) in GSRT (golf specific rotational test) and total driving for women \((r=0.59, p=0.07)\), \(n=10\).
Figure 6. Correlation between peak power (W) in GSRT (golf specific rotational test) and total driving in men (r=0.10, p=0.74), n=14.

Correlations between peak velocity and total driving
The strength of the correlation between peak velocity and total driving for the whole group (figure 7) was poor (r=0.35, p=0.10). For women (figure 8) and men (figure 9) separately the correlation was also poor (r=0.44, p=0.20 and r=0.28, p=0.33).

Figure 7. Correlation between peak velocity (m/s) in GSRT (golf specific rotational test) and total driving for the whole group (r = 0.35, p=0.09), n=24.
Figure 8. Correlation between peak velocity (m/s) in GSRT (golf specific rotational test) and total driving for women ($r=0.44$, $p=0.20$), $n=10$.

Figure 9. Correlation between peak velocity (m/s) in GSRT (golf specific rotational test) and total driving for men ($r=-0.17$, $p=0.55$), $n=14$.

Correlations between peak force and total driving

The strength of the correlation between peak force and total driving for the whole group (figure 10) and for women only (figure 11) was poor ($r=0.10$, $p=0.66$ and $r=0.45$, $p=0.20$). For men (figure 12) there was a poor negative correlation ($r=-0.17$, $p=0.55$).
Figure 10. Correlation between peak force (N) in GSRT (golf specific rotational test) and total driving for the whole group ($r = 0.10$, $p=0.66$), $n=24$.

Figure 11. Correlation between peak force (N) in GSRT (golf specific rotational test) and total driving for women ($r=0.45$, $p=0.20$), $n=10$. 
Figure 12. Correlation between peak force (N) in GSRT (golf specific rotational test) and total driving in men ($r=0.28$, $p=0.33$), $n=14$.

Table 2. Pearson’s correlation coefficient ($r$) for PP-TD, PV-TD and PF-TD for whole group, women and men ($n=24$).

<table>
<thead>
<tr>
<th></th>
<th>Whole group</th>
<th>Women</th>
<th>Men</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$r$-value</td>
<td>$r$-value</td>
<td>$r$-value</td>
</tr>
<tr>
<td>PP-TD</td>
<td>0.23 (p 0.29)</td>
<td>0.59 (0.07)</td>
<td>0.10 (0.74)</td>
</tr>
<tr>
<td>PV-TD</td>
<td>0.35 (p 0.09)</td>
<td>0.44 (0.20)</td>
<td>0.28 (0.33)</td>
</tr>
<tr>
<td>PF-TD</td>
<td>0.10 (p 0.66)</td>
<td>0.45 (0.20)</td>
<td>-0.17 (0.55)</td>
</tr>
</tbody>
</table>
Discussion

Result discussion

The present study found only poor and moderate correlations between peak power, peak velocity or peak force and total driving for the whole group or for men and women separately. The moderate correlation was found between peak power and total driving in women.

In the present study, there were poor to moderate correlations between peak power and total driving. A previous study has found a significant correlation between leg power (standing long jump test) and average golf score (r=-0.36, p<0.05) and, also between total score and muscle vertical jump (Torres-Ronda et.al., 2011). Leary et. al., 2012 show physical training to be important for golfers and that the ability to create power and apply force quickly seem to be specifically important to hit the ball far.

Furthermore, the present study found only poor correlations between peak force or peak velocity and total driving. Torres-Ronda et.al., 2011 found positive relationships between golf skill and muscle strength and according to Schofield (2015) rotational velocity should be highlighted in a golfer’s strength and conditioning program. Koegh et. al., (2009) studied the strength in a golf specific cable wood chop and found it to be 28% greater for low handicap (hcp=0.3±0.5) golfers than for high handicap (hcp=20.3±2.4) golfers. The same study also showed greater strength for low handicap golfers than high handicap golfers in bench press (30%). Torres-Ronda et.al., (2011) found a significant correlation between total golf score and push-ups/pull-ups in 60s or grip strength.

The present study found a moderate correlation (r=0.59, $r^2 = 0.35$) between peak power and total driving for women only. This shows that peak power in the golf specific rotational test might explain 35% of the women’s total driving performance. Only poor correlations were found for men. This could mean that peak power generation in a golf specific rotational test is more important for driving performance for women than men. To the authors knowledge, no other study has compared peak power and total driving. Therefore, it is not possible to compare the correlations from the present study with earlier correlations. Additionally, the
correlations in the present study were not significant and no definitive conclusions could be made from the results.

There is a general difference in musculotendinous stiffness between men and women (Brown et.al., 2011) and the genders also differ in several golf swing characteristics (Egret et.al., 2011; Zheng et.al., 2008; Horan et.al., 2010). To a different amount depending on group characteristics, men have greater absolute strength than women (Mc. Ardle et.al., 2010). Generally, men also hit the golf ball further than women with the same world golf ranking. In 2007 that difference was 15% (Zheng et. al., 2008). These differences in physical and golf characteristics might contribute to the gender differences between the correlations of the present study.

**Method discussion**

The golf specific rotational test used in the present study has been tested for reliability and validity. All tests for all loads except for peak power with 2kg, showed good reliability (Parker personal communication, 2017). A limitation in this study was the low number of participants. This could be a contributing factor to the non-significant results of the correlations. A higher number of participants is therefore recommended for future studies.

The golfers in the present study all had different amount of previous practice with the GSRT. More experience of the test could lead to more efficient technique and better results. Further studies should consider determining a minimum number of hours of previous GSRT experience needed to be included in the study.

Total driving has previously been calculated using statistics from professional tournaments over a period of time (Wisemann et.al., 2006; Engelhardt, 2002). The present study instead used a launch monitor (trackman.com) to measure total driving indoors at Halmstad Högskola. Sweeney et.al. (2009) and Robertson et. al. (2013) have used launch monitors for similar golf tests. None of them has however measured side displacement with a driver indoors. No one has, to the test leader’s knowledge, measured side displacement with a driver indoors in previous studies. Using a launch monitor for this purpose could result in measurement errors since the ball is stopped by a net and Trackman therefore has to estimate the shot distance and side dispersion. Future studies should compare results of indoor- and
outdoor launch monitor tests to. To completely avoid measurement errors future studies could use total driving statistics from tournaments and study how it correlates with a GSRT performed during the same period of time.

Different from regular golf the present total driving test was performed indoors. Several reasons lead to this decision including; erasing the difference in temperature and wind between tests, simplifying standardization of clothing, and improving logistics and time efficiency. Even though there were many positives in testing indoors, there were also negatives to consider. The biggest difference experienced by the golfers themselves was that they did not get to see the ball flight or the usual long distance target. This makes aiming different from regular golf. Outdoors it is possible to aim at small targets 200< meters away, hitting the ball with or against the wind and using the courses’ elevations get the preferred result. In the present indoor setting, the golfers aimed at a net 15m in front of them. This could both interfere with the players’ perceptions and tactics. According to Robertson et.al., (2013) tactical-, psychological- and perceptual skills are crucial for elite golfers’ performance.

The dates of the tests were in most golfers’ off-season. This means some of them were working on technique changes in their swing. During a period of technique practice they might not be practicing with their driver club as frequently as they would during the tournament season. They might also be unaccustomed to focusing on a target. These factors could affect the results of the total driving tests. To avoid these implications future studies should consider doing golf tests during the tournament season.

**Conclusion**

In conclusion, there seems to be a moderate correlation between peak power and total driving for women, suggesting that peak power might influence total driving. Peak force and peak velocity, however, seem to correlate poorly with total driving for women. There also seems to be poor correlations between peak power, peak force or peak velocity and total driving for men and for a whole group of men and women. Future work should consider studying the correlation between golf specific rotational tests and total driving calculated from tournament rounds.
References


Appendices

Informationsblad

Undersökning av sambandet mellan ett nytt golfspecifikt rotationstest och olika driverparametrar inom golf

Hej,

Vi är två studenter (Oliver Larsson och Christoffer Andersson) på programmet Biomedicin inriktning fysisk träning på Högskolan i Halmstad. Vi skriver nu vår kandidatuppsats inom området golf och undrar om du vill delta i vår studie. Vi kommer att undersöka hur resultatet av ett rotationstest hänger ihop med olika mätvärden för golfsvingen med en driver.

Syftet med studien är att undersöka sambandet mellan ett golfspecifikt rotationstest och olika mätvärden för golfsvingen samt undersöka potentialen för framtida användning av rotationstestet i träning och testning för golfare. Man kan optimera träningsresultat genom att individanpassa träning för olika rörelser och vi hoppas detta rotationstest kan vara ett framtida hjälpmedel för att åstadkomma detta.

Förfrågan om deltagande


Tillvägagångssätt

Du som deltagare kommer få göra en generell uppvärmning med en pulshöjande del och en rörlighets del. Ditt deltagande i studien utgör inga skaderisker utöver de från din vanliga träning.

**Frivilligt deltagande**

Ditt deltagande i studien är helt frivilligt och du som testperson har rätt att avbryta testet när som helst utan att ange orsak.

**Sekretess**


För frågor eller ytterligare information gällande studien, hör gärna av dig till oss enligt kontaktuppgifter nedan.

**Ansvariga för studien**

Oliver Larsson
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Christoffer Andersson
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**Handledare**

Ann Bremaner
Ann.bremander@hh.se

**Samtycke**
Undersökning av sambandet mellan ett nytt golfspecifikt rotationstest och olika
driverparametrar inom golf

Här nedan ger ni ert samtycke till att medverka i studien som kommer innefatta; rotationstest
i maskinen Quantum 1080 samt golftester utförda med en driver, båda i Halmstad Höskolas
lokaler. Gå igenom informationen och signera sedan längre ner på sidan om du samtycker
med det som står.

Jag medgiver att jag:

- Har tagit del av informationen och förstår dess innebörd.
- Fått möjlighet att ställa de frågor jag önskar och vet vem som är ansvarig huvudman
  om jag skulle ha ytterligare frågor.
- Deltar frivilligt i studien och förstår varför man har frågat mig.
- Vet att jag när som helst under studiens gång kan avbryta och behöver ej ange orsak.
- Jag godkänner att mina personuppgifter samlas in och lagras enligt de instruktioner
  som givits.
- Jag intygar här att jag läst det informerade samtycket och tagit del av informationen
  kring studien. Jag förstår vad deltagandet i studien innebär och ställer upp av egen
  vilja.

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………………………….. ………………………………..

Datum/ Ort Testpersonens namnteckning Namnförtydligande


Oliver Larsson is a student of the Bachelor’s Programme in Exercise Biomedicine in Halmstad, Sweden.