Test-retest reliability and construct validity of three golf specific rotational power tests in 1080 Quantum

and a presentation of the power-force-velocity profiles of elite level golfers

Bálint Paulovics

Biomedicine with Exercise Physiology application, 30 credits

Halmstad 2018-01-24
Test-retest reliability and construct validity of three golf specific rotational power tests in 1080 Quantum and a presentation of the power-force-velocity profiles of elite level golfers

Bálint Paulovics

2018-01-09

Master Thesis 30 HP in Exercise Biomedicine – Human Performance

Halmstad University

School of Business, Engineering and Science

Thesis supervisor: Ann Bremander

Thesis examiner: Emma Haglund
Abstract

Background: Evaluation of power-force-velocity profiles in ballistic push-off and sprint movements are beneficial to enhance sport performance. There have only been a few studies investigating force-velocity profiles in rotational movements and there have not been any studies conducted on golf specific rotational movements. There is a lack of isoinertial power assessment protocols which can relate to golf swing performance. For this reason, 1080 Quantum was used for testing which is a machine able to measure power, force and velocity in several different resistance modes. Aim: The aim was to study the reliability of three golf specific rotational tests and to assess the reliable test’s validity. The secondary aim was to study the isoinertial force-velocity power relationship in tests that assessed acceptable test-retest reliability and acceptable construct validity. Methods: Twelve high level golfers (handicap -1.5±1.2), 8 men and 4 women performed the tests with five different loads; 2 kg, 6 kg, 10 kg, 14 kg and 18kg with three golf specific rotational movements in a motorized cable machine (1080 Quantum, Sweden). The three new tests utilized were: full body rotational test (FBRT), thorax rotational test (TRT) and pelvis rotational test (PRT). Data gathered was used to study golfer’s individual force-velocity profile and to assess construct validity of the reliable tests against previously recorded normal-swing driver clubhead speed (CHSnormal), and maximum-swing driver clubhead speed (CHSmax). Construct validity was based on a priori stated hypotheses, and data were analyzed with Spearman’s correlation coefficient (rs). Intraclass correlation coefficient (ICC) and coefficient of variation (CV) was used to assess test-retest reliability of FBRT, TRT and PRT. Results: In the reliability assessment, the highest peak power (PP) (ICC, 0.968, 95% CI (0.889- 0.991)), corresponding peak force (PF) (ICC, 0.993, 95% CI (0.96- 0.998)) and corresponding peak velocity (PV) (ICC 0.773, 95% CI (0.17- 0.936)) was only found to be acceptable in FBRT. Construct validity assessment of FBRT was not found acceptable in either of the resistances. The calculated average slopes indicated a velocity dominant force-velocity profile for women and a force dominant for men. Conclusion: The study demonstrated that only the FBRT assessed acceptable test-retest reliability for measuring force, velocity and power. Based on our hypotheses FBRT is not a valid indicator of golf performance on either resistance, however it had a significant moderate to good correlation with CHSmax and with CHSnormal at all resistances apart from 2 kg. FBRT should not be applied as a test, nor to be used for the calculation of the force-velocity profile since it is not valid, even though it is reliable. As a result, FBRT could only be used for exercise and needs further development to improve its validity.
Table of Contents

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

Background .......................................................................................................................... 1

Indicators of Golf performance ............................................................................................ 1

The association between physical performance and club head speed .............................. 2

Differences between high and low handicap golfers ............................................................ 3

Conditioning programs and club head speed ...................................................................... 3

Force-velocity profile and individualized training ............................................................... 4

Reliability and validity ......................................................................................................... 6

Rotational tests ...................................................................................................................... 7

Aim ........................................................................................................................................ 8

Research Questions .............................................................................................................. 8

Methods ................................................................................................................................ 9

Subjects ................................................................................................................................ 9

Rotational performance ....................................................................................................... 9

Golf swing performance ....................................................................................................... 10

Test-retest reliability for FBRT, TRT and PRT .................................................................... 10

Standardization of the full body rotational test ................................................................... 11

Standardization for the pelvis rotational test ...................................................................... 12

Standardization for the thorax rotational test ..................................................................... 13

Construct validity assessment of the reliable tests .............................................................. 13

Force-velocity profile ......................................................................................................... 14

Ethical and social considerations ....................................................................................... 15

Statistical analyses .............................................................................................................. 16

Hypotheses ............................................................................................................................ 17

Results .................................................................................................................................. 18
Introduction

Optimal performance progression is essential for success in sports. Several aspects need to be considered and specified for each individual athlete. A key factor to success is to focus on exercises that develop relevant abilities to a specific sport.

The thesis will examine golf, where performance is highly dependent on the golf swing, which is a complex rotational movement. For proper execution, a well-coordinated control over several muscle groups is required. The movement’s primary function is to maximize linear velocity, when the club head reaches the golf ball (Hume, Keogh & Reid, 2005). Therefore, the main objective of golf coaches is the development of effective and efficient training programs that improve maximal power production in a dynamic, multi-joint movement. A recent study shows that an individualized training program, based on the individual force velocity profile, is more efficient in improving jumping performance than a traditional training intervention which can generally be applied to any athlete (Jiménez-Reyes, Samozino, Brughelli & Morin, 2017). It would be sensible to apply the same principles in golf. Those who do carry out trainings based on force velocity profiling need a reliable and valid test to assess their force-velocity-power relationships, in a consistent, reliable way since, if the test results are not deemed to be valid and reliable, then the findings are inapplicable. (Mokkink et al., 2010).

The type of movement involved in the exercise has an impact on maximal power generation in complex multi-joint movements, thus the optimal load for maximal power output in different exercises occurs at various percentages of 1RM (Cormie, Mc Caulley, Triplett & MCBrige 2007; Newton RU et al. 1996; Siegel, Gilders, Staron & Hagerman 2002), therefore the evaluation of maximal power output in golf requires a specific test. Several studies have dealt with the force-velocity profile in lower-limb exercises, but only a few examined force-velocity profiling in rotational exercises, and no studies were conducted on golf specific exercises.

Background

Indicators of Golf performance

Two important determinants of golf performance are driving distance and accuracy (Lewis, Ward, Bishop, Maloney & Turner, 2016). Driving distance is proportional with ball velocity, which is associated with club head speed (CHS) (Fletcher & Hartwell, 2004; Sell, Tsai,
Smoliga, Myers & Lephart 2007) and the relationship between ball speed and CHS can be described by Newton’s second law; the initial velocity of the golf ball at impact is equal to the velocity of the club head multiplied by the ratio of the mass of the club head to the mass of the ball (Hume et al., 2005). It has been found that driving distance and CHS at ball contact significantly correlates with golf handicap (r=0.95; p<0.01) (Hume et al., 2005), thus golfers with a lower handicap has increased CHS and increased efficiency compared to higher handicap golfers (Fradkin, Sherman and Finch, 2004). Due to this relationship, CHS is a measurement that is commonly used in golf literature to distinguish performance levels (Gordon, Moir, Davis, Witmer & Cummings 2009; Fletcher & Hartwell, 2004). Therefore, CHS may be considered as a valid indicator of golf performance. As a result, it is an aim of many golf coaches to increase CHS. Observation of possible correlations between different physical tests and CHS could reveal conditioning exercises that may enhance golf performance and provide tests for golfers.

There are three main factors which effect CHS; muscular force applied through the limb segments, the distance over which the force acts, and the segmental sequence which contributes to the final velocity (Milburn, 1982). These factors can be developed through regular and sport specific training. Golf specific training, may allow greater improvements in CHS and driving performance (Hellström, 2008).

The association between physical performance and club head speed

Physical performance in field based tests, which are highly dependent on the ability to generate velocity and force, such as; medicine ball rotational throw, medicine ball seated throw, countermovement jump peak power, and squat jump peak power, all showed a moderate correlation with CHS in 48 male subjects with a handicap of 5.8 ± 2.2 (Read, Lloyd, De Ste Croix & Oliver, 2013). Also, chest strength in the pec deck motion and total body rotational power, which was evaluated by the distance thrown of a 3-kg medicine ball during a hip toss movement correlated moderately with CHS in male golfers (Gordon et al., 2009). In another study on golf performance, rotational power proved to be important as well (Keogh, Marnewick, Maulder, Nortje, Hume & Bradshaw, 2009), they found a good correlation between a golf specific wood-chop test and CHS, in low handicap (0.3 ± 0.5) and in high handicap players (20.3 ± 2.4). In elite national level golfers, women's CHS had a moderate correlation with dominant leg vertical jump, while men had moderate correlation between CHS, vertical jump, pull-up and push-up exercises. Connections were also found between lower limb performance and CHS, moderate correlations were reported between CHS and leg power (squat
jump peak power), and leg strength (back squat), while pushing strength (bar dips) had a low correlation with CHS in elite amateur male golfers (Hellström, 2008).

**Differences between high and low handicap golfers**

In a previous study, low handicap golfers (handicap of 0.3 ± 0.5) hit the target 115% more and had a 12% faster CHS than high handicap golfers (handicap of 20.3 ±2.4). Low handicap golfers also demonstrated greater strength in a golf specific cable wood chop exercise (28% more than the force generated by high handicap golfers) and a greater bench press strength (30% more than the force generated by high handicap golfers) (Keogh et al., 2009). Peak pelvis rotational speed, gluteus medius and gluteus maximus strength was also higher in lower handicap golfers when compared to higher handicap golfers (Callaway, Glaws, Mitchell, Scerbo, Voight & Sell, 2012). Moreover, the former has better golf related strength, flexibility and balance characteristics (Sell et al., 2007).

**Conditioning programs and club head speed**

From the late 1990s there has been an increased level of emphasis on physical conditioning in both golf professionals and collegiate level athletes. As a result, their physical conditioning has become a significant aspect of the sport, igniting several studies, leading to the development of conditioning programs to enhance golf performance (Callahan, 2004; Fletcher & Hartwell, 2004).

A general 8-week strength and flexibility program improved club head speed by 3-6 % (Thompson & Osness, 2004); (Hetu, Christie & Faigenbaum, 1998) in elderly subjects with a mean age of 65.1 ± 6.2. Higher level Collegiate Athletic Association Division I golfers increased CHS to a smaller degree by 1.7 % in response to a 11-week high volume strength, power and flexibility training intervention (Doan, Newton, Known & Kraemer, 2006). Similarly, to Doan et al., an 8-week training intervention based on weight-training and plyometric exercises increased CHS by 1.5 % in subjects with a golf handicap of 5.5 ± 3.7 (Fletcher & Hartwell, 2004). In contrast, there was no significant change observed in CHS when training interventions were carried out once a week for seven weeks (Olivier, Horan, Evans & Keogh 2016). The protocol had a lower volume and consisted of more bodyweight exercises and less weight training exercises. The subjects were from the Professional Golfers Association of Australia International Golf Institute with a handicap of 8.6 ± 8.3 (Olivier et al., 2016). An 8-week golf specific training program, which involved 3-4 training occasions per week resulted,
similarly to Doan et al. (2006) and Hetu et al. (1998) in a 5.2% improvement in CHS, in subjects with a handicap of 12.1 ± 6.4 (Sell et al., 2007). It was evident, following an 8-week golf specific exercise program in recreational golfers, that improvements achieved in strength, flexibility and balance increased the upper-torso axial rotational velocity and CHS. Development in the golfer’s kinematic sequence was observed as well, therefore it was assumed that improvements in kinematic sequence may have contributed to the better results in the above-mentioned variables (Lephart et al., 2007). Furthermore, higher velocities can be achieved in the upper torso rotation and in torso pelvic separation, by separating them in the initiation of the downswing, thus leading to greater ball velocity (Myers, Joseph et al., 2008).

A phenomenon called” x-factor” constitutes an important part of the kinematic sequencing. The x-factor aims to describe the degree of shoulder rotation in relation to the hips at the top of the golf swing (Cheetham, Martin, Mottram & St Laurent, 2001). Cheetham et al., (2001) found that lower skilled golfers rotate their shoulder and hips towards the target at the same time, keeping very little separation between the activation of their hips and shoulders, in contrast to highly skilled players who rotate their hips faster than their shoulders, during the start of the downswing (Cheetham et al., 2001). These characteristics have also been demonstrated to be modifiable through golf-specific training programs (Sell et al., 2007).

These findings suggest that, golf performance can be enhanced in a higher degree by improving physical abilities through golf specific exercises. Therefore, targeting golf specific physical limitations by tests and exercises, which have similar kinematical characteristics of a golf swing may improve golf performance more efficiently.

**Force- velocity profile and individualized training**

Power is defined as the velocity of the movement multiplied by the applied force. Maximal power output can be increased by developing the ability to generate higher levels of force at lower levels of velocity, or higher levels of velocity with lower levels of force. (Morin & Samozino, 2016). In a dynamic movement it is preferable to assess power that can be produced against a constant mass, rather than at constant velocity because it offers more specific insights into the dynamic qualities of muscles. Such testing practice has been named iso-inertia testing. (Murphy, Wilson & Pryor, 1994).

Power profiling, or the assessment of the mechanical capacities which influence power, grants insight of an athlete’s characteristics and can provide valuable guidance for training
prescription based on individual imbalances at the level of force or velocity, at which maximal power is developed (Samozino, Rejc, Di Prampero, Belli, & Morin, 2012). The optimal power output has been examined by previous studies via the manipulation of the power-load relationship (Cormie, McGuigan & Newton, 2011; Jaric & Marcovic, 2009; McBridge, Triplett-McBridge, Davie & Newton, 2002). The force generating capacity of a muscle negatively correlates with the velocity during a movement, thus maximal power can be achieved when an optimal ratio is present in-between the two values (Yamauchi & Ishii, 2007). Therefore, performance in explosive physical exercises is highly determined by force, velocity and power (Cormie, Prue et al., 2007). The same applies to testing club head speed (Fletcher & Hartwell, 2004) or jump height (Yamauchi & Ishii, 2007).

Beside the positive effect of increased maximal power on performance, there is an optimal balance between force- and velocity that maximizes ballistic performance, independently from the athlete’s ability to generate maximal power (Samozino et al., 2012; 2013). This optimum can be calculated based on a previously proposed equation by using the actual individual force-velocity profile and the individual maximal power (Samozino et al., 2012; 2013). The necessary data can be calculated from a series of tests performed with different loads from vertical jumps (Samozino et al., 2012; 2013).

A validated theoretical approach of jumping showed that ballistic performance is also influenced by the force-velocity mechanical profile of the lower limb neuromuscular system independently from maximal power output (Samozino et al., 2012). It has been found that reducing force-velocity imbalance without even increasing maximal power output can enhance jumping performance (Samozino et al., 2013). A recently published study found that an individualized training program designed to decrease the gap between optimal and actual force velocity profile by manipulating the two variables through exercise, is more efficient in improving jumping performance than a traditional resistance training program (Jiménez-Reyes et al., 2017). An unoptimized force-velocity profile however, can lead to a ~30% lower performance for a given maximal power output. This experimentally supports that ballistic performance depends, in addition to maximal power output, on the force-velocity profile of lower limbs. Therefore, a training program which focuses on the advancement of the weaker factor of the power profile, will cause the greatest adaptations to increase sport performance.

Thus, implementing individualized training based on athlete’s force-velocity profile might be beneficial for golfers. A golf specific exercise and test, which could provide information about the individual force velocity profile is necessary to increase performance more efficiently than
general exercises would allow. This way the balance between force and velocity may be reached by developing golf specific physical limitations (Leiphart et al., 2007).

Unfortunately, it is problematic in a rotational exercise to calculate the individual optimal force-velocity profile in the same way as it was previously proposed (Jiménez-Reyes et al., 2017). While a vertical jump is performed, peak power occurs at the takeoff phase. On the other hand, peak power output during could take place in different moments during the golf swing. There is no research being conducted on developing methods to accurately assess individual force-velocity-power relationships in rotational movements such as in golf swing. Nevertheless, for jumping, sprint cycling and for sprint running, previously proposed methods (Driss & Vandewalle, 2013; Soriano, Jiménez-Reyes, Rhea, & Marin, 2015; Jiménez-Reyes et al., 2017) are available for optimizing performance through the assessment of the force-velocity-power relationships.

In conclusion, one possible way to calculate the optimal profile and to individualize training for golfers, might be to measure the force-velocity output of a large number of highly skilled golfers and calculate an average power profile from their results. It might be assumed that the average force-velocity profile of highly skilled golfers is a good representation of the optimal balance between force and velocity, since highly skilled golfers have unique and better physical characteristics than their less skilled counterparts (Sell et al., 2007).

**Reliability and validity**

Reliability and validity are fundamental factors in testing physical performance. In the fields of research, coaching and rehabilitation, valid and reliable measurements of force, velocity and power are essential to objectively record and analyze the rate of development, stagnation or deterioration.

Reliability is the degree to which a measurement is free from measurement error. It examines the extent to which scores of subjects who have not changed, are the same for repeated measurements, under similar conditions (Aaronson et al., 2002). To examine the reliability of a performance test, different approaches exist. These are test-retest reliability, inter-rater reliability and intra-rater reliability. Test-retest reliability evaluates reliability over time, inter-rater reliability is the degree of agreement among raters on the same occasion. In the case of intra-rater reliability, reliability is evaluated by the same person on different occasions. Test-
retest reliability can be measured by using intraclass correlation coefficient (ICC) (de Vet, Terwee, Knol & Bouter, 2006).

Validity is the degree to which an instrument measures the construct it intends to measure (Mokkink et al., 2010). The validity coefficient will be limited by the reliability of the test. For that reason, the maximum correlation of the test of measure with any other variable has an upper limit determined by the reliability.

Construct validity is one important indicator of performance tests. It shows how well a test measures, what it is supposed to measure. The more we can convert the theoretical definition of a test into a practical concept the higher its construct validity is. Construct validity has to be evaluated by testing a predefined hypothesis. An instrument has an acceptable construct validity if 75% of its results correspond to the previously defined hypotheses. These hypotheses have to be as specific as possible concerning the concepts that are being measured in order to avoid bias (Mokkink et al., 2010).

Criterion validity assesses the extent to which scores on a particular scale correlate to a gold standard. To rate an instrument positively on criterion validity assessment, convincing arguments have to confirm that the gold standard is actually a gold standard and can be used as a reference, furthermore the value of the correlation between the examined instrument and gold standard has to be at least 0.70 (Impellizzeri & Marcora, 2009).

**Rotational tests**

Several tests exist to measure rotational performance, either in a seated or in a standing position. Previously, test-retest reliability of a seated rotational test was examined (Andre et al., 2012). The test was performed from a static start and subjects were not allowed to move their hips and pelvis, therefore only the upper body rotation was measured. The test-retest reliability was high with all 3 resistances (9, 12, 15% of bodyweight). The tests were performed in a cable machine and power was measured with a linear encoder.

A sitting rotational test - the sitting rotational medicine ball throw - can be applied to measure rotational performance. The test is carried out in a sitting position on the floor with bent knees and heels on the floor, therefore similarly to the previously mentioned test, power development is limited and mainly generated from the spinal column. (Nikolenko et al., 2011). Another rotational test, performed on a bench has the same motional limitations and only allows the hip and pelvis to get involved to a limited degree in the movement (Shinkle, Nesser, Demchak &
McMannus 2012). These tests were correlated against general athletic performance tests, as countermovement jump, 40-yard sprint and 5-10-5-yard shuttle run which are not rotational movements and only low correlations were found (Shinkle et al., 2012; Nikolenko et al., 2011).

Standing rotational tests are more golf specific than sitting rotational tests, since the motion involved is more similar to a golf swing. Two previous studies were conducted on a standing rotational medicine ball throw test (Gordon et al. 2009; Read et al., 2013). Participants were experienced golfers with inexperienced physical training background. Moderate correlations were found between the standing medicine ball throw test and club head speed. Furthermore, the standing rotational medicine ball throw showed a high test-retest reliability (Read et al., 2013). These physical tests are not specifically designed for golf, and there has been very little discussion about how the medicine ball throw should be utilized in a golf specific way. In the past, the power curve for different medicine ball tests with various weights has not been discussed. The existing rotational tests provide insufficient information on an athlete’s rotational power, force and velocity. As the pelvis and thorax are main contributors of the so called “x-factor”, which was found to be an important factor of the final swing performance, it may be beneficial to assess their ability to generate force, velocity and power in golf specific exercises (Cheetham et al., 2001). As a result, highly reliable and valid golf specific tests, which provide information about force-velocity profiling is necessary for optimizing golf performance.

**Aim**

The aim was to study the reliability of three golf specific rotational tests and to assess the reliable test’s validity. The secondary aim was to study the isoinertial force-velocity and power relationship in tests that assessed acceptable test-retest reliability and acceptable construct validity.

**Research Questions**

1. Do full body rotational test (FBRT), thorax rotational test (TRT), and pelvis rotational test (PRT), assess acceptable test-retest reliability?
2. Do the test(s) that assess acceptable test-retest reliability, also assess construct validity?
3. How does the individual force-velocity profile relate to the mean force-velocity profile for the group?
Methods

Subjects

Twelve subjects, eight men and four women participated in this methodology study. All the subjects competed at a national level or higher and had a handicap of 5.0 or better registered with the Swedish golf association at the time of the study, they were living in Halmstad, and studying at Halmstad University. All participants were informed in advance by one of the test leaders about the study via written information leaflets sent personally or by e-mail. The test leader, who conducted the study also fulfilled the role of the contact person for the participants. The test leader, met with the possible test participants individually, and discussed the criteria concerning the study during the first meeting. After further examination of the 20 students that were selected, twelve participated in the study.

Their mean ± SD handicap, age, height, and body mass were -1.5 ± 1.2 handicap, 22 ± 4 years, 177 ± 14 cm and 73 ± 19 kg, respectively. All subjects were free of musculoskeletal injuries for the previous 12 months and had a minimum of three years golf-specific strength training experience.

Rotational performance

The construct validity and test-retest reliability assessment of the three golf specific rotational tests were performed in quantum computerized robotic engine system (1080 Quantum synchro, 1080 Motion AB, Lidingö, Sweden). It’s adjustable lever with a 5 meters long cable allows the user to test vertical, horizontal and diagonal movements. The maximum load for the machine is 175 kg and the maximum speed is 8 m/s. Accuracy and repeatability of force, position and speed measurements were high for 1080 Quantum (Bergkvist et al., 2015). It is capable of measuring both maximal and average values of a movement’s force, velocity and power. Furthermore, both a 1 RM test and a rotational power test performed in 1080 Quantum assessed construct validity and test-retest reliability in a Master’s thesis. It was concluded that the tests can be used to measure standing rotational power and standing rotational maximum strength (Algotsson M., 2016). In addition, measurements of rotational strength, speed and power measured in 1080 Quantum had a good correlation with club head speed (Eriksrud, Ghelem, Parnevik & Muth, 2016). The machine can be adjusted to a mode which keeps the resistance constant both in the eccentric and concentric phase of an explosive movement by rewinding the
cable back. In this way, the alterations of the load in an explosive movement’s eccentric phase can be prevented.

**Golf swing performance**

For the construct validity test, golf swing performance was measured using TrackMan radar 3e (TrackMan A/S, Vedbaek, Denmark). Although the validation of the TrackMan system, which measures club head speed has not been completed yet, it has been used in past researches (Sweeney, Alderson, Mills, & Elliott, 2009) and it is commonly used by Australian golf coaches and on European PGA tours and on the USPGA (Robertson, Burnett & Newton, 2013).

**Test- retest reliability for FBRT, TRT and PRT**

Two sessions per subject were conducted to perform 3 golf specific rotational movements, using five different loads in each test per occasion (2 kg, 6 kg, 10 kg, 14 kg, 18 kg) in 1080 Quantum for test-retest reliability assessment. Testing occasions were separated by 7-14 days and all testing sessions were performed in similar time of day (Keogh et al., 2009).

Each participant engaged in 3 tests consisting of the full body rotational test (FBRT), thorax rotational test (TRT) and pelvis rotational tests (PRT), with the following resistances: 2 kg, 6 kg, 10 kg, 14 kg, 18 kg. All three trials in each resistance and their peak force (PF), peak velocity (PV), and peak power (PP) was recorded, from which the best result from the three trials was used for further analysis. Taking reliability into consideration, the highest PP was selected, along with its corresponding PV and PF on the same resistance in test 1 and in test 2 (McGuigan et al., 2006). If the highest PP was to be recorded at different resistances in test 1 and in test 2 than an additional ICC analysis would be conducted to assess the consistency of the occurrence of highest PP throughout test 1 and test 2.

Speed limits were set to 8 m/s for the concentric phase and to a constant 1 m/s for the eccentric phase.

A general warm up was performed before the two test-retest reliability sessions. 10 minutes warm up, starting with 5 minutes cycling on an ergometer followed by a movement of participants choice and finished by up to 10 practice swings with the lightest weight on the machine before each specific rotational test. To ensure sufficient recovery, two minutes rest were performed between sets.
For the rotational tests, all the participants went through a familiarization process. The familiarization included 2 sessions, where the participants performed all 3 exercises with 2kg, 10kg and 18k for ten to fifteen repetitions with each weight.

**Standardization of the full body rotational test**

Standardization for the test retest reliability of the full body rotational test included a consistent standing width. Participants were asked to stand in a stable and comfortable width in which they would perform a golf swing, then the individual stance widths were recorded and used throughout the test-retest sessions.

Each participant was asked to stand 1 meter from the pulley of the 1080 Quantum machine with the 1080 Quantum on their right or left side, dependent on which was their dominant arm. Right handed golfers stood with their right shoulder facing the machine. Feet, knees, hips and shoulders were positioned on a horizontal line following the angle of the lever. The height of the cable coming from 1080 Quantum was adjusted to the highest setting. For imitating a golf swing, participants were asked to grab the cable handle as they would grab a golf club, extend their arms in front of their body, slightly bend their knees and slightly lean forward their hips. The golfers were then instructed to perform a golf like back swing. The motion was started with a rotation in the hips and trunk towards the pulley and an elevation in the arms. From this position participants were rotated their trunk and hips away from the pulley and moved their hands downward (Figure 1). 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 pointing forwards. A repetition was considered valid if the handle rotated past the knee which was positioned farther away from the 1080 Quantum.
Standardization for the pelvis rotational test

The standing width and the position of the golfers relative to the 1080 Quantum was the same as in the full body rotational test. A belt was placed on participant’s pelvis. The cable height was adjusted to pelvis height and attached to the belt at the participant’s back, approximately at the top of their sacrum. To prevent the involvement of the thorax to the movement, participant’s arms were crossed across their chest, with left hand on right upper arm and right hand on left upper arm. Their hands rested on their front of their upper arm. Then they rotated their pelvis to the right or left depending on their stance and performed a dynamic rotational movement (Figure 2).

Figure 1. Set up, top and finishing position for the full body rotational test (FBRT).

Figure 2. Golfer performing the pelvis rotational test (PRT). Starting, mid and finishing position.
Standardization for the thorax rotational test

The standing width and the position of the golfers relative to the 1080 Quantum was the same as in the full body rotational test.

The cable was attached to a vest, which was worn by the participants. The cable was attached to the vest at the participants back, approximately between their scapula. The cable height was adjusted to mid sternum height. To avoid interrupting the path of the cable, and to keep balance during the exercise, participants held their arms in front of them with their elbow bent in approximately 90 degrees. Then they rotated their thorax to the right or left depending on their stance, performing a dynamic rotational movement (Figure 3).

Figure 3. Golfer performing the thorax rotational test (TRT). Starting, mid and finishing position.

Construct validity assessment of the reliable tests

Since no gold standard exists á priori hypothesis was needed to be set, and the validation of the reliable rotational tests was assessed by investigating a correlation between their results and previously recorded club head speed data.

To assess construct validity one session was performed to record normal-swing driver club head speed (CHSnormal) and maximum-swing driver club head speed (CHSmax) by using TrackMan radar 3e (TrackMan A/S, Vedbaek, Denmark).
The TrackMan radar 3e was positioned three meters behind a cleared space on a golf course before each swing. The same club (drive) and ball was used during the tests, all the subjects used their own driver and new Titleist pro v1x golf balls (Acushnet Sverige AB, Malmo, Sweden) during testing. Subjects were blinded about their swing speed to ensure they were not changing their swing technique. Each subject performed the tests in their aiming side.

The testing session started with a standardized warm up and with some light practice swings. Participants were instructed to stand in their normal stance width in the artificial tee and perform the golf swing as fast as they can, during each test swing. The first swing which was a practice swing, was not recorded. To record, normal-swing driver clubhead speed (CHSnormal), participants were instructed to hit “three normal drives as they would down an average distance par four hole”, then maximum-swing driver clubhead speed (CHSmax) was recorded where the goal for every subject was to hit the golf ball with their maximal speed and force. The best of the three trials for CHSnormal, CHSmax (presented in m/s) was used for further analysis (Gordon et al., 2009).

The results of the reliable rotational tests and CHS were correlated with each other and studied in relation to the prior stated hypothesizes.

**Force-velocity profile**

In the second part of the study, the force-velocity profile was of interest, coefficient of variation (CV) was used to determine whether test 1 or test 2 would be used from the reliable rotational tests, to investigate individual force-velocity-power capabilities. To investigate force-velocity profiling, the following mechanical parameters were recorded by 1080 Quantum: peak force (PF), peak velocity (PV), peak power (PP).

To determine individual force- velocity relationships, each subject was asked to perform with maximal effort in the reliable rotational tests against five loads (2 kg, 6 kg, 10 kg, 14 kg, 18 kg). For each trial, subjects were asked to perform the rotational movement as powerful as possible. Peak force and peak velocity were chosen from each loading condition in every participant case.

The least squares linear regressions and the best PF and PV of each loading condition were used to determine each golfer’s individual force-velocity profile ($S_{Fv}$). To obtain theoretical maximal force at zero velocity ($F_0$) and theoretical maximal velocity at zero force ($V_0$), force- velocity
curves were extrapolated, which respectively correspond to the intercepts of the force-velocity curve and the force, velocity axis.

Then the force-velocity linear relationship which was the force-velocity profile was calculated using the following equation which is from Samozino et al., (2012):

\[ S_{Fv} = -\frac{\bar{F}_0}{\bar{v}_0} \]  

The mean of the 12 force-velocity profiles was calculated as reference point (\(S_{Fv, opt}\)). Then the F-v imbalance (\(F_{vimb}, \text{in } \%\)) which is the difference between the average slope and the individual slope was calculated as suggested previously (Samozino et al., 2013).

A value of 0% of force-velocity imbalance means that the force-velocity profile is equal to 100% of the mean profile, and a force-velocity profile value higher or lower than the mean indicates a profile oriented toward the force or velocity end of the spectrum. Force-velocity profiles were studied using the following equation which is from Samozino et al., (2013):

\[ F_{vimb} = 100. |1 - \frac{S_{Fv}}{S_{Fv, opt}}| \]  

**Ethical and social considerations**

Subjects partaking in the study gave an informed consent after being briefed verbally, and on paper, about the study. Privacy and confidentiality were maintained throughout the study and subjects were notified that participation can be terminated, without an explanation, at any time. Subjects were also informed that no additional health risks were associated with participation on top of their regular training routines. Identifiable information pertaining to the individuals, collected during testing was undisclosed, unless given permission to do so otherwise. Data collected could only be presented on a group level and does not apply to individual subjects.
Physical activity has several health benefits. Physical inactivity is a modifiable risk factor for more than 25 chronic medical conditions, including premature mortality, diabetes and cardiovascular disease (Warburton, 2006; Pedersen & Saltin, 2015). According to the World Health organization, physical inactivity accounts for more than 3.2 million deaths annually and is the fourth major risk factor of global mortality (World Health Organization, 2010). A recent review on the relationship between golf and health concluded that practitioners should be encouraged to support more people to play golf, since playing golf is associated with improved mental well-being and physical state, while potentially increasing life expectancy (Murray et al., 2016).

Individualized training by assessing golfer’s force-velocity profile by a golf specific exercise has to the author’s knowledge not been investigated. By implementing a force-velocity profile assessed by valid and reliable performance tests, athletes can directly evaluate their training effectiveness and performance. The study findings have the possibility to present guidelines for further research on improving training performance in many other sports as well, which involve rotational movement. Since not only professional players practice the sport golf, this knowledge will possibly increase the health and training effectiveness of recreational players as well.

**Statistical analyses**

Data from the tests were analyzed with SPSS version 24.0. (IBM Corp., Armonk, NY).

In the reliability assessment, the consistency throughout three trials on five different loads, during both testing occasions was analyzed with the coefficient of variation (CV). Test-retest reliability of FBRT, TRT and PRT along with the assessment of the consistency of the occurrence of highest PP throughout test 1 and test 2 in the reliable test(s), was analyzed by using intraclass correlation coefficient (ICC). The tests were considered reliable if the ICC >0.7 (Lubans, Smith, Harries, Barnett & Faigenbaum, 2014).

To assess construct validity, from each load, the highest PP, PV, and PF independently from each other were chosen from the 3 rotational tests and correlated with the recorded CHS measurements (CHSnormal and CHSmax). To assess construct validity, hypotheses were proposed prior to the testing and 75% of the hypotheses should be fulfilled according to the COSMIN recommendations (Mokkink et al., 2010; Terwee, Mokkink, Steultjens & Dekker, 2006). Spearman’s correlation coefficient ($r_s$) was used to calculate the correlations between the rotational test output variables and the CHS. A correlation was considered excellent ($r_s$,
≥0.90), good (rs 0.75–0.89), moderate (rs 0.50–0.74) or poor (rs < 0.50) (Mentiplay, Perraton, Bower, Adair, Pua, Williams, McGaw & Clark, 2015).

**Hypotheses**

To investigate construct validity the following hypothesis were set previously:

1. A good to excellent correlation (rs ≥ 0.75) would be found between peak power (PP), peak velocity (PV) and peak force (PF) recorded in the reliable rotational test(s) and maximum-swing driver clubhead speed (CHSmax) at all resistances.
2. A good to excellent correlation (rs ≥ 0.75) would be found between PP, PV and PF recorded in the reliable rotational test(s) and normal-swing driver clubhead speed (CHSnormal) at all resistances.
3. PV recorded in the reliable rotational test(s) will have a higher correlation to CHSnormal and to CHSmax at 2 kg resistance than PF.
4. PF recorded in the reliable rotational test(s) will have a higher correlation to CHSnormal and to CHSmax than PV at 18 kg resistance.

The first two hypotheses were set because all the rotational tests and the golf swing have similar coordination patterns, range of motion, direction of power application and they are performed in a similar posture (Chek, 2001).

Hypothesis number 3, 4 were set because maximal power output has an important role in rotational movements and in ballistic performance. Maximal power output may be reached by either generating high levels of force at low levels of velocity or by maximizing velocity production at low levels of force or by keeping both capacities in a close to equal ratio (Morin & Samozino, 2016), furthermore force and velocity contributions to power output depends on the load involved (Cormie et al., 2007; Frost Cronin & Newton 2010).

Therefore, it was hypothesized that power output at low resistance would be dominated by velocity and at high resistances it would be dominated by force and at mid resistance the ratio between force and velocity would be the closest to equal. Thus, at each resistance the dominant physical outputs will show the higher correlations with CHSmax and with CHSnormal.
Results

Since FBRT’s test-retest reliability was the first analysis in FBRT’s evaluation, all of the initial components of the 12 subject’s data was used for the reliability analysis (PP and its corresponding PF and PV). After the reliability analysis, due to technical error during evaluation, one of the subject’s data (his PP measurements and the results of his three maximal trials from test 2), pertaining to FBRT was lost. As the above-mentioned subject’s missing data would have been necessary to include him in the analysis of FBRT’s CV and construct validity, only 11 out of the 12 subject’s data were used.

To study the subjects force-velocity profile and for the reliability analysis, all 12 participants data were used. During the TRT, a woman was unable to perform the test with 18 kg on the first occasion and another woman was excluded from TRT due to missing data. Furthermore, four women were omitted from the reliability analysis of PRT because of an incomplete testing session, caused by illness and injury. On behalf of unreliable data, the results recorded from 2 kg were exempted from the assessment of the force-velocity profile.

Coefficient of variation (CV)

The CV of PP ranged from 1 to 22% in FBRT 1 and from 1 to 13% in FBRT 2 (table 1). The best consistency (the lowest CV range) was found in the FBRT 2, where CV was more stable between the five different loads (table 1).
Table 1. Range of coefficient of variation (CV) for test 1 and test 2 of full body rotational test (FBRT), thorax rotational test (TRT) and pelvis rotational test (PRT) in 5 resistances.

<table>
<thead>
<tr>
<th></th>
<th>2 kg</th>
<th>6 kg</th>
<th>10 kg</th>
<th>14 kg</th>
<th>18 kg</th>
<th>CV range</th>
</tr>
</thead>
<tbody>
<tr>
<td>FBRT- test 1</td>
<td>1-11%</td>
<td>0-9%</td>
<td>1-12%</td>
<td>2-10%</td>
<td>1-22%</td>
<td>1-22%</td>
</tr>
<tr>
<td>(n=11)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>FBRT- test 2</td>
<td>1-7%</td>
<td>1-11%</td>
<td>1-10%</td>
<td>2-13%</td>
<td>2-12%</td>
<td>1-13%</td>
</tr>
<tr>
<td>(n=11)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRT- test 1</td>
<td>3-20%</td>
<td>0-20%</td>
<td>3-34%</td>
<td>4-15%</td>
<td>4-19%</td>
<td>0-20%</td>
</tr>
<tr>
<td>(n=11)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>TRT- test 2</td>
<td>4-32%</td>
<td>3-32%</td>
<td>1-24%</td>
<td>1-17%</td>
<td>1-18%</td>
<td>1-32%</td>
</tr>
<tr>
<td>(n=11)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRT- test 1</td>
<td>4-17%</td>
<td>2-24%</td>
<td>7-18%</td>
<td>2-27%</td>
<td>5-14%</td>
<td>2-27%</td>
</tr>
<tr>
<td>(n=8)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PRT- test 2</td>
<td>3-24%</td>
<td>5-30%</td>
<td>0-14%</td>
<td>4-25%</td>
<td>4-16%</td>
<td>0-30%</td>
</tr>
<tr>
<td>(n=8)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Test-retest reliability

Thorax rotational test and pelvis rotational test

When assessing reliability, the results were inconsistent for the highest PP, and for the corresponding PV in PRT and in TRT. The two tests were not found to assess test-retest reliability (table 2).

In the TRT only PF showed acceptable test-retest reliability, ICC= 0.864 (95% CI 0.552- 0.960) (table 2).

In PRT highest peak power measurements were collected from different resistances in two subjects case (test 1: 18 kg, test 2: 14kg and test 1: 14 kg and test 2: 6 kg) and only PF showed acceptable test-retest reliability, ICC= 0.761, (95% CI -0.029- 0.951) (table 2).

Full body rotational test

In FBRT, an additional ICC analysis was conducted to assess the consistency of the occurrence of highest PP throughout test 1 and test 2. The results of the ICC (0.939, 95% CI 0.790- 0.982) analysis exceeded the preset threshold level (an ICC of >0.70 was considered acceptable) which indicated that, the above-mentioned phenomenon would not influence the reliability of FBRT.
Test-retest reliability of the FBRT for highest PP had an ICC of 0.97 (95% CI 0.88-0.99), corresponding PF an ICC of 0.99 (95% CI 0.96-0.99) and the corresponding PV had an ICC of 0.77 (95% CI 0.17-0.94), all results indicating acceptable reliability (table 2).

**Table 2.** Test-retest reliability for full body rotational test (FBRT), thorax rotational test (TRT) and pelvis rotational test (PRT) using Intraclass correlation coefficient (ICC).

<table>
<thead>
<tr>
<th>Rotational test</th>
<th>Test 1 Mean± SD</th>
<th>Test 2 Mean± SD</th>
<th>ICC 95% CI</th>
<th>p value</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>FBRT (n=11)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power (W)</td>
<td>1254.42±404.49</td>
<td>1250.67±463.26</td>
<td>0.97(0.88-0.99)</td>
<td>p&lt;.001</td>
</tr>
<tr>
<td>Force (N)</td>
<td>294.50±97.36</td>
<td>285.25±94.55</td>
<td>0.99(0.96-0.99)</td>
<td>p&lt;001</td>
</tr>
<tr>
<td>Velocity (m/s)</td>
<td>4.88±.53</td>
<td>4.89±.44</td>
<td>0.77(0.17-0.94)</td>
<td>0.013</td>
</tr>
<tr>
<td><strong>TRT (n=10)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power (W)</td>
<td>500.25±172.13</td>
<td>547.33±136.15</td>
<td>0.64(-0.15-0.89)</td>
<td>0.048</td>
</tr>
<tr>
<td>Force (N)</td>
<td>281±53.32</td>
<td>292.75±49.55</td>
<td>0.86(0.55-0.96)</td>
<td>0.001</td>
</tr>
<tr>
<td>Velocity (m/s)</td>
<td>1.83±.33</td>
<td>1.92±.26</td>
<td>0.58(-0.37-0.88)</td>
<td>0.079</td>
</tr>
<tr>
<td><strong>PRT (n=8)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power (W)</td>
<td>467.37±88.97</td>
<td>515.12±67.80</td>
<td>0.52(-0.74-0.89)</td>
<td>0.150</td>
</tr>
<tr>
<td>Force (N)</td>
<td>308.12±29.18</td>
<td>317.87±22.41</td>
<td>0.76(-0.03-0.95)</td>
<td>0.035</td>
</tr>
<tr>
<td>Velocity (m/s)</td>
<td>1.58±.20</td>
<td>1.66±.20</td>
<td>0.67(-0.40 -0.93)</td>
<td>0.076</td>
</tr>
</tbody>
</table>

Watt=W, Newton=N, meter/second=m/s, Standard deviation=SD, Confidence interval=CI.
Construct validity

Data from 11 subjects rotational power outputs (PP, PF and PV) and CHS measurements (CHSnormal and CHSmax) were included in the test of construct validity. The results of the correlational analysis between CHS measurements and FBRT’s power outputs can be seen in table 3 and in table 4. The average CHSmax for the 11 subjects, included in the analysis, was 48.8 ± SD 5.5 m/s, 52 ± SD 2.6 m/s for men and 41.8 ± SD 2.6 m/s for women.

PF ($r_s = 0.74$- 0.8 and 0.63- 0.73), PV ($r_s = 0.83$- 0.88 and 0.75- 0.79) and PP ($r_s = 0.779$- 0.89 and 0.73- 0.82) for all loads had statistically significant moderate to good correlation with both CHSnormal and CHSmax respectively, apart from 2 kg (table 3). At 2 kg PF had a poor to moderate correlation with both CHSnormal and CHSmax (CHSnormal $r_s = 0.39$ & CHSmax $r_s = 0.430$), PV ($r_s = 0.63$ & 0.6) and PP ($r_s = 0.61$ & 0.58) (table 4).

Hypothesis analysis

Hypothesis 1
The first hypothesis for the FBRT stating that a good to excellent correlation was to be found between PP, PV, PF and CHSmax at all resistances, was not confirmed. Hypothesis number one was not confirmed at 2 kg resistance in either 3 mechanical outputs. PF at all resistances was unverified and neither was PP at 14 kg. It was fulfilled however for PV at 6 kg, 10 kg, 14 kg, 18 kg and in PP at 6 kg, 10 kg, 18 kg (table 4).

Hypothesis 2
The second hypothesis was that a good to excellent correlation would be found between PP, PV, PF and CHSnormal at all resistances, was not confirmed. Hypothesis number two was not fulfilled at 2 kg resistance in either of the 3 mechanical outputs and at 14 kg in PF. On the other hand, the second hypothesis was confirmed in PV, PP at 6 kg, 10 kg, 14 kg, 18 kg and in PF at 6 kg, 10 kg, 18 kg.

Hypothesis 3
The third hypotheses, stating that PV ($r_s = 0.629$ & $r_s = 0.6$) will have a higher correlation to CHSnormal and to CHSmax than PF ($r_s = 0.39$ & $r_s = 0.430$) at 2 kg resistance was accepted.

Hypothesis 4
The fourth hypothesis stating that PF ($r_s = 0.779$ & $r_s = 0.727$) will have a higher correlation to CHSnormal and to CHSmax than PV ($r_s = 0.834$ & $r_s = 0.745$) at 18 kg resistance, was rejected.
Construct validity assessment of FBRT was not found acceptable in either of the resistances. At 2 kg and at 18 kg resistance one out of the four (25%) hypothesis was confirmed. At 6 and at 10 kg, one out of the two (50%) and at 14 kg resistance neither of the hypotheses were fulfilled.

Table 3. Spearman’s rank correlation coefficient for peak power (PP), peak force (PF), peak velocity (PV) in resistances apart from PF (0.39, 0.430), PV (0.63, 0.6) and PP (0.61, 0.58) at 2 kg, measured in full body rotational test (FBRT) against normal swing-driver club head speed (CHSnormal) and maximal swing-driver club head speed (CHSmax) (n=11).

<table>
<thead>
<tr>
<th>Resistance</th>
<th>CHSnormal</th>
<th>CHSmax</th>
</tr>
</thead>
<tbody>
<tr>
<td>PP</td>
<td>0.78- 0.89</td>
<td>0.73- 0.82</td>
</tr>
<tr>
<td>PF</td>
<td>0.74- 0.80</td>
<td>0.63- 0.73</td>
</tr>
<tr>
<td>PV</td>
<td>0.83- 0.88</td>
<td>0.75- 0.79</td>
</tr>
</tbody>
</table>

Table 4. Spearman’s rank correlation coefficient for peak power (PP), peak force (PF), peak velocity (PV) according to each resistance, measured in full body rotational test (FBRT) against normal swing-driver club head speed (CHSnormal) and maximal swing-driver club head speed (CHSmax), (n=11).

<table>
<thead>
<tr>
<th>Resistance</th>
<th>CHSnormal</th>
<th>CHSmax</th>
</tr>
</thead>
<tbody>
<tr>
<td>2 kg</td>
<td>0.40- 0.63</td>
<td>0.43- 0.60</td>
</tr>
<tr>
<td>6 kg</td>
<td>0.80- 0.88</td>
<td>0.70- 0.82</td>
</tr>
<tr>
<td>10 kg</td>
<td>0.77- 0.86</td>
<td>0.67- 0.76</td>
</tr>
<tr>
<td>14 kg</td>
<td>0.74- 0.86</td>
<td>0.63- 0.78</td>
</tr>
<tr>
<td>18 kg</td>
<td>0.78- 0.83</td>
<td>0.73- 0.75</td>
</tr>
</tbody>
</table>
Force- velocity profile

The second test (CV, 1-13%) from FBRT had a lower coefficient of variation than the first (CV, 1-22%) test, therefore it was used to study individual force-velocity-power capabilities. According to the present study’s aim, FBRT did not fully meet with the previously set criteria for describing isoinertial force-velocity and power relationships. For this reason, 2 kg was removed from the description.

The calculated average slope was 63.86 and the calculated average difference for the whole sample from the mean slope, (F-v imbalance) was 30.8%. When the data was analyzed separately by gender the average slope was 40.28 for women, 75.65 for men (figure 4) and the average difference from the mean slope (F-v imbalance) was 23.2% for women (figure 5) and 24.43% for men (figure 6).

Figure 4: Mean force-velocity profiles for women (n=4), men (n=8) and for the whole group (n=12).
Figure 5: Mean force-velocity profile for women, and individual force-velocity profiles ($S_{Fv}$) of each woman (n=4).

Figure 6: Mean force-velocity profile for men, and individual force-velocity profiles ($S_{Fv}$) of each man (n=8).

Figure 7 illustrates the average profile/slope (75.65) of men golfers and the profile of 2 men with similar CHSmax (Boy 3, f-v profile: 63.06, CHSmax: 49.17 m/s; Boy 8, f-v profile: 96.52, CHSmax: 49.4 m/s).

The two subjects generated very similar CHSmax measurements during the testing session, even though Boy 8’s force-velocity profile differed to a higher degree (27.58 %) from the
average force-velocity profile ($F_{\text{vimb}}$) than Boy 3 (16.64 %). The previously proposed method (Jiménez-Reyes et al., 2017) suggests that Boy 8 is force dominant and his training should be prioritized to develop his ability to generate velocity. On the contrary, boy 3 is velocity dominant, therefore his training should focus on developing his force generating capabilities. Theoretically if these methods were utilized, it would be possible to decrease their force-velocity imbalances and potentially improve their CHS. To further improve their golf performance the next step for athletes would be to maintain their corrected force-velocity profile and develop their ability to generate force and velocity proportionally to each other.

**Figure 7:** force–velocity profiles ($S_{Fv}$) of 2 men golfers (handicap 5.0 or better) (CHSmax for boy 3: 49.17 m/s, and 49.4 m/s for Boy 8) obtained from the full body rotational test (FBRT) against additional loads of, 6, 10, 14, and 18 kg. Boy 3 has a force deficit (magnitude of the relative difference between the slope of the individual force–velocity profile and the mean of the men’s force- velocity profile) of 16.64 %, while the other golfer has a velocity deficit of 27.58 %.
Discussion

Three new standing rotational tests that were developed to measure force, velocity and power in rotational movements were tested for test-retest reliability and only one of the three tests assessed acceptable test-retest reliability, the full body rotational test (FBRT). This test was further tested for construct validity through correlational analysis with club head speed (CHS) where á priori hypotheses were not fully confirmed and the FBRT did not assess acceptable construct validity. These findings will affect the understanding and interpretation of the force-velocity profile derived from the FBRT.

Test-retest reliability

Only one of the three rotational tests were found to assess acceptable test-retest reliability, the FBRT.

One factor which may contribute to corresponding peak velocity’s (PV) and peak power’s (PP) unreliable outcome in thorax rotational test (TRT) and pelvis rotational test (PRT) is that participants who were high level golfers were less familiar with the kinetics involved in TRT and PRT than in the FBRT, which is the most similar to a golf swing out of the three tests. Previous research demonstrated that, the shoulder, elbow and wrist joints contribute with a higher degree to the applied segmental forces and to CHS during a golf swing than the musculature of the hip and spine. (M Burden, Grimshaw & Wallace, 1998; Milburn, 1982). Neither shoulder, elbow or wrist joints were actively involved in both PRT and TRT. Further research is necessary to investigate if the TRT’s and PRT’s reliability would increase if the golfers were to strengthen the involved muscles and familiarize themselves with the motion, since previous research found that isolated core training programs increase CHS (Weston et al., 2013). It can be concluded that TRT and PRT are not reliable, thus they could be used only as exercises but not as tests.

It was brought to our attention even before analyzing the ICC results, that FBRT might be unreliable because PP occurred at different resistances in three out of the 12 subjects case. For this reason, an additional ICC analysis was conducted to assess the consistency of the occurrence of highest PP throughout test 1 and test 2. The results of the ICC analysis exceeded...
the preset threshold level which demonstrates that, the above-mentioned phenomenon would not restrain FBRT from assessing acceptable reliability.

For this reason, the results recorded at the affected subjects were not excluded from the test-retest reliability analysis. This indicates a reliability problem of the FBRT, which may have occurred since force and velocity contributions to power output are dependent on the load involved. It could be hypothesized that the underlying physical characteristics of power, when performing the FBRT at 2 kg and at 6 kg, are very similar (Cormie et al., 2007; 2011; Frost et al., 2010). This may have resulted in the alternating occurrence of the highest PP between these two resistances in test 1 and in test 2, which indicates why it may be reasonable to exclude 2 kg or 6 kg from the FBRT.

Consistent with previous studies (Algotsson M., 2016; Andre et al. 2012; Ikeda, Kijima, Kawabata, Fuchimoto & Ito, 2006; Read et al., 2013), FBRT typically exhibited high levels of reliability across all assessed mechanical outputs. Andre et al., (2012) reported an ICC of 0.97, 0.94 and 0.95 for loads corresponding to 9, 12 and 15% of bodyweight in a seated power rotational test. Read et al. (2013) reported an ICC of 0.89 and 0.90 in a standing medicine ball throw test. Ikeda et al. (2006) reported ICC ranging from 0.87 to 0.97 in a side standing rotational medicine ball throw test. Furthermore, Algotsson M. (2016) found an ICC of 0.94 for a power rotational test and 0.98 in a 1RM rotational test, the two tests were performed on 1080 Quantum just as the 3 rotational tests were in the present study. However, it was somewhat surprising that only paired force was reliable in both PRT and TRT. Research suggests that the thorax and pelvis are important determinants of golf performance (Weston, Coleman & Spears, 2013).

**Construct validity**

To assess construct validity 75% of our prior set hypothesizes should be fulfilled. There were four hypothesizes to validate FBRT, the first two hypothesizes were examined according to each resistance individually, however the third hypothesis applied only to 2 kg and the fourth to 18 kg resistance, which also aimed to determine the overall validity of the test. For this reason, it is difficult to evaluate FBRT’s construct validity at each resistance separately.

Overall if we evaluate FBRT’s construct validity as a test, including all 5 resistances then the only hypothesis accepted, which was based on the observation that force and velocity contributions to power output depends on the load involved (Cormie et al., 2007; Frost Cronin
& Newton 2010), was the third one. Therefore 1 out of the 4 hypotheses was confirmed (25%). It should be noted that, each of the first two hypotheses were formulated with expectations to fulfill 15 correlations, of which, if one correlation was not met then the hypothesis was rejected.

When FBRT’s validity was analyzed according to each resistance, the test still proved to be invalid. At 2 kg and at 18 kg resistance one out of the four (25 %) hypothesis was confirmed. At 6 and at 10 kg, one out of the two (50 %) and at 14 kg resistance neither of the hypotheses were fulfilled.

Thus, based on our hypothesizes it can be stated that the test is not valid, with either resistance.

In comparison with previous studies, generally higher correlations were found between PP, PV and PF measured in FBRT and CHS than between general athletic field based measurements, medicine ball rotational throws and CHS (Read et al., 2013) in male golfers with a handicap of 5.8 ± 2. Interestingly, in PGA professional golfers (Lewis et al., 2016) similar correlations were reported between squat jump height and CHS (r = 0.817) in comparison to the present study, however generally weaker correlations were reported between rotational medicine ball throw test and CHS (r = 0.572). They concluded that younger golfers utilize more leg strength while older golfers (>30 years) utilize more upper body strength. In addition, they also concluded that correlation size may vary due to the skill level of the golfers. Furthermore, most of the correlations between FBRT measurements in all loads and CHS were higher than in a similarly preformed golf specific cable wood chop test and CHS (Keogh et al., 2009). These findings strengthen conclusions drawn from previous studies, which suggest that implementing golf specific exercises are critical to increase CHS (Doan et al., 2006, Fletcher & Hartwell, 2004; Lephart et al., 2007), since FBRT is very similar to a golf swing in terms of range of motion, velocity, direction of force application and coordination characteristics (Chek, 2001).

In the present study FBRT did have an acceptable test-retest reliability with consistent results over time but FBRT did not assess construct validity with CHS, thus it cannot be used to evaluate golf performance, and can only be used for exercise and needs further development to improve its validity.
**Force-velocity profile**

A secondary aim was to study the isoinertial force-velocity and power relationship in tests that assessed acceptable test-retest reliability and acceptable construct validity. In FBRT, findings of the present study suggest that, the force-velocity profile should be interpreted with care; even though the 2 kg resistance was removed from the analysis to better the results.

The equation used in previous studies to calculate individual optimal force-velocity profile ($S_{Fv_{opt}}$) was inapplicable since it was designed to calculate the optimal profile in squat jump exercise (Samozino, Morin, Hintzy & Belli, 2008; Jiménez-Reyes et al., 2017). Thus, since there was no method to describe the optimal individual slope in golf while the present study was being conducted, the average slopes were calculated as reference points. It should be noted, that since there was no method available to describe the optimal individual slope in golf while the present study was being conducted the average slope of our participants could not be considered as the optimal force-velocity slope.

Thus, since there was no method to describe the optimal individual slope in golf while the present study was being conducted, the average slopes were calculated as reference points.

The analysis of subject’s force-velocity profile revealed possible differences between gender. Although research suggests there are sport specific differences between sex (Laffaye, Wagner & Tombreleson, 2014; Horan et al., 2010), there is lack of research suggesting that force-velocity profile should be different in between men and women. It is however apparent (figure 4) that there are visible differences in the slopes between gender. Women tended to be more velocity dominant than men, and had lower force and power measurements, but they generated similar velocity outputs as men. It is not clear whether a more velocity dominant profile or a more force dominant profile is optimal for golf. Despite the fact, that males generated higher power and CHS with a more force dominant profile, it does not mean necessarily that the more optimal profile is a more force oriented profile for golf. One explanation might be that, the upper limit of an athlete’s potential to generate maximal power will always be set by their current strength level since their ability to generate force rapidly is of little advantage if maximal force is low (Newton, Kraemer, 1994). In general, there is little research where gender was indicated (Horan, Evans, Morris & Kavanagh, 2010) or where men and women were mixed (Wells, Elmi & Thomas, 2009). It has been suggested (Doan et al., 2006) that men and women golfers have
different responses to training, they reported a greater trend toward increase in CHS in women (3.36 %) than in men (0.61%) from pre- to post training. Wells et al., (2009) based on their observations on how physical test results correlates with golf related measures suggested that, very different recruitment patterns may present for different gender during different aspects of golf. Another study which observed thorax and pelvis kinematics during the downswing of men and women golfers (Horan et al., 2010), suggested that skilled men and women golfers have different kinematics for thorax and pelvis motion during the golf swing, thus optimal swing characteristics for women golfers should not be generalized to men golfers and vice versa. Similarly, to the present study sample sizes were too small to generalize the observed correlations to the target population (Hopkins, 2006).

The average CHSmax in the present study for the whole sample was 48.8 ± 5.5 m/s and men (52 ± 2.6 m/s) achieved higher results than women (41.8 ± SD 2.6 m/s). In comparison, another study (Doan et al., 2006) found comparable results (CHS: 47.27 ± 3.77 m/s) in a sample with similar characteristics (n=16, 10 men, 6 women, National Collegiate Athletic Association Division I golfers) to the present study, they also recorded higher CHS measurements from men. Another study with a larger sample observed 48 men subjects (handicap: 5.8 ± 2.2) and reported an average CHSmax of 53.7 ± 3 m/s. These results are in accordance with our CHSmax measurements for men with a 52 ± 2.6 m/s.

In conclusion, as FBRT did not assess acceptable validity in either of the resistances, the force-velocity profile should be interpreted with care. Sample size was too small to draw sound conclusions about the impact of gender on force- velocity profiling in golf, thus it is not clear if a real sex difference is present in the calculated force- velocity profiles, however a possible trend is clearly observed and warrants further investigation.

**Future research**

Further investigations are crucial, to develop valid and reliable tests to accurately define both individualized optimal force-velocity profile and force-velocity imbalance in a golf specific rotational test. More research must also be conducted to precisely describe the possible gender differences in force velocity profiling in rotational tests.
Limitations

As some participants reported discomfort and/or pain during PRT and TRT the results may have been compromised which may have affected the reliability of these two tests, both in the first and second testing session. The cause of the pain in PRT might have been due to the belt, which connected the cable to subject’s hip or the chosen cable drain. Testing sessions were also very demanding and time consuming. On each testing session, a total of 45 maximal trials were performed by each participant. PRT, TRT and FBRT were carried out on the same occasions, consequently performance may have been influenced either by demotivation, or by fatigue.

In comparison, previous studies which tested rotational power applied less maximal trials on one occasion. They conducted three tests with three attempts which resulted in a total of nine maximal trials per occasion (Andre et al., 2012, Nikolenko et al., 2011, Read et al., 2013). Another study which tested total body rotational power, applied 5 maximal attempts throughout one test (Gordon et al., 2001).

By reducing the number of the resistances utilized during the tests and implementing FBRT, PRT and TRT on separate occasions, may eliminate these possible negative, intervening factors. Further research is necessary however to determine which weights should be selected to use for the three tests. This may further improve the tests reliability and validity, since it would decrease the duration and trial number of the test. This, would make it easier for the athletes to perform, thus decreasing lack of motivation and exhaustion of athlete’s which influences the outcome of the test. In addition, it may also be beneficial to define the resistances used in the test based on the individual’s body weight, tailoring the resistance according to each individual.

Conclusion

The study demonstrated that only the full body rotational test (FBRT) assessed acceptable test-retest reliability for measuring force, velocity and power. Based on our hypotheses FBRT is not a valid indicator of golf performance on either resistance, however it had a significant moderate to good correlation with normal swing-driver club head speed (CHSnormal) and maximal swing-driver club head speed (CHSmax) at all resistances apart from 2 kg. FBRT should not be applied as a test since it is not valid, even though it is reliable. As a result, FBRT could only be used for exercise and needs further development to improve its validity.
References


33


Appendix 1

Förfrågan om medverkan i studien:

"XX titel på studien"

Studiens syfte är att ser om fysiskt träning med en unik träningsmaskin kan förbättra ”drive” prestation hos elit golfspelare.

Du har blivit förfrågat att delta i studien eftersom du tävla i junior eller senior golf på nationell eller landslag nivå.

Studien innefattar två delar


Genom att delta kommer du efter studiens slut få tillgång till dina egna individuella resultat. Testerna kommer vara under kontrollerade förhållanden vilket gör att det inte är större risk än vid vanliga tränings- och tävlingsförhållanden inom golf.


Självklart får du tillgång till studiens färdiga resultat som kan gynna din egen och andras framtida träning och utveckling. Dessutom kommer resultatet att publiceras som artikel i en internationell tidskrift och dessutom ligga till grund för ytterligare studier som ska utveckla och undersöka förbättrade träningsmetoder inom golf

Ditt deltagande är givetvis helt frivilligt och du kan avstå från att delta, eller avbryta under studiens gång, utan att behöva lämna någon förklaring. Om du avböjer medverkan kommer detta inte på
något sätt att påverka framtida kontakter med några av de involverade forskningsledarna. Väljer du att delta så ber vi dig att fylla i samtyckesblanketten.

Har du några frågor så kontakta oss gärna!

Högskolan i Halmstad  den XX månad 2015

Charlotte Olsson
Forskningsledare
Docent i Idrottsfysiologi
Högskolan i Halmstad
charlotte.olsson@hh.se

James Parker
Testledare
Doktorand i Hälsa och Livsstil
Högskolan i Halmstad
james.parker@hh.se
Bálint completed his Master's degree in Sports and Exercise Science - Human Performance at the University of Halmstad. He has a keen interest in the limitations and the potentials of human exercise performance and in the fundamental role of physical activity and training.