Golf swing rotational max power correlation to clubhead speed, ball speed and carry distance in young elite golf players.

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Abstract

Background: In ballistic sports like golf, power production in rotational movement plays a major role for performance. To hit the ball far, high clubhead speed is crucial in golf and rotational power (medicine ball throws) have shown to have a good correlation to clubhead speed. A lower golf handicap has also shown to correlate well with higher clubhead speed. Few sport specific power tests have been executed and training and testing sport specific are associated with high performance in a sport. Aim: The aim of this study was to examine the correlation between three parameters (power, velocity and force) measured in a golf specific rotational test and clubhead speed (CHS), ball speed (BS) and carry distance (CD) on young elite golfers. Methods: Twenty-six golfers, 16 men and 10 women, completed the study. Two tests were performed on separate occasion; one golf performance test using Trackman launch monitor and one golf specific rotational test in 1080 Quantum. CHS, BS and CD were collected in the golf performance test and max power, force and velocity in the golf specific rotational test. To study the relationship between the selected variables, spearman’s correlations coefficient ($r_s$) was used and analyzed the total group, and in men and women separately. Results: Excellent correlation was found between max power and CHS ($r=0.9$, $p<0.00$). Good correlation was found between force and CHS ($r=0.8$, $p<0.00$). Moderate correlations were found between force and BS and force and CD and max power and CD ($r=0.7$, $p<0.00$). Poor correlations were found between velocity and CHS, BS and CD ($r=0.3$, $p>0.50$). Conclusion: This study showed that strong correlations seem to exist between power production in a golf specific rotation test and Golf performance in young elite golfers. Even force also seems to have an impact on golf performance while velocity showed little to no correlation to golf performance.
Abstrakt

Bakgrund: I ballistiska sporter som golf spelar power en stor roll för prestation. För att slå bollen långt är hög klubbhastighet av stor betydelse i golf och rotations power mät med medicinbollskast har visat sig korrelera väl med klubbhastighet. Klubbhastighet har även visat sig korrelera bra med golf handicap. Få sport specifika power test för golf har gjorts, då sport specifik träning och testning har bäst överföring till hög prestation inom idrotten bör detta studeras. Syfte: Syftet med studien var att undersöka korrelationerna mellan Power, hastighet och kraft mäta i ett golf specifikt rotations test och klubbhastighet (CHS), bollhastighet (BS) och carry distans (CD) hos unga elit golfare. Metod: Tjugosex golfare, 16 män och 10 kvinnor, slutförde studien. Två tester gjordes på olika tillfällen, ett golf prestationstest med Trackman launch monitor och ett golf specifikt rotationstest i 1080 Quantum. CHS, BS och CD samlades in via golf prestationstestet och max power, hastighet och kraft via golf specifika rotationstestet. För att studera sambandet mellan de valda variablerna användes spearmans korrelationskoeficient (rₚ) och analyserade hela gruppen, och män och kvinnor särskilt. Resultat: Utmärkt korrelation hittades mellan max power och CHS (r=0.9, p<0.00). God korrelation hittades mellan kraft och CHS (r=0.8, p<0.00). Måttliga korrelationer hittades mellan kraft och BS, kraft och CD och max power och CD (r=0.7, p<0.00). Svaga korrelationer hittades mellan hastighet och CHS, BS och CD (r=0.3, p>0.50). Konklusion: Den här studien visade att starka korrelationer verkar finnas mellan power mätt i ett golf specifik rotations test och golfprestation hos unga elit golfare. Kraft i rotationstestet verkar också ha en påverkan på golfprestation medan hastighet i rotationstestet visade liten till ingen korrelation till golfprestation.
# Table of Content

Introduction ................................................................................................................................. 1

Background ................................................................................................................................. 2

  Gender differences ....................................................................................................................... 2
  Biomechanics in golf rotation .................................................................................................... 3
  X-factor ....................................................................................................................................... 4
  Stretch shortening cycle ............................................................................................................ 4
  Power (speed and force) ............................................................................................................. 5
  Training for power ...................................................................................................................... 5

Method .......................................................................................................................................... 7

  Study design ............................................................................................................................... 8
  Subjects ....................................................................................................................................... 8
  Equipment ................................................................................................................................... 8
  Testing procedure ...................................................................................................................... 9
  Golf specific rotational test (GSRT) .......................................................................................... 9
    1080 quantum Set Up .............................................................................................................. 9
    Back swing ............................................................................................................................. 10
    Downswing ............................................................................................................................. 10

Results .......................................................................................................................................... 12

  Relationship between power and CHS, BS and CD ............................................................... 13
  Relationship between velocity and CHS, BS and CD .............................................................. 13
  Relationship between force and CHS, BS and CD ................................................................. 14

Discussion .................................................................................................................................... 16

  Result discussion ...................................................................................................................... 17
    Power ....................................................................................................................................... 17
    Force ....................................................................................................................................... 18
    Velocity ................................................................................................................................... 19
Introduction

Golf is one of the biggest sports in the world with over 30 million players worldwide. For a long time, golf was perceived as a relatively gentle sport, with no to little physical demands, but in the last decades golf has evolved to a more power requiring sport (Hellström, 2009). The driver (longest shot in golf) is an important part in golf because, players today are driving the ball further than in past years and golf courses are getting longer (Hellström, 2009). The primary function of the full swing is to drive the ball as far as possible with accuracy, control, and consistency, and physical conditioning for golfers now has become a significant aspect of the game (Gordon, Moir, Davis, Witmer & Cummings, 2009). Hellström (2009) showed that golfers swing better if they are strong and flexible, and have good balance, which in terms lead to less injuries.

Schofield (2015) discussed the importance of developing a reliable sport specific rotational test for assessing golfers. Previous studies have shown that more golf like movement, like cable wood chop have better correlations to driving performance than more general power/strength exercises. It is therefore relevant to test the golf swing in a more golf like movement as previously investigations have stated the importance of testing the athlete in similar movements as they have the greatest association to sports performance (Schofield, 2015). Therefor this study examined power development in a more golf like rotational test in relation to club head speed, ball speed and carry distance.
**Background**

Putting the golf ball in the hole with few strokes is associated with lower golf handicap, therefore the lower handicap golfers have, the better they are. Hitting the golf ball far seems to influence golf handicap and important factors in hitting the ball far is, clubhead speed (CHS), ball speed (BS) and carry distance (CD). CHS is the speed the club head is traveling immediately prior to impact. Higher club speed equals more potential distance. Adding 1 miles per hour (mph) of CHS can increase the distance by up to 2.7 meters with the driver (Trackman, 2017). BS is the speed of the golf ball immediately after impact. Although a golfer’s CHS is key to potential distance, the BS that is created at impact is the biggest factor in how far the ball actually carries (Trackman, 2017). Carry is the distance the ball travels through the air (Trackman, 2017).

The ability to hit the golf ball a great distance is an important factor to place high on the world golf ranking. In 2016, seven of the top 10 golfers in the world also placed very high on the top driving distance list (inside top 20 on average driver distance) (PGA tour, 2017; Official World golf ranking, 2017). The ability to generate high CHS has shown to correlate well with lower golf handicap \( r = 0.95 \), and driving distance correlate medium to high \( r = 0.41 – 0.88 \) with performance (prize money) on PGA (Professional Golfers Association) tour (Fradkin, Sherman & Finch, 2004).

A strong and flexible body helps the golfer rotate faster and create higher power with the golf club. Although maximal strength seems to have a big impact on high CHS, the ability to apply force quickly in the downswing, a rotational movement, is also of importance. Golfers create power by rotating their body around the spine and an increased rotation \( (x\text{-factor}) \) can lead to more power/carry distance (Hume, Keogh & Reid, 2005). A strong and flexible body also helps to golfer the prevent injuries and withstand the forces acting on the body during a full golf swing. Studies have showed that weightlifting can have a positive effect on CHS (Hellström, 2009; Leary et al., 2012). Studies have also shown that conducting a resistance training (traditional or golf specific) can have positive effects on CHS in both men and women.

**Gender differences**

It is well known that women have a smaller amount of muscle mass on their body in comparison to men. When testing absolute strength, men possess considerably greater strength for all muscle groups (50 % more in upper body and 30 % in lower body than women...
Mcardle, Katch and Katch (2015) writes that when looking at relative strength (strength/body mass, fat free mass) the differences are not that big. Men are stronger in the upper body but in the lower body small differences in relative strength appear between women and men (Mcardle, Katch & Katch, 2015).

Wells, Elmi and Thomas (2009) investigated different physiological factors (strength, flexibility and anthropometrics) and golf performance. It was founded that leg power (vertical jump), upper body strength (push and pull ups) and arm strength (grip strength) all correlated well with golf performance. Men were observed to have a higher correlation with vertical jumps with both legs while women had a stronger correlation with vertical jumps on the dominant leg. Wells, Elmi and Thomas (2009) suggested that men and women could use different ways of creating power in the golf swing, coaches and researchers should investigate this more to understand the physiological differences between men and women.

**Biomechanics in golf rotation**

The modern golf swing is a complex movement that consists of the setup, backswing, downswing and finish (see figure 1). The setup position creates a foundation for the golf swing to be performed; golfers stand approximately shoulder width, slight flexion in the hip, knees, upper torso and gripping the golf club with a golf grip. In the backswing, a body rotation around the spine away from the ball occurs, preparing for the downswing. The downswing starts when the body is on the top of the backswing and begins to rotate down past the ball. Finally, the finish occurs after ball contact (Schofield, 2015).

The backswings purpose is to position the golfer in a powerful position to start the downswing. In the downswing, the muscles and joint structures stretch and are responsible for creating power in the golf swing. The distance of the golf shot is directly related to club-head linear velocity at impact between the ball and club. The linear club-head velocity is a function of angular club head velocity and lever length (arms and club length) at impact. To maximize the golf shot, the golfers must therefore maximize angular club head velocity (Hume, Keogh & Reid, 2005). In golf the rotation of torso and pelvic is often described as the x-factor which seems to have an important role in creating CHS.
**X-factor**

X-factor is a common term in golf and it describe the separation between torso and pelvic turn at the top of the backswing (see figure 2). Myers et al (2008) describe the x-factor as the difference in axial rotation between upper torso and pelvic rotation and is measures in degrees.

According to Hume, Keogh and Reid (2005) the greater the x-factor was, the higher a professional golfer was ranked on driving distance. The golfers hitting shorter demonstrated a lower x-factor, indicating that flexibility is of great importance for maximizing driving distance (Hume, Keogh & Reid, 2005).

Myers et al (2008) found that maximizing the x-factor contributes to an increased ball speed and longer golf shots. The torso-pelvic separation creates a stretch in the torso-muscles which is believed to contribute to increased driving distance. The X-factor enhances the power of the golf swing by means of utilizing the stretch shortening cycle (SSC). During the backswing as the muscles of the hips, trunk/torso, and shoulders are dynamically stretched, elastic energy is stored, the amount of which depending on the degree of X-factor achieved (Myers et al, 2008).

**Stretch shortening cycle**

Sports involving high movement speed often include the muscle-tendon units to pre-stretch before quickly shortening, without any delay between the two phases. This is called the stretch-shortening cycle (SSC), throwing, jumping, running, hitting and kicking are just a few examples were the SSC is used (Cardinale, Newton, & Nosaka, 2011). SSC acts by storing potential elastic energy in series elastic components (muscle spindle and tendons). During the stretch cross-bridges between actin and myosin filament arise against their natural tendency (creating elastic energy, pre-activation) and because of the lifetime of cross-bridges (15 – 120ms) its preferable to keep the transition between stretch and shortening of the muscle as short as possible (Komi, 1984). SSC increase the performance compared to only concentric-movement, for example vertical jump have shown to increase by 8 % if SSC is used (Cardinale, Newton, & Nosaka, 2011).

The golf swing can be described as a powerful SSC activity, where muscles in the lower, mid-section and upper body rapidly stretch prior to shortening. Golfers stretch the major muscle
groups in the eccentric phase (the backswing) and then go over to the concentric phase in the
downswing. Golfers use the SSC to improve their performance by minimizing the transition
from backswing to downswing (Hume, Keogh, & Reid, 2005). Cardinale, Newton and Nosaka
(2011) describe that the stretch reflex in the muscles react very fast (>200ms) and a delay in
concentric phase results in reduced concentric movement performance and efficiency.
Therefore, if a longer pause between backswing (the eccentric phase) and downswing
(concentric phase) occur the SSC effect disappear and the potentially power enhancement
transfers to heat (Hume, Keogh, & Reid, 2005).

**Power (speed and force)**

Strength and power are two common terms used to describe important factors in human
abilities in sports and other physical activities. Strength is the ability to generate force, for
example lifting something heavy. Power (P) is a combination of force (F) and velocity (V),
power is measured in watt (W). In many sports activates, the ability to generate high force and
velocity is crucial for success, example weight lifting, shot put, javelin, baseball, boxing, golf
and jumping (Hamill, Knutzen & Derrick, 2015).

The following equation is noted in Hamill, Knutzen and Derrick (2015):

\[ P = F \times V \] (1)

In golf, power has shown to be an important factor in creating CHS. Correlations between
power measured in diverse ways and CHS range from \( r = 0.5 – 0.8 \) (Schofield, 2015; Leary et
al., 2012; Gordon et al., 2009; Winqvist & Grenzdörfer, 2013). Fletcher and Hartwell (2004)
has reported that CHS was significantly higher after a period of resistance training,
strengthening the active muscles in the golf swing seems to have a positive effect on CHS.
Power type resistance training is effective to increase CHS where a rapid force development
and rotational velocity are two important factors in increasing CHS.

**Training for power**

Baechle and Earle (2008) showed that golfers use the phosphate system energy system as
their primary energy system. To train the phosphate system golfers should adopt training at 90
-100 % maximum power and a work-to-rest-period at 1:12 – 1:20. Baechle and Earle (2008)
recommend a volume of power based training at 1-2 repetitions (80 - 90 % 1RM, single effort
movement) and 3-5 repetitions (75 – 85 % 1RM, multi effort) and 3-5 sets.
When creating golf specific training programs or choosing exercises, coaches should implement maximal power and ballistic type movements to the program. Dynamic stretching and ballistic type jumping should be integrated into golf-specific warm-ups (Schofield, 2015). Exercises mimicking the golf swing should be a primary focus when designing golf specific programs because sport specific movements offer greatest performance enhancement. Those movements should be performed with maximal velocity regardless of load (Schofield, 2015).

**Rotational power**

Hamill, Knutzen and Derrick (2015) describes the rotational movement as a motion around same point with no change in distance. Golfers rotate their body around the lumbar spine and rotate as fast as possible down towards the ball to generate high CHS. The downswing in golf takes about 200 to 300 milliseconds for an elite golfer (Leary et al., 2012). Therefore, the ability to apply force rapidly can seem more relevant than maximal strength. According to Baechle and Earle (2008) it takes a proximal 300 milliseconds to generate maximum velocity and force (power) in a movement/exercise, which underpins that golfers should train maximum power to develop their CHS. Leary et al. (2012) describes that peak force-generating during time periods <150 milliseconds are of importance for golfers. Using midthigh pull and vertical jump testing, the maximal force was showed to be generated within 150 milliseconds, and Leary et al. (2012) emphasized that golfer should train to increase rate of force development. The ability to rotate fast is a crucial moment in the golf swing and testing rotational power can be done in many ways.

**Testing rotational power**

To assess power in sport, different jumps (vertical and horizontal) and throwing (medicine ball) have been used; it is argued that there are no gold standard test for assessing rotational power (Algotsson, 2016). For measuring power in a rotational movement, medicine ball throws, seated cable rotation and a standing rotational test all have shown to be valid and reliable (test-retest ICC 0.92) (Andre et al., 2010; Algosston, 2016).

Medicine ball throws have been used for measuring rotational power and showed to correlate well with CHS (r=0.63 – 0.67) (Gordon et al., 2009; Read et al., 2013), but medicine ball throws do not measure force, velocity or power. Frennessen (2016) showed that a standing rotational test measuring power correlated moderately to CHS on golfers dominant side (r = 0.58). Exercises and tests should be sport specific and include similar muscles and energy systems for the greatest transfer to sport performance (Morrison & Chaconas, 2014). Studies
have correlated different rotational tests against CHS but few golf specific rotational tests (GSRT) have been used, and since golf is an explosive sport it would be of interest to examine the force-velocity profile in a more sport specific test.

Rotational power in golf seems to have a big impact on creating CHS and driving the golf ball far and doing sport specific training and testing seems to be the best way of optimizing sport performance (Morrison & Chaconas, 2014). Few studies have investigated men and women separately which support the research questions of this study. Because of the limited research in this area this study examined the power-, force and velocity production in a golf specific rotational test and their correlations to three important factors of golf performance (CHS, BS, and CD in young elite golfers).

**Aim**

The first aim of this study is to examine the correlation between three parameters (power, velocity and force) measured in a golf specific rotational test and clubhead speed (CHS), ball speed (BS) and carry distance (CD) on young elite golfers. The second aim is to investigate the correlations for men and women separately.

**Research Questions**

What is the correlation between max power measured by a golf specific rotational test and CHS, BS and CD in the total sample and in men and women separately?

What is the correlation between force measured by a golf specific rotational test and CHS, BS and CD in the total sample and in men and women separately?

What is the correlation between velocity measured by a golf specific rotational test and CHS, BS and CD in the total sample and in men and women separately?
Methods

Study design
This correlation study was performed on a group of young elite golfers (hcp ≤ 6) examining the correlations between max power, force and velocity against golf performance.

Subjects
Thirty-eight young elite golfers were approached from Scandinavian school of golf and Aspero high school and 31 subjects accepted to participate in the study (19 men and 12 women). The participants were asked by their coaches to participate in the study and an announcement on the school’s Facebook page was posted. Inclusion criteria for participation were handicap ≤ 6, 16 – 25 years old, injury- and illness free and ability to participate in two tests. Twenty-six participants met the inclusion criteria and finished both tests (16 men and 10 women). Descriptive data (mean ±SD) of the 26 participants were: 19 ± 3 years old, 1.7 ± 2.6 hcp and 59.8 ± 6.7 stance wide (cm).

Equipment
For measuring CHS, BS and CD Trackman 3 e (TrackMan A/S, Vedbaek, Denmark) was used. Trackman 3 e was placed three meters behind the golfer aiming at the intended golf shot direction (Trackmangolf, 2017). Trackman 3 e has been used in previously research and is considered as a reliable and valid method for measuring CHS, BS and CD (Gordon, Moir, Davis, Witmer & Cummings, 2009; Read, Lloyd, De Ste Croix & Oliver, 2013; Leary et al., 2012). Robertson, Burnetti and Newton (2013) also showed good test-retest reliability for measuring golf shots with Trackman launch monitors.

1080 Quantum (1080Motion AB, Lidingö, Sweden) is a relatively new equipment for measuring variables like power, velocity, force and acceleration in movements like rotation, jump, pull and push. 1080 Quantum has two adjustable arms and a smith machine for training and testing in the optimal angle for a specific movement pattern. The machine can control the resistance, loads, speed of concentric and eccentric phase of movement. The concentric movement is adjustable from 0.1 – 8 m/s and the eccentric movement are adjustable from 0.1 – 6 m/s (1080 motion AB, 2017). 1080 Quantum have showed to be a reliable and valid device/machine for measuring power in a rotational movement (Algotsson, 2016).
Testing procedure
Before the testing started a familiarization session was done for the participants to test the movement and stance width for the golf specific rotational test (GSRT). The testing was divided into two occasions, the first occasion for GSRT in the Human Movement laboratory at Halmstad University and the second occasion for golf performance in a sports hall at Halmstad University. Participants signed an informed consent (see appendix 1) before starting the tests. The tests were conducted at separate occasions to avoid that the two different tests to influenced on each other and the participants performed the two tests within two weeks. The subjects were informed not to perform any demanding physical activity 24 hours before the two testing occasions.

Golf specific rotational test (GSRT)
Prior to GSRT participants performed a standard warm-up including five minutes of cycling, upper and lower body stretches and ten practice swings at a 10 kg load in 1080 Quantum (Koegh et al, 2009).

After the warm-up, each subject performed three maximal repetitions at five different loads with the 1080 Quantum (see figure 3) to find the total body rotation maximal power development. The loads were set at 2, 6, 10, 14 and 18 kg, arbitrary measures based on former experience by a golf coach (J. Parker, personal communication, 16 mars 2017). Rest between sets were set to two to four minutes to secure full recovery. The load where the athletes managed to achieve max power (watts) was singled out and the power components, force (newton) and velocity (meter per second) was noted from that repetition. The 26 golfers performed the test in smaller groups.

Test-retest of the GSRT has been showed good reliability for different loads (ICC = 0.84 – 0.97) except for max power at 2 kg (ICC = 0.29) (J. Parker, personal communication, 16 mars 2017).

1080 quantum Set Up
The “arm” was set at the highest point, the 12e hole and a speed limit for the wire was set at eight meter per second for the concentric phase and one meter per second for the eccentric phase. An individual profile was created in 1080 Quantum database for each participant.
**Golf Setup**

To mimic the golf swing motion a golf like set up was used (see figure 4). The used stance width was the same as the golfers own driver stance and this was measured in the golf performance test and used in GSRT. Feet, knees, hips and shoulders was lined up parallel to the 1080 quantum machine and hands gripping the handle like a golf club. For right handed golfers, the right shoulder should face the machine. Tape was set one meter from the 1080 quantum machine were the golfers placed the arch of the foot on the tape.

**Back swing**

The “backswing” or the rotation from left to right for right handed golfers. The participants were instructed to perform a golf like back swing and minimum backswing rotation required for an accepted repetition was set to the left arm parallel to the floor (see figure 5).

**Downswing**

The participants were instructed to rotate as fast as possible in a golf like downswing. For the movement to be accepted the hands must be rotated past the distal knee (see figure 6). The force was measured in Newton (N), velocity in meter per second (m/s) and max power in Watt (W).
**Golf performance**

Prior to performing the golf swing testing and before assessing CHS, BS and CD, each participant completed a semistandardized warm-up, consisted of, ~ 10 minutes of progressively more intense golf swings and stretching (Koegh et al, 2009). TrackMan placed three meters behind the golfer aiming at the golf shots intended direction. For the test participants used their own golf club (driver) and real golf balls (Titliest pro V1x). Participants were then given the instruction to hit three golf shots as far as possible at a net wall with a rest of 60 seconds between each shot (Read, Lloyd, De Ste Croix & Oliver, 2013). The shot with the highest CHS was used for further analysis and BS and CD was taken from that shot. CHS and BS were measured in miles per hour (mph) and CD in meters (m).

**Standardization of testing**

Participants were informed by the following; no training that could generate muscle soreness seven days before the test, no hard training two days before testing (e.g. high-intensity intervals or weight lifting that require long recovery), to rest or train lightly the day before testing and no training on the test day (Bellardini, Henriksson & Tonkonogi, 2013).

**Statistics**

The data was analyzed using IBM Statistical Package for the Social Sciences (SPSS) (version 22, IBM, New York, USA). Descriptive data was presented with mean ± SD. Shapiro-Wilks test showed that some outcome variables of the collected data was not normally distributed (p < 0.05). Thus, spearman’s non-parametric correlation coefficient ($r_s$) was used to examine the relationship between: max power, velocity and force from the 1080 Quantum machine and the different golf performance parameters (CHS, BS and CD). Data was also analyzed separately for men and women. Reference values for strength of the correlation coefficient ($r_s$): excellent ($\geq0.90$), good ($0.75–0.89$), moderate ($0.50–0.74$), and poor ($<0.50$) (Portney & Watkins, 2009). Data was set to be significant with a P-value $<0.05$.

**Ethical considerations**

All participants were given information (appendix 1) of the purpose and methods for the study before testing started. Since the participants presume to understand the procedure in the study participants at or over 15 years of age can sign the informed consent by themselves (18 §). The participants of the study were informed about voluntary participation and possibility to stop their participation at any time without any explanations in accordance with the
Declaration of Helsinki, (2013). Participants signed the informed consent (appendix 1) before testing.

Participants only got access to their own data and collected data was stored safely, personal data was not published and all data was presented on a group level.

**Social considerations**

Golf is a worldwide sport and hitting the golf ball far correlate very well with lower handicap (Fradkin, Sherman & Finch, 2004). All golfers strive for development in their golf game and a longer drive is an important factor in golf. Professional golfers can rotate faster in their swing than amateur golfers. This can be an effect of lower physique or poor swing mechanics, with physical training the amateurs can get the physique abilities to hit longer shots. Therefore can it be of great interest for golfers and golf coaches to known what to focus on in their physical training to generate higher clubhead speed, force, velocity or power.

Since physical training has multiplied positive effects on people’s general health status, adopting a training program regardless the purpose will benefits people’s life. A more active lifestyle with good nutrition will help people have a healthier and longer life which will decrease health costs for the government and benefit society.
Results

Twenty-six subjects, 16 men and 10 women, completed the two chosen tests (GSRT and golf performance test). Subject handicap varied from + 4.5 to 6. Mean (±SD) for total group of CHS 105.2 ± 10.4 mph, for BS 153.7 ± 15.9 mph, for CD 231.6 ± 28.7 m, for max power 1246.2 ± 399.4 W, for velocity 5.4 ± 0.7 m/s and for force 270.8 ± 68.1 N (see table 1).

<table>
<thead>
<tr>
<th></th>
<th>All n = 26</th>
<th>Men n = 16</th>
<th>Women n = 10</th>
</tr>
</thead>
<tbody>
<tr>
<td>CHS (mph)</td>
<td>105.2 ± 10.4</td>
<td>112.7 ± 4.5</td>
<td>93.2 ± 3.0</td>
</tr>
<tr>
<td>BS (mph)</td>
<td>153.7 ± 15.9</td>
<td>164.8 ± 7.7</td>
<td>135.9 ± 5.8</td>
</tr>
<tr>
<td>CD (m)</td>
<td>231.6 ± 28.7</td>
<td>251.2 ± 15.5</td>
<td>200.3 ± 11.2</td>
</tr>
<tr>
<td>Max power (W)</td>
<td>1246.2 ± 399.4</td>
<td>1471.9 ± 331.4</td>
<td>885.0 ± 156.4</td>
</tr>
<tr>
<td>Velocity (m/s)</td>
<td>5.4 ± 0.7</td>
<td>5.6 ± 0.7</td>
<td>5.1 ± 0.7</td>
</tr>
<tr>
<td>Force (N)</td>
<td>270.8 ± 68.1</td>
<td>303.9 ± 59.5</td>
<td>217.8 ± 43.4</td>
</tr>
</tbody>
</table>

CHS = Clubhead speed; BS = Ball speed; CD = Carry distance

Relationship between power and CHS, BS and CD

There was an excellent positive correlation between max power and CHS ($r_s=0.9$, $p<0.01$). Between max power and both CD and BS there was a moderate positive correlation ($r_s=0.8$ for both, $p<0.00$), indicating that higher power generated higher CHS, BS and CD (see table 2). Figure 6 – 8 shows that power can explain the values of CHS, BS and CD to 76 - 66 % ($R^2$ values). Analyzing men and women separately showed that men had moderate or excellent correlations between max power and CS, BS and CD while women had poor to non-correlations between max power and CS, BS and CD (see table 2 and figure 7-9).

Relationship between velocity and CHS, BS and CD

There was a poor positive correlation between velocity and CHS ($r_s=0.3$, $p=0.13$), and also a poor positive correlation between velocity and both BS and CD ($r_s=0.3$, $p=0.10$) (see table 2). Studying men and women separately both had poor positive correlations between CHS, BS and CD to velocity (see table 2). Velocity can explain the values of CHS, BS and CD to 9 – 12 % ($R^2$ values).
Relationship between force and CHS, BS and CD
There was a good positive correlation between force and CHS ($r_s=0.8$, $p<0.00$) and there was a moderate positive correlation between force and both BS and CD ($r_s=0.7 – 0.6$, $p<0.00$) (see table 2). Analyzing correlations between men and women separately the correlations between force and CHS were similar. Correlations between force and both BS and CD in men were considerably higher, while women showed poor correlations between force and CD and BS (see table 2). Force can explain the values of CHS, BS and CD to 62 – 41 % ($R^2$ values).

Table 2. N = 26 (16 men and 10 women) Correlation between collected data ($r_s$) and p values (p).

<table>
<thead>
<tr>
<th></th>
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<tbody>
<tr>
<td><strong>Max power and CHS</strong></td>
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<td>0.81</td>
<td>0.24</td>
</tr>
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<td></td>
<td>$p = 0.00$</td>
<td>$p = 0.50$</td>
</tr>
<tr>
<td><strong>Velocity and CHS</strong></td>
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<td>0.25</td>
<td>0.20</td>
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<tr>
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<td>$p = 0.35$</td>
<td>$p = 0.59$</td>
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<td>0.70</td>
<td>0.51</td>
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<td>0.72</td>
<td>0.04</td>
</tr>
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<td>0.32</td>
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<td>$p = 0.38$</td>
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<tr>
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<td>0.58</td>
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</tr>
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<td>$p = 0.02$</td>
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</tr>
<tr>
<td><strong>Max power and CD</strong></td>
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<td>-0.13</td>
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<td>0.13</td>
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<td><strong>Force and CD</strong></td>
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<td>0.42</td>
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<td></td>
<td>$p = 0.11$</td>
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CHS = clubhead speed; BS = Ball speed; CD = Carry distance
Figure 7: Correlations between max power (W) and CHS (mph) for a) all participants (n = 26) $r = 0.87$, b) women (n = 10) $r = 0.24$, and c) men (n = 10) $r = 0.81$ and $R^2$ values in figures. CHS = clubhead speed.

Figure 8: Correlations between max power (W) and BS (mph) for a) all participants (n = 26) $r = 0.83$, b) women (n = 10) $r = 0.04$, and c) men (n = 16) $r = 0.72$ and $R^2$ values in figures. BS = ball speed.
Figure 9: Correlations between max power (W) and CD (m) for a) all participants (n = 26) $r = 0.81$, b) women (n = 10) $r = -0.13$, and c) men (n = 16) $r = 0.68$ and $R^2$ values in figures. CD = carry distance.
Discussion

Strong to excellent correlations were found between max power and CHS, BS and CD in the large group, indicating that max power has an impact on golf performance. Force also had relevant correlations to CHS, BS and CD but velocity showed weak correlations to CHS, BS and CD, indicating that force is more important than velocity in golf performance. Studying men and women separately, correlations were in general higher for men than women except for the correlation between velocity and CHS, and velocity and BS. Strength (force) and power seems to have a positive effect on golf performance regarding the gender.

Result discussion

Power
In agreement to Schofield (2015) the present study examined power test in a golf like movement for greatest association to sport performance. Power measured in different ways has been shown to be a good predictor for maximizing CHS and golf performance in earlier studies. Read et al. (2013) used counter movement jump, squat jump and medicine ball throws as power predictors in male single figured handicap golfer and showed a moderate correlation (r=0.5 - 0.65) between all three and CHS. The present study displayed even better correlation (excellent, r=0.9) between power measured in GSRT and CHS indicated that power tests that mimic the golf swing could be a better method for evaluating golfers physical training. As hypothesis by Koegh et al, (2009) a stronger correlation was find in our study between max power and golf performance indicators due to the specificity of the rotational test, GSRT being very sport specific due to posture, stance and movement like the golf swing. Koegh et al, (2009) also found a significant correlation between a golf swing specific cable woodchop test and high CHS for male golfer under five hcp.

Torres-Ronda, Sánchez-Medina and González-Badillo (2011) investigated a numerus of studies correlated power and strength measured in different ways and golf performance. Only a few studies had at least one golf specific exercise while the other examined various type of strength exercises to golf performance. Torres-Ronda, Sánchez-Medina and González-Badillo (2011) discussed that important muscle groups in the golf swing are; leg, hip, trunk and grip strength are relevant to golf performance. Exercises mimic the golf swing showed greater correlations than non-golf specific. There seems to be a positive correlation between muscular strength/power and golf performance variables and this is strengthening by this present study that shown strong correlations between power and strength (force) to golf performance.
Wells, Elmi and Thomas (2009) found in their study that women may create power in the golf swing differently to men. This could be one explanation to the large variety correlations between men and women separately and needs to be investigated further. Since the present study has focused on measuring power, force and velocity in absolute measures and did not consider body weight (Mcardle, Katch & Katch, 2015), it would be of great interest in future studies to examine rotational power, force and velocity relative to body mass.

Hegedus, Hardesty, Sunderland, Hegedus and Smoliga (2016) studied the effect of randomized trial of traditional and golf specific resistance training in amateur women golfers 3 days per week during a 10-week period. Findings of the study showed that both traditional and golf-specific resistance training had similar improvements in body composition, golf performance and physical performance. However, Hegedus, Hardesty, Sunderland, Hegedus and Smoliga (2016) discussed if the improvements on golf performance were due to strength gains or technical enhancements since the golfers were amateur with high handicap (around 20 hcp).

In comparing to the present study greater CHS leads to more potential CD and in this present study high power productions in golf specific movements is associate well with high CHS ($r=0.9$ and $R^2=0.76$). Being able to hit the driver greater distance allows golfer to have shorter distance into green for their second shot, which could potentially lead to lower scores. Driving distance and higher CHS has been positive correlated to score/handicap in both average and elite golfers (Doan, Newton, Kwon & Kraemer, 2006). Early studies even showed that increasing the driver shot by 17 m could lead to an improvement by 2.2 strokes per played 18 holes on a professional level. A more realistic improvement in driving distance (4.9m) would lead to and 0.63 stroke improvement over 18 played holes. Professional tournament played over 72 holes (four 18 hole rounds) which could lead to an improvement by 2.52 strokes and since the margins for winning and losing in golf are small, every stroke counts (Doan, Newton, Kwon & Kraemer, 2006).

**Force**

This study showed strong to moderate correlations between force and golf performance, and this is strengthening by Hellström (2009) who mention that elite golfers often are stronger and can generate more force than average golfers. Hellström (2009) discussed that a strong and flexible body for golfers help creating force fast which generate higher CHS. The ability to generate force quickly seems important in the golf swing which is showed by the present study as max power and force correlated strong to golf performance.
To apply much force in the golf swing, golfers must be strong and studies have shown that resistance training can have a positive impact on golf performance (Hellström, 2009; Leary et al., 2012; Torres-Ronda et al., 2011; Doan et al., 2006; Fletcher and Hartwell, 2004). Studies have also shown that conducting a resistance training (traditional or golf specific) can have positive effects on CHS in both men and women. Schofield (2015) on the other hand recommend that specific golf training programs should be executed with exercises that mimics the golf swing to offer greatest improvement in golf performance. In addition, such exercises should be performed with maximal power. This strengthen by this study as we showed that power productions in a sport specific motion correlate high to golf performance and it would therefore be of great interest to examine an intervention of power based training in sport specific movement, as in this study during a prolonged time. The GSRT could potentially be used force measuring total body rotation power for non-golfers, but is designed to be more specific for golfers.

**Velocity**
This study showed relatively low correlations to velocity and golf performance in relation to power and force. Low correlations between velocity and golf performance found in this study go against Doan, Newton, Kwon and Kraemer (2006) who find medicine ball velocity correlate to CHS at $r = 0.86$. The different correlations could be due to different methods for measuring velocity, and Doan, Newton, Kwon and Kraemer (2006) medicine ball throw not being golf specific. We showed in our study that especially power and even force seems to have a big influence on golf performance variables. Samozino, Rejc, Di Prampero, Belli and Morin (2012) studied the force – velocity profile in ballistic movements on the lower limb and found that force – velocity profile can be a great accessory to power based training. They discussed that if a force – velocity imbalance exist the profile can help to detect this. The force – velocity profile is good to investigate to find out what the athlete should work on in order to enhance their performance, velocity or force. Both athletes and coaches should force – velocity profile to prevent imbalance between force and velocity in power based sports like golf.

**Gender differences**
Men’s correlations were in general higher than women’s. One explanation could be due to the differences in absolute muscular strength between men and women (Mcardle, Katch & Katch, 2015). Wells, Elmi and Thomas (2009) discussed that men and women may create power in the golfswing differently. Women may use more technical aspects in their golfswing to create
power and men may use more muscular strength to create power. This is of greatest interest to know whether men and women should train different to develop more power in their golf swing. In accordance to Wells, Elmi and Thomas (2009) this should be examined in more detail in future studies.

**Method discussion**

In this study max power, velocity and force was measured in a GRST and since the testing method was relatively new, participants had trouble getting the right technic (execution) of the test. Scandinavian school of golf participants had performed the test before and this could be observed visually as supposed to Aspero participants. Therefore, participants evolve different technics and the movement was hard to standardize. This could potentially affect the results negatively since Aspero golfers learned the movement of the test by performing it. Because of the specificity of the rotational power test to mimic the golf swing and every golf swing do not look the same this was overlooked. In future studies load on the GSRT may be different in men and women or relative to body mass. Since the load was same for men and women, women had trouble rotation at all at higher loads, however most participants had trouble keeping the right technic at the high loads. Visually it was preferable to be tall and strong to perform well at GSRT and earlier experience of the test showed.

Fifteen participants created max power at resistance six kg and eleven participants at resistance two kg. Since max power at two kg was not reliable according to Parker (J. Parker, personal communication, 16 mars 2017), these values can be questionable if they are reliable. Further studies need to examine the reliability of the GSRT even more.

The GSRT was performed in 1080 quantum which let you control the speed limits of the cable both concentric and eccentric. This was considered safer than performing the same test in a regular cable machine in typical gyms, were you can not control the cable. The speed limits minimize the risk of injuries on the eccentric phase of the movement for the participants. This by the line did not rush back to the machine, so participants didn’t need to withstand the load on the way back after performed movement. There were also limitations to speed limits which only allow the participants to move the cable at maximum 8 m/s (machines maximum eccentric speed), no participant was near this limit but this could be considered in future studies.

Conducting the study during offseason when golfers usually train technical aspects of their golf swing could have affected the results negatively. During offseason, the driver practice is
not typical priority and many of the golfers noticed this. They had many technical changes in their swing on their mind which could inhibit optimal performance during the golf performance test. Undertaking the study closer to season start may give a more correct result of golf performance.

The golf performance test was conducted in an inside environment due to creating the same conditions to everyone. Since golf is sport played outside, the participants had a hard time getting comfortable hitting maximal drives into a net. Conducting the golf performance test outside would be more sport specific but then weather conditions must be considering. The golfers were told to hit the golf ball as forceful and long as possible, hitting the ball “good” was not prioritized by participants. This was showed and the highest CHS did not always lead to high BS and long CD. Since the sport specificity of the GSRT high correlations was believed to be found. Thereof the high demands on the correlations to CHS, BS and CD.

Dealing with career driven golfers, students and private persons was noted to be tough, planning and executing the test took much longer time than expected. The logistic planning was harder than expected because of timing the test to the persons private and career life. All tests were done in the time period of each participant (two weeks), but much planning and individual session were done as a result. Checks of hard physical training days before were not controlled before tests and familiarization session was not done due to limited time period for the study, these factors could have a negative effect on the results. To strengthen the results more participants could have been involved in the study, the limited numbers of women is believed to have a negative effect on the women’s correlations

**Conclusion**

This study supports a strong relationship between power production in a golf specific rotation test and golf performance in young elite golfers. Force also seems to have an impact on golf performance while golf performance in relation to velocity was little to none. The study also displayed differences in correlations between genders which could indicate that men and women create CHS differently. These findings may help coaches in evaluating and training golfer’s physical performance by using a sport specific motion to find force – velocity imbalances. Future studies would have to examine the force-velocity profile on a more detail level to determine imbalances in golfers swing and conducting intervention studies in using this test as a training method for creating more CHS.
References


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http://trackmangolf.com/products/trackman-3e [2017-02-01]

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 resultat i 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.

Appendix 1

Informationsblad

Undersökning av sambandet mellan ett nytt golfspecifikt rotationstest och olika driverparametrar inom golf
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  Christoffer Andersson
Oliver.larsson@schoolofgolf.se  chande14@hh.se

Handledare

Ann Bremander
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 Högskolas
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.

.......................................................... ..........................................................
Datum/ Ort Testpersonens namnteckning Namnförtydligande