The Effects of Power Type Resistance Training on Golf Driver Club Head Speed

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Attestation of authorship

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning.

Signature:

Date: 18 / 8 / 2015

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All experimental studies within this thesis received ethics approval from AUTEC (approval number 14/191)

Co-authored works

The following four manuscripts are in preparation for submission for peer reviewed journal publication as a result of the work presented in this thesis;

- Schofield, M., Storey, A., Cronin, J. (2015). Resistance training for increased golf club head speed: a review of the literature. Sports Medicine. (Targeted publication)

- Schofield, M., Storey, A., Cronin, J. (2015). The reliability of isometric mid-thigh pull peak force and early impulse utilising chain bar fixation. Measurement in Physical Education and Exercise Science (Targeted publication)

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Author Contributions

The Master's candidate Michael Schofield was the primary contributor (90%) to the research within this thesis and any analysis and interpretation from the associated results. All co-authors have approved the inclusion of the joint work in this thesis.

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List of Abbreviations

CHS	Club head speed
DD	Driving distance
GIR	Greens in regulation
LHG	Low handicap group
MHG	Moderate handicap group
HHG	High handicap group
HCP	Handicap
N	Newton
N·s	Newton second
m/s	Meters per second
°/s	Degrees per second
Rad/s	Radian per second
PF	Peak force
RFD	Rate of force development
IMTP	Isometric mid-thigh pull
CDS	Cable down swing
VGRF	Vertical ground reaction force
MVC	Momentary voluntary contraction
CV	Coefficient of variation
CMJ	Countermovement jump
ICC	Intra class correlation coefficient
CV	Coefficient of variation
CM	Change in mean
PGA	Professional golf association

Abstract

Resistance training for golf performance has grown in popularity as golfers are seeking increases in driving distance to combat longer golf courses. Various gym based interventions are employed within golf, with flexibility, rehabilitation, hypertrophic and strength type protocols being integrated by strength and conditioners. Currently, the vast majority of golf specific resistance training programs consist of hypertrophic type training parameters yet the effects of maximal power type training remain unknown. Therefore, the purpose of this thesis was to investigate the question: What are the effects of power type training on the club head speed (CHS) of professional male golfers?

Four separate investigations were undertaken within this thesis. First, a review of the current literature pertaining to resistance training in golf was performed. The literature review identified several key outcomes. Firstly, it was evident that the golf swing is an explosive movement in which maximal velocity is obtained in a relatively short period of time. Secondly, cross sectional data supported the inclusion of power training within golf conditioning as increasing explosive muscular force capabilities likely increases CHS. However, such a methodology had not been previously utilised in a longitudinal research design. Finally, it was apparent that rapid force production and rotational ability should be targeted and thus tracked over a conditioning period. In light of this need, we sought to include two novel methods of assessments; the isometric mid-thigh pull (IMTP) performed with chain fixation and the cable down swing.

Prior to the inclusion of adapted or new testing methods into academic research reliability of the method is warranted. As such, chapter two sought to determine the reliability of isometric mid-thigh pull (IMTP) peak force (PF), and early impulse at predetermined time brackets (0-30, 0-50, 0-100, 0-200) using the new chain fixation method. Ten participants were recruited for the purpose of test-retest reliability and were assessed over three separate occasions (separated by a minimum 3 days, max 7 days). It was concluded that all kinetic variables were reliable when IMTP chain fixation was used (ICC = 0.85 – 0.98, CV = 3.29% – 4.02%, CM = - 6.17 – 3.54%). As such this novel method was included into study four to determine pre to post changes in muscular force expression.

In addition to the IMTP force measures it was concluded that a golf specific rotational assessment was warranted as no such assessment existed in the current literature. Therefore, a cable downswing (CDS) load velocity spectrum was proposed as a novel assessment of golf specific rotational velocity. As such Chapter 4 aimed to quantify the test-retest reliability of the CDS load velocity spectrum. Ten elite golfers were recruited and participated in three separate testing occasions (separated by a minimum of 3 days and a maximum 7 days). Following data analysis velocity at all loads (1.25 – 18.75kg) were observed to be extremely reliable (ICC = 0.70 – 0.97, CV = 1.5% – 6.4%, CM = -5.1% – 2.9%). Thus the CDS load velocity spectrum was included in the thesis as a method of quantifying change in rotational velocity over a longitudinal conditioning period.

During Chapter 5, two high performance professional golfers were recruited to take part in a six week intervention investigating the effects of maximal power resistance type training on golf driver CHS. Due to the intensive tournament and travel schedules of professional golfers, a single subject research design was chosen for this investigation. Three pre intervention baseline measures of neuromuscular performance (IMTP and CDS load – velocity spectrum) and two golf specific baseline measures (CHS and accuracy) were taken over a 10 day period. In addition, the post intervention measures of neuromuscular performance were collected on three occasions across 10 days to establish if real changes occurred over the course of the intervention. Golf CHS was assessed at two pre intervention intervals and two post intervention time points.

Following the six-week training intervention, both participants were observed to have substantially increased CHS (P1 = 3.1%, P2 = 3.9%, > ± 2SD) and had trended towards greater accuracy as depicted by visually interpreted statistics. However, no substantial change in kinetic variables occurred during IMTP testing with the exception of early impulse. Furthermore, CDS velocity increased through all assessed loads (P1 = 5.2 – 20.1%, P2 = 14.0 – 17.6%, > ± 2SD). Thus, the training study provided evidence that maximal power training is an effective means to increase CHS in highly trained and experienced professional golfers. However, in light of the lack of definitive increase in IMTP kinetics it is possible that Olympic movements are possibly too complex to elicit a training effect in such a short intervention.

In conclusion, the current thesis provides evidence that power training within golf is a valid method of increasing CHS. In addition, increasing rotational velocity should be a primary focus within golf specific strength and conditioning. As limited improvements in isometric kinetic outputs were observed, decisive conclusions on the impact the training intervention had on lower (i.e. IMTP) body kinetics cannot be made.

Chapter One: Preface

1.1 Thesis rationale

Golfers of all levels seek to improve their performance by improving any one of the many contributing factors that make up a final golf score. Previously the importance of driving distance in golf was somewhat over looked due to the old stereotype “drive for show, putt for doe”. However, this view has now changed as PGA tour statistics show the top 5 longest drivers have lower scoring averages, closer proximity to the hole, and greater greens in regulation (GIR) percentages than those in the bottom 5 (PGATOUR, 2015). Thus, it is likely longer drives allow shorter distances to the hole which increases the likely hood of a more accurate shot. Therefore, driving the ball further with no decrease in accuracy contributes to better scoring opportunities.

Current avenues to increase driving distance are equipment, technique, or physical performance related. However, as the rules of golf impose design restrictions for golf clubs (R&A, 2011), professional golfers are left with two avenues for increasing driving distance which are technical changes and/or physical improvements. However, once technical mastery is achieved, improving a golfer’s physical characteristics (e.g. muscular force capabilities) should become a priority to help increase driving distance. Increasing club head speed (CHS) has been shown to be strongly related ($r = 0.86$) to driving distance (Fletcher et al., 2004). CHS has been observed to improve following a period of hypertrophic (Fletcher et al., 2004; Lamberth et al., 2013; Lephart et al., 2007), rehabilitation (Chen et al., 2010), strength (Alvarez et al., 2012) and flexibility (Fradkin et al., 2004b) type training, whereas the effects of power type resistance training are unknown. Interestingly cross sectional data advocates the inclusion of power type resistance training as high CHS golfers can be differentiated by the ability to jump higher (Hellstrom, 2008; Read, Lloyd, et al., 2013; Wells et al., 2009), exhibit greater rotational power (Gordon et al., 2009; Read, Lloyd, et al., 2013) and display greater within golf swing torque and power levels (Nesbit et al., 2009; Nesbit et al., 2005). As previously mentioned longitudinal resistance training interventions utilising power training have not previously been investigated despite this form of training being a possible avenue of CHS advancement. Therefore, the rationale behind this thesis was to fill the identified gap in the literature by investigating the overarching question- what are the effects of power type training on the CHS of professional male golfers?

In order to understand the effects changing physical characteristics have on CHS, neuromuscular tracking is needed to quantify the change in muscular ability in conjunction with CHS. It has previously been suggested that high CHS golfers display time specific kinetics (i.e. rate of force development), as assessed via isometric testing (Leary et al., 2012). In addition, training induced increases in muscular kinetics (i.e. peak force) have been attributed to increases in CHS (Fletcher et al., 2004; Lephart et al., 2007; Thompson et al., 2004). As isometric kinetics have been related to dynamic performance (McGuigan et al., 2010; McGuigan et al., 2008), the isometric mid-thigh pull (IMTP) is an ideal method to assess changes in key kinetic variables such as peak force (PF) and impulse that relate to golfing performance (Sell et al., 2007; Wells et al., 2009). However, the adjustability of the available isometric bar fixation apparatus method has been questioned. Therefore, the rationale behind Chapter 3 was to present a new method of bar fixation for the IMTP and to quantify the reliability of PF and early impulse at pre-determined time brackets (0-30, 0-50, 0-100, 0-200). In addition, rotational ability as assessed by speed, power, and maximal strength has been associated with CHS ($r = 0.63, 0.54, 0.71$ respectively) (Gordon et al., 2009; Keogh et al., 2009; Read, Lloyd, et al., 2013) with the cable downswing (CDS) employed by Keogh et al., (2009) being proposed as the most golf specific movement. Therefore, the rationale behind Chapter 4 was to quantify the reliability of a CDS load velocity spectrum.

After establishing the reliability of the neuromuscular tests to be used in this thesis, the variables that were deemed reliable were integrated into Chapter 5. The purpose of Chapter 5 was to investigate the overarching question of; “what are the effects of power type conditioning on the CHS and accuracy of professional male golfers” through a longitudinal power type resistance training period.

1.2 Research aims and hypothesis

The major aims of this thesis were;

1) To examine and compare the current resistance training practices within golf specific strength and conditioning, with particular emphasis on strength and power conditioning protocols.

2) To establish the test-retest reliability of chain fixation method during an IMTP, with particular emphasis on early force time variables.

3) To establish the test-retest reliability of the CDS load velocity assessment.

4) To determine the effects of power type conditioning protocols on golf CHS in male professional golfers.

The following hypotheses were generated for the studies undertaken within this thesis:

1) Chain fixation would provide a reliable (ICC ≥ 0.70, CV ≤ 10%) means of bar fixation during an IMTP when assessing peak force and impulse through pre-determined time brackets.

2) The cable downswing velocity spectrum would provide a reliable (ICC ≥ 0.70, CV ≤ 10%) means of testing golf specific rotational velocity.

3) Power training would substantially (i.e. change outside ± 2 SD) increase maximal driver CHS in male professional golfers.

1.3 Research design

Four studies were undertaken to achieve the hypotheses within this study. These studies used a number of cross-sectional and longitudinal designs and involved a variety of statistical methods.

1) A review of the current literature pertaining to golf CHS and golf resistance training was undertaken.

2) A cross sectional analysis was undertaken to establish the reliability of IMTP force time kinetics when employing the chain fixation method.

3) A cross sectional analysis was undertaken to establish the reliability of the CDS load velocity spectrum.

4) A single subject research design involving a longitudinal training invention with two male professional golfers was undertaken to investigate the effects of power type conditioning on golf CHS.

1.4 Thesis originality

The thesis can be observed to be original in a number of areas:

- To date no IMTP investigation had reported the reliability of early impulse measures. In addition test-retest reliability of isometric testing while fixating the bar with chain was unknown.

- Previously rotational assessment have been concerned with either assessing singular loads (Gordon et al., 2009) or using a narrow range of testing loads (Andre et al., 2012; Ikeda et al., 2007). Until now no golf specific physical assessment had included a large range of loads where both low load, high velocity and high load, low velocity are assessed through a kinematically similar movement to that of golf. In addition, the test retest reliability of the CDS load velocity spectrum was unknown.

- Currently there is limited research on power type conditioning (i.e. Olympic and ballistic type movements) and its impact on driver CHS increase across a training cycle.

- No golf-related study had used kinetic and kinematic profiling to compare pre to post changes in muscular kinetics following a resistance training intervention.

1.5 Thesis organization

The following body of this thesis consists of six chapters. Chapter 1 introduces the thesis topic and, outlines the rationale and thesis organisation. Chapter 2 is a review of the current golfing literature that begins with an overview of the importance of driving distance in golf. Following this, biomechanical and cross sectional data is reviewed. The specific kinematic and kinetic profiles of high CHS golfers are established and the relationship between muscular kinetics and CHS is noted. Next, current literature pertaining to resistance training based interventions is examined. From the literature it is clear that resistance training in a broad sense has a positive impact on CHS. However, a paucity of power based resistance training interventions was identified which highlights the novel aspect of our research.

Chapters 3 and 4 are test-retest reliability investigations. Chapter 3 quantifies the reliability of peak force and impulse during initial time periods of an IMTP. Chapter 4 quantifies the test-retest reliability of a CDS load velocity spectrum. Novel findings and practical applications for both protocols are detailed in the respective discussions of these chapters.

Variables that were found reliable from these chapters were integrated into Chapter 5. Chapter 5 is a longitudinal single subject research design investigating the effects of maximal type power training on professional golfers' CHS and accuracy. Interpretation of the effects of power training is given in the discussion along with practical applications and a direction for future research.

Chapter 6 is a full summary of the complete thesis. It provides synthesized conclusions from the entire thesis and identifies areas of further research based on current limitations and areas that were deemed to be beyond the scope of the current thesis.

Chapter Two

Resistance training for increased golf club head speed: a review of the literature

2.1 Preface

The purpose of this chapter is to review the current literature pertaining to factors that influence golf CHS. Particular emphasis is placed on the current literature pertaining to the application of resistance training in golf and this was undertaken to enhance the understanding of the physical variables that positively influence golf CHS.

2.2 Introduction

The sport of golf is extremely popular throughout the world and it is estimated that over 60 million people (Golftoday, 2009) participate in the game annually. Golf was featured in the official programs for the 1900 and 1904 Summer Olympic Games and it will reappear at the world's largest sporting event in the 2016 Rio Olympic Games. A round of golf takes place over 18 holes with the aim of getting the ball into each hole in as few shots as possible. Thus, achieving the lowest possible score within a given round is the ultimate goal for each player. Golfers will play 18 to 72 holes within a tournament and within each round players will putt, chip and hit full shots from a range of distances using various clubs. When approaching par fours and fives a player will most likely use the driver off the tee, after which irons will be used during the approach shots. The iron that is selected will be dependent on the distance the ball has been driven and the remaining distance to the green. The distance a golf ball travels is proportional to ball speed which is a associated with golf club head speed (CHS) (Fletcher et al., 2004). Environmental (i.e. ground conditions and wind) and technological factors (i.e. golf equipment) along with standard projectile motion principles contribute to golf ball distance. However, it is beyond the scope of this review to discuss such factors. Although several shots are played over a round of golf, driving distance has been found to have the highest correlation to handicap ($r = 0.95$) where handicap can be seen as a measure of golfing ability (Fradkin et al., 2004a). The longer the ball is driven the shorter the approach shots will be which will increase the likelihood of achieving a lower score. Therefore, driving distance is a primary variable of interest due to its relationship to scoring ability.

Exercise is widely regarded within the golfing community as a means to increase golf CHS and thus driving distance (Westcott et al., 1996). In regards to this contention, exercises that are used to achieve this goal are discussed. First the determinants of a golf drive are examined. Second, the integration of biomechanical and muscular factors that relate to golf driving performance are discussed. Thereafter, cross-sectional and longitudinal data pertaining to golf-specific strength and conditioning is reviewed. Finally, specific resistance training recommendations for golf are provided and we highlight potential areas for future research.

2.3 Literature review search methods

A literature search was completed up until the end of November 2014 using SportDiscus, and Google Scholar databases. The key terms ‘golf’, ‘golf conditioning’, ‘resistance training and golf’, and ‘biomechanics and golf’ were used to find relevant literature. In order to further broaden the literature search, a manual reference list screen was performed on each of the gathered articles and previously published reviews (Hume et al., 2005). Using the aforementioned search methods, 2238 articles were returned, this was narrowed to 35 articles by implementing the following inclusion criteria; 1) the literature was published in English, 2) appeared in a peer reviewed journal from 1980 to November 2014, and 3), articles needed to reference “golf” in relation to resistance training for, biomechanics for, or correlation to golf CHS. Given the multifaceted structure of this review, a narrative approach was utilised. As such, between group differences are discussed and similar articles are grouped in an attempt to provide relevant resistance training recommendations. Within such a multifaceted review articles were sub-sectioned and summarised into the following categories:

- Biomechanics relating to high CHS
- Correlational data between physical characteristics and CHS
- Acute effects of resistance type conditioning on CHS
- Longitudinal effects of resistance type conditioning on CHS

Finally, only one interventional study was excluded from the current review due to handicap being the performance variable assessed. As such, any attempt to extrapolate the results relative to CHS increases would be speculative.

2.4 Determinants of a golf drive

A perfect golf drive is characterized by maximal horizontal displacement of the ball with the lowest possible lateral dispersion, which indicates a high degree of accuracy. Maximal driving distance and accuracy rely on correct kinematic sequencing and swing technique. Golfers with greater CHS have better kinematics (e.g. trunk rotational velocities, joint angles and sequencing) (Callaway et al., 2012; Healy et al., 2011; Zheng et al., 2007), reach greater kinetic values (e.g. ground reaction forces and rate of force development) (Chu et al., 2010; Leary et al., 2012; Nesbit et al., 2005), and are stronger (Callaway et al., 2012; Gordon et al., 2009; Keogh et al., 2009; Sell et al., 2007; Wells et al., 2009) than lesser skilled counterparts. For those who exhibit such factors, their swing mechanics are considered to be near optimal. Therefore, the opportunity to improve CHS via technique improvements is limited. However, since muscle morphology can be adapted through effective conditioning, which in turn can improve kinetic variables such as peak force (PF), impulse (I), and rate of force development (RFD) (Campos et al., 2002), golf specific resistance training may increase driving distance with little to no changes in swing mechanics.

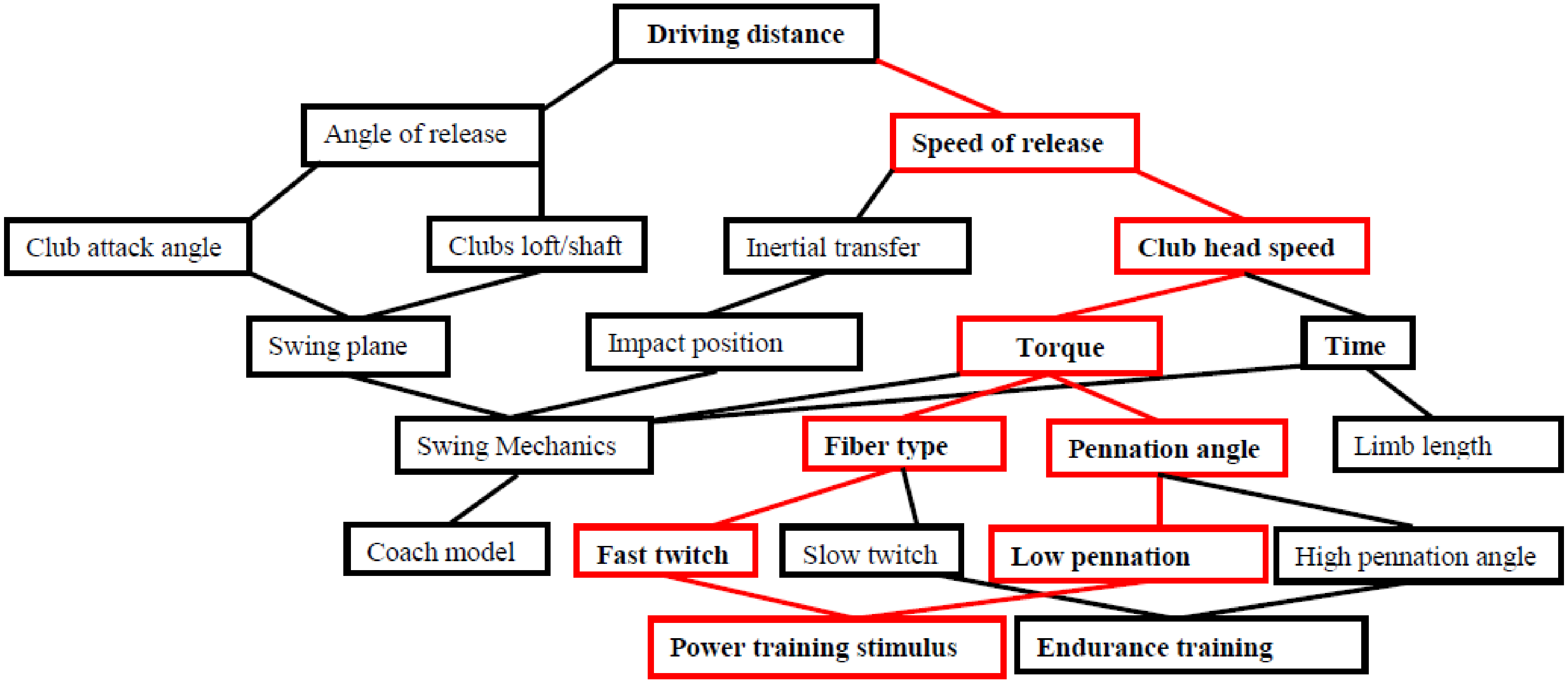


Figure 1. A deterministic model of key factors that contribute to driving distance.

N.B. This model is adapted from current golf and resistance training literature (Fletcher et al., 2004; Ikegawa et al., 2008; Storey et al., 2012a; Wells et al., 2009). Factors likely affected by longitudinal power training are highlighted in red.

2.5 Integrated biomechanics and muscular factors affecting the golf drive

For the purpose of analysis the golf swing is broken into four phases (McHardy et al., 2005); backswing, downswing, acceleration and follow through. The backswing consists of the body rotating away from the ball in preparation for the downswing. The downswing phase begins when the body finishes rotating away, and ends when the club is parallel to the ground. Acceleration starts from the club being parallel to the ground and ends at ball contact. Finally, the follow through occurs after ball contact.

Higher CHS are associated with greater trunk rotation during the backswing and greater hip and trunk rotation velocity leading into ball contact (Chu et al., 2010; Healy et al., 2011; Zheng et al., 2007). Increased hip rotation velocity is likely a function of greater resultant vertical and horizontal ground reaction forces that are created during hip extension and characterizes hip rotation (McNitt-Gray et al., 2013; Okuda et al., 2010). In the context of a right hander's swing, hip extension is initiated by gluteal activation the in the trail leg (right) and this is seen in the early down swing phase (McHardy et al., 2005). The left vastus lateralis activates to provide a pivot point for the rotation to occur. The occurrence of rapid hip rotation is thought to increase "x factor stretch" (i.e. the relative rotation of the pelvis to the upper torso) during the early down swing (Hume et al., 2005). It is likely that "x factor stretch" initiates a stretch reflex through the core musculature leading to increased internal and external oblique activation, which in turn increases trunk rotation velocity (Aggarwal et al., 2008; Healy et al., 2011; Marta et al., 2013). In line with this concept, it is thought that higher CHS players utilize the stretch reflex to a better effect within the golf swing than lesser skilled players (Leary et al., 2012).

The upper body works predominantly to transfer the lower body work to the ball as ~75% of the total work is done by the hip, lumbar, and thoracic regions, with the shoulders and arms accounting for ~25% of total work, (see Table 1) (Nesbit et al., 2005). With regards to muscle activation patterns, high to moderate levels of maximal voluntary contraction (MVC) have been observed within the pectorals, latissimus dorsi, trapezius, rhomboids and serratus anterior (>50% MVC respectively) during the acceleration phase. It is thought the upper body musculature acts to adduct and internally rotate the right arm and to protract and retract the scapulae in order to accelerate and re-orientate the club head in the later stages of the swing (Kao et al., 1995; McHardy et al., 2005). Within the upper body, higher CHS is associated with an increase in shoulder range of motion and external and internal rotation velocities leading into impact (Zheng et al., 2007). The final segment to release is the wrist and increased wrist flexion leading into ball contact is a characteristic of high CHS (Brown et al., 2011). Therefore, increasing wrist flexion (i.e. delaying the release) is a sought after technical attribute. However, wrist extension during the final phase of a downswing may be a passive movement that is a function of the work performed during the downswing leading to greater momentum of the golf club. Therefore, some players and coaches believe that focusing on this technique factor yields little benefit to CHS (Nesbit et al., 2005).

At impact, contact forces work to decrease club momentum and an increase in work transference occurs when club head deceleration is minimized (Abernethy et al., 1990). In order to do so an increased torque about the shoulder and wrist joints must occur (Abernethy et al., 1990; Brown et al., 2011; Pink et al., 1990).

During a golf swing peak angular velocity arises from the summation of the proceeding joint velocities. For example, hip, thoracic and shoulder angular velocities peak at 60, 70, and 75% of the downswing and reach 5.7 - 9.56, 8.41 - 13.51, and 15.44 - 19.83 rad/s respectively, see Table 1 (Nesbit et al., 2005; Vena et al., 2011). Therefore, it would seem that the musculature working at each joint needs to create specific tension within a short timeframe to create maximal joint velocity about each joint (Vena et al., 2011). Furthermore, the transference of velocity to the proceeding segment relies on muscular and joint stability, which will be a function of contraction level (Abernethy et al., 1990). A full report of all kinematic and kinetic variables relating to increases CHS can be observed in Table 1. The reader is referred to Hume et al., (2005) comprehensive biomechanical review.

Table 1: Key variables, attributes and correlations that are indicative of higher CHS in golfers

Authors	Participants	Protocol	Outcomes
Nesbit et al., (2005)	n = 4M, 32.2yrs, 78.3kg, 180cm, 9HCP.	3D work analysis of the golf swing.	Lumbar, thoracic and hip joints account for 71.8% of total work. Shoulders and arms account for 24.7% of total work done. Leg joints account for the remaining 3.6%. Total work peaks 0.004s prior to impact. Linear work peaks at impact. Angular work peaks 0.02s prior to impact.
Zheng et al., (2007)	Pro, n = 18M, 31.6yrs, 83.7kg, 183.1cm, 0HCP. LHG, n = 18M, 36yrs, 84.9kg, 182.9cm, 3.22HCP. MHG, n = 18M, 44.9yrs, 81.4kg, 179.7cm, 12.5HCP. HHG, n = 18M, 48.2yrs, 88.7kg, 180.8cm, 21.3HCP.	Comparison between professional and amateur golfers using angular displacement and 3D kinematic variables.	Professional exhibited a proximal to distal timing of peak velocity. Professional exhibited: ↑ L Shoulder horizontal adduction (10° p<0.01), ↑ R Shoulder external rotation (20° p=<0.01), ↑ trunk rotation a POB (11° p=<0.01), ↓ L elbow flexion (11° p=<0.01), ↑ wrist extension (11° p=<0.01), and ↑ trunk rotation (15° p=<0.01) at Ball contact. Velocities: ↑ R Shoulder internal rotation (196°/s p=<0.01), ↑ L elbow extension (69°/s p=<0.01), ↑ L Wrist extension (423°/s p=<0.01), ↑ R wrist extension (475°/s p=<0.01), ↑ R elbow extension (303°/s p=<0.01), ↑ club shaft velocity (657°/s p=<0.01). Values listed are relative to HHG group.
Gulgin et al., (2009)	n =15F, 19.7yrs, 59.6kg, 163cm, Division 1 golfers.	3D analysis of female hip rotational velocities.	Lead hip internal rotation velocity 227.8 (°/s), trail hip external vel 145.3 (°/s) occurring at 89.1 and 85.2% of the down swing respectively.
Okuda et al., (2010)	LHG, n =1M, 26.3yrs, 81.4kg,	3D and force plate Kinetic and.	**Kinematics Data** Skilled golfers exhibit: ↑ trunk (7.1° p=<0.05), ↑ pelvic

	181cm, .8HCP. HHG, n = 17M, 23.9yrs, 76kg, 177cm, 30.8 HCP.	Kinematic analysis of the ground reaction forces and kinematics.	rotation (7° p=<0.05) during back swing , ↑ pelvic rotation during down swing (10.6° p=<0.05), ↑ pelvic side bending (4.1° p=<0.01) during down swing. **Kinetic Data** Skilled golfers exhibit; ↓ lead foot VGRF (.10 %BW) during backswing, ↑ lead foot VGRF during down swing (.26 %BW), ↑ tail foot VGRF (0.16 %BW) during the backswing. ↑ maximal VGRF (0.9 %BW).
Chu et al., (2010)	n = 266M, 42F, 43.2yrs, 83.5kg, 177cm, 8.4HCP.	The relationship between biomechanical variables and DD using 3D analysis.	Variables that showed significance at each phase (p=<0.05): Back Swing: lateral bend (°), superior-inferior shift velocity (m/s), x factor, leading arm angle (°), wrist hinge (°), and leading knee flexion (°). Acceleration: Forward tilt (°), lateral bend (°), lateral bend velocity (°/s), upper torso rotational velocity (°/s), leading arm angle (°), wrist hinge (°), lead foot VGRF (%BW). Last 40 ms and impact: forward tilt (°), lateral bend (°), lateral bend velocity (°/s), superior-inferior shift (m) (impact only), upper torso rotation (°) (last 40ms only) and (°/s), leading arm angle (°), wrist hinge (°) and velocity (°/s), leading foot VGRF (%BW), leading foot VGRF change (%BWs-1) (impact only), Trail foot VGRF change (%BW s-1).
Brown et al., (2011)	n = 16F, 24.8yrs, 65.9kg, 168cm, 1.8HCP.	3D analysis of female golf swing characteristics.	Grip strength and seated flexibility significantly correlated to CHS (0.54, 0.71 p=≤0.05), pelvis- thorax axial angular velocity at wrist uncocking showed a 0.489 (p≤ 0.05) correlation to CHS
Vena et al., (2011)	n = 5M, 35.6yrs, 80.74kg, 179.8cm, 8.6HCP.	3D analysis of the sequential nature on	Peak angular velocity of the pelvis, shoulders, and left arm occur at 60, 70, and 75% of the down swing

		the golf swing.	reaching 5.7-9.56, 8.41-13.51, and 15.44-19.83 rad/s respectively.
Healy et al., (2011)	High CHS; n = 15M, 27.5yrs, 78.8kg, 179.9cm, 4.3HCP. Low CHS; n = 15M, 41.4yrs, 82.3kg, 176.6, 11.3HCP	3D and golf club launch characteristics comparison between male high CHS and low CHS.	High CHS: ↓ L Shoulder internal rotation (17.4° p=<0.01), ↑ L/R Shoulder flexion during the backswing (22.6°, 12.8° p=<0.01). ↑ L Shoulder abduction during the down swing (11.2° p=<0.01), Hip rotation (11.7° p= 0.002), ↑ R Hip abduction (11.3°), ↑ x factor (10.3° p=0.007). ↑ L/R shoulder flexion/extension velocity (269.7, 91.1 °/s p=<0.01), ↑ L/R hip extension velocity (105, 152.8°/s p=<0.01). Values listed are relative to low CHS group.
Callaway et al., (2012)	LHG; n = 38M, <5HCP HHG; n = 18M, >18HCP	Analysis of pelvis speed and its association with glute strength, using high and low handicap groups. (All strength measure as a % BW)	Correlations to CHS (p= <0.01) R/L Gluteus maximus r=0.419, 0.430, R and L Gluteus medius r=0.490, 0.466. LHG ↑ pelvic rotation velocity (123.15°/s). LHG glute strength (%BW). ↑ R, L Gluteus maximus 8.6%BW, 9.9%BW, ↑ R and L Gluteus medius 7.9%BW, 7.8%BW.

Key: ↑ = increase, R = right, L = left, VGRF = vertical ground reaction force, BW = body weight, LHG = low handicap group, MHG = moderate handicap group HHG = high handicap group, HCP = handicap, cm = centimeters, mins = minutes, yrs = years old, kg = kilograms, n = number of participants, M = Male, F = Female, °/s = degrees per second

2.6 Relationship of Strength and Power to CHS: Cross-sectional Data

Chest, back and lower limb maximal strength measures (see Table 2) assessed through non-specific compound movements (e.g. upper body presses, upper body pulls, and squat type movements) were found to have strong to moderate correlations (0.69, 0.69, 0.53, respectively) with CHS (Gordon et al., 2009; Hellstrom, 2008; Keogh et al., 2009; Read, Lloyd, et al., 2013; Read, Miller, et al., 2013; Wells et al., 2009). In contrast endurance capacity, as assessed through similar movements (e.g. lower body squat, upper body push) were found to have weak correlations (0.23, 0.29) to CHS (Loock et al., 2013). Thus, higher CHS golfers are characterized by higher maximal strength as opposed to endurance. In addition, strength through biomechanically similar movements such as the golf specific cable down swings (CDS) can be observed to have stronger correlations to CHS (0.71) when compared to less specific movements (refer to Table 2) (Gordon et al., 2009; Keogh et al., 2009; Read, Lloyd, et al., 2013; Read, Miller, et al., 2013). Such findings have relevance to golf specific testing situations as previous investigations have stated the importance of testing kinematically similar movements as they have the greatest association to sporting performance (Haff et al., 2005). With regards to ballistic (i.e. projection of mass) movements, single leg jump height appears to have the strongest correlations to CHS (0.77, 0.73), as compared to countermovement jumps (0.61) and squat jumps (0.45) (Hellstrom, 2008; Read, Lloyd, et al., 2013; Wells et al., 2009). Therefore, high CHS golfers are characterized by greater unilateral jump ability as opposed to bilateral ability.

Rotational based power assessment has been limited to machine and seated medicine ball protocols, with similar correlations (0.54, 0.67) observed to that of strength testing (Gordon et al., 2009; Read, Lloyd, et al., 2013). Only one study has compared power based upper body pressing movements (i.e. chest medicine ball throw) with CHS and similar correlations were noted to that of maximal force testing (0.63 vs 0.69) (Read, Lloyd, et al., 2013).The data presented above and in Table 2 have revealed non-specific and specific movements correlate to CHS. Strength and power has been found to correlate to CHS to a similar degree however, both correlate to CHS to a greater degree than endurance capacity. With regard to training modalities, specific and non-specific strength and power movement correlates leave much of the variance in CHS unexplained suggesting that gym based movements are poor predictors of CHS. However, the tracking of muscular kinetics within time frames that correspond to the golf downswing are more likely to portray the specific force requirements of golf (Leary et al., 2012). In addition, a paucity of literature currently exists on velocity based downswing specific rotation, non-specific upper body pressing and pulling movements. Thus, the inclusion of such movements in future research will extend the current body of golf specific cross-sectional data.

Table 2. Cross sectional data. Correlations between physical attributes and golf CHS.

Author	**Participants**	**Protocol**	**Correlations to CHS**
Hellstrom., (2008)	n = 33M, 18-30yrs, <0HCP.	Correlations between the Swedish golf associations testing battery and CHS.	Bar dip (kg) (r = 0.35), vertical sit ups (kg) (r = 0.42), R grip (kg) (r = 0.36), Squat (kg) (r = 0.54). Squat jump PP (r = 0.61), cm (r = 0.45), CMJ PP (r = 0.61), cm (r = 0.47), CMJ with arms (cm) (r = 0.45), PP (r = 0.61). 10 & 20m sprint mean power (r = 0.49), (r = 0.53).
Gordon et al., (2009)	n = 15M, 34.3yrs, 86.2kg, 178.0cm, 4.9HCP.	Correlational analysis assessing the magnitude of the relationship between selected variables and CHS.	Chest strength (r = 0.69), Total body rotational power (r = 0.54).
Keogh et al., (2009)	LHG; n = 10M, 22.9yrs, 76.8kg, 180.0cm, 0.3HCP. HHG; n = 10M, 27.8yrs, 73.5kg, 177.0cm, 20.3HCP.	Correlational analysis of selected anthropometric, strength and flexibility measures.	Hack squat kg (r = 0.53), Bench press (r = 0.5), Golf specific cable wood chop (r = 0.71). Upper arm length (r = 0.45), total arm length (r = 0.45).
Wells et at., (2009)	n = 9F, 15M, 22.7yrs, 70.0kg, High performance Canadian golfers.	Correlation between physical characteristics and CHS.	Vertical jump (r = 0.59), dominant leg (r = 0.73), Non dominant (r = 0.77), pull up (r = 0.80), push up (r = 0.66), dominant grip strength (r = 0.78), Non dominant (r = 0.82).
Leary et al., (2012)	n = 12M, 20.4yrs, 77.0kg, 177.7cm, 14.5HCP.	The relationship between lower body force time curve characteristics and CHS, using a isometrics mid-thigh pull, CMJ, and squat jump as physical tests.	RFD at 150m/s (r = 0.47) Eccentric utilization was 11% higher in low handicap golfers.
Loock et al., (2013)	n = 101M, 17-71yrs, experience golfers.	The associations between endurance type muscular tests, CHS and carry distance using a driver and 5 iron.	Lower back strength (r = 0.56), push-ups/minute (r = 0.29), and wall squats/minute (r = 0.25).

Read, Llod, et al., (2013)	n = 48M, 20.1yrs, 72.8kg, 176.0cm, 5.8HCP.	The relationship between field based measures of strength and power and CHS.	CMJ height (r = 0.44), and PP (r = 0.54), Squat jump height (r = 0.50), and PP (r = 0.53), Medicine ball seated chest pass, (r = 0.67), Medicine ball seated rotation (r = 0.63).
Gulgin et al., (2014)	n = 36M, 25.4yrs, 76.2kg, 175.9cm, 14.2HCP.	Correlations between Titleist Performance Institute (TPI) Level 1 movement screens and swing faults.	Inability to toe touch relates to early hip extension (p = .015), Inability to bridge on the right side relates to early hip extension and loss of posture (p = 0.05, p = 0.03). In ability to overhead squat shows a 2 fold increase in the likely hood of presenting loss of posture as a swing fault.

All variables that reached significance ($p<0.05$) are listed under results for each of their respected studies. Key: R = right, L = left, PP = peak power, CM = centimeters, CMJ = counter movement jump, RFD = rate of force development , DD = driving distance, LHG = low handicap group HHG = high handicap group, HCP = handicap, cm = centimeters, mins = minutes, yrs = years old, kg = kilograms, n = number of participants, M = Male, F = Female

2.7 Acute responses of CHS to warm-up protocols

Golf warm-ups methods vary from static and dynamic stretching to non-fatiguing resistance and post activation potentiation protocols. The intent of a warm-up is to increase muscle temperature and muscle length in order to enhance contractile potential and joint range of motion, which is thought to enhance performance (Moran et al., 2009). However, the type of warm-up employed has been found to elicit varying effects on driving performance (Gergley, 2009; Gergley, 2010; Moran et al., 2009; Read, Miller, et al., 2013; Tilley et al., 2012). For example, static stretching has been shown to produce an acute negative effect on CHS, accuracy and centeredness of strike (i.e. ability to make contact in the middle of the club face) (Gergley, 2009; Gergley, 2010; Moran et al., 2009) and these negative effects may last up to 30 minutes in duration (Gergley, 2010; Moran et al., 2009). In contrast warm-up protocols including dynamic stretching (Moran et al., 2009), linear non-fatiguing resistance, rotational non-fatiguing resistance (Tilley et al., 2012), and post activation potentiation (Read, Miller, et al., 2013) increase CHS and driving distance (see Table 3). Ballistic countermovement jumps preceding a golf drive increased CHS to a greater extent than non-specific (i.e. squats, bench press, deadlift) and specific (i.e. lunge and twist, theraband wood chop) resistance exercise (1.08 m/s increase vs 0.9 m/s). However, non-specific rapid dynamic stretching (i.e. butt kicks, standing trunk rotations) exceeded both the previous protocols (non-specific and specific resistance exercise) by increasing CHS by 1.7 m/s ($p = < 0.01$). Read, et al., (2013), Moran et al., (2009), and Tilley et al., (2012) made no attempt to examine any underlying physiological measures however, all three attributed increases in CHS following warm-up protocols to; 1) increases in nerve conduction velocity, 2) increased muscular synchronization, 3) increased muscle tendon unit interaction and, 4) increased neural excitability.

It would seem from this brief treatise of the literature that rapid movements both specific and non-specific may be the best form of warm-up prior to a golf drive for acutely increasing CHS in elite (HCP < 6.0) male golfers who are <40 years old (Moran et al., 2009; Read, Miller, et al., 2013; Tilley et al., 2012). A golf warm-up should include rapid movement about all joints and ballistic jumping, however static stretching should be avoided when looking for performance enhancements.

Table 3. The acute effects of warm-up type protocols on CHS and driving performance

Author	Participants	Protocol	Effects on driving performance
Gergley., (2009)	n = 15M, 20.6yrs, 79.9kg, 182.5cm, 2.5HCP.	The acute effects of statics stretching on golfer drive performance immediately post static stretching protocol.	CHS ↓ 1.72 m/s. DD ↓ 5.62%. Accuracy ↓ 31.04%. Consistent ball contact ↓ 16.34% (quantitatively measured).
Moran et al., (2009)	n = 18M, 23.2yrs, 76.2kg, 181.1cm, <6HCP.	The effects of a dynamic warm up on golf CHS, compared with static and no stretch.	Dynamic stretch ↑ CHS 1.9 m/s above that of static and 1.7m/s above that of no stretch. Dynamic stretch produced a straighter swing path than static and no stretch, -0.6°, and -0.7°. More central impact was noted.
Gergley., (2010)	n = 9M, 20.4yrs, 79.9kg, 182.8cm, 3.2HCP.	Latent effect of static stretching on driver performance measured at 0, 15, 30, 45, and 60 minutes post stretching protocol.	CHS ↓ 4.92 m/s at (0 mins), ↓ 2.59 m/s (15 mins), ↓ 2.19 m/s (30 mins) but not at 45 and 60 mins. Distance ↓ at 0, 15, 30, 45, 60 mins. Accuracy ↓ at 0, 15, 30, 45, but not 60 mins. Consistent ball contact ↓ at 0, 15, 30, 45, but not at 60 mins.
Tiller et al., (2012)	n = 15M, 18-40yrs, <2HCP.	Comparison between a, dynamic golf specific (AD), dynamic golf specific and linear resistance only (deadlift, bench press, row, squat) (DLR), Dynamic golf specific and functional resistance (lunge with theraband rotation) (DFR) on driving variables.	DFR ↑ CHS 0.9 m/s and DD 14.98 m above AD, and 0.27 m/s and DD 12.88 m above DLR DLR ↑ CHS 0.63 m/s and DD 2.1 m above AD.

Continued on page 34

Read, Miller, et al., (2013)	n = 16M, 20.1yrs, 72.8kg, 176cm, 5.8HCP.	The influence of post activation potentiation (PAP) on CHS in a group of young elite untrained golfers.	CHS ↑ 1.08 m/s following PAP protocol utilizing a CMJ ($p \leq 0.05$).

All variables that reached significance ($p<0.05$) are listed under results for each of their respected studies. Key: CM = centimeters, CMJ = counter movement jump, DD = driving distance, LHG = low handicap group HHG = high handicap group, HCP = handicap, cm = centimeters, mins = minutes, yrs = years old, kg = kilograms, n = number of participants, M = Male, F = Female

2.8 Longitudinal data

Resistance type exercise is widely used as a method for enhancing sports performance. However, researchers have reported mixed outcomes with resistance and stretch based interventions within golf. Both increases (Alvarez et al., 2012; Chen et al., 2010; Doan et al., 2006; Fletcher et al., 2004; Fradkin et al., 2004b; Hetu et al., 1998; Kim, 2010; Lephart et al., 2007; Thompson et al., 2007; Thompson et al., 2004; Weston et al., 2013) and decreases (Lamberth et al., 2013; Loock et al., 2012) in CHS have been reported (-1.96m/s to + 17m/s^2) following various resistance exercise protocols. To date the majority of studies have used high repetition (i.e. 8-20 repetitions), slow movement speed or rehabilitation type exercises (Chen et al., 2010; Doan et al., 2006; Fletcher et al., 2004; Fradkin et al., 2004b; Lamberth et al., 2013; Lephart et al., 2007; Loock et al., 2012; Thompson et al., 2007; Weston et al., 2013) with the exception of one study that used more strength/power orientated repetition ranges (i.e. 5-6 repetitions) (Alvarez et al., 2012). The following sections compare the effects of different training protocols (e.g. hypertrophic, strength and power) intervention lengths and participants' descriptive information (i.e. biological and training age, and gender) on golf drive performance.

2.8.1 Type of conditioning protocol

The selected conditioning protocol (i.e. hypertrophy, strength and/or power) affects the type of adaptations that take place, which in turn can influence performance. Hypertrophic-type training (i.e. moderate number of sets, high repetitions, slow movement velocity) creates peripheral adaptation (e.g. increased cross sectional area, increased pennation angle) while little central adaptation (e.g. increased rate coding, synchronization, disinhibition) occurs (Hakkinen, 1986). However, strength (i.e. high number of sets, low repetitions, slow movement velocity), and power-type (i.e. high number of sets, low repetitions, high movement velocity) training create both central and peripheral adaptations leading to increases in muscular kinetics (Stone et al., 2002; Storey et al., 2012a). In order for a maximal transfer of training induced adaptation to occur, the principle of training specificity must be adhered to, which requires biomechanically similar exercises, performed at specific movement speeds to be integrated into the program (Baechle et al., 2008; Lehman, 2006).

A lack of movement specificity was apparent in two of the nine hypertrophic type studies, both of which observed decreases in CHS (Lamberth et al., 2013; Loock et al., 2012). Although, significant increases (8 - 11%) in leg and chest strength were observed, CHS decreased by 1.96 m/s (non-significant) over an eight week intervention (Lamberth et al., 2013). In addition, Loock et al. (2012) observed a 0.89 m/s (non-significant) decrease in CHS following 12 weeks of CorePower machine training (2 x 3 minute sessions, 3 times per week; CorePower allows movement only though a sagittal plane) (Loock et al., 2012). The low training volume and lack of movement specificity is likely attributable to the decrease in CHS. When applying the principle of movement specificity it is unlikely that solely training through a sagittal plane, or for general hypertrophy will increase performance through an explosive and rotational movement such as the golf swing (Baechle et al., 2008; Lehman, 2006). However, Weston et al. (2013) found that an isometric, general core exercise protocol produced significant increases in CHS (1.2m/s). Therefore, it is possible that improved muscle kinetics that arise from general conditioning contribute to torque generation, which in turn improves swing mechanics (Chu et al., 2010; Gulgin et al., 2009). However, careful consideration needs to be given to understanding methodological issues with the participant cohorts (i.e. differences in age, training status and skill level), which may account for the disparity between the results of the aforementioned studies.

Researchers integrating ballistic medicine ball rotations and velocity based golf swing training have reported significant improvement in CHS (0.76, 0.75, 1.36 and 1.47 m/s increase) following 8 to 18 week interventions despite the primary focus of these training programs being hypertrophy. (Doan et al., 2006; Fletcher et al., 2004; Hetu et al., 1998; Thompson et al., 2007). Although speculative, it is likely that the velocity and movement specific exercises (i.e. medicine ball rotations and golf swings) employed in these studies enhanced intra- and inter-muscular co-ordination that allowed the subjects to integrate the increased kinetics (i.e. peak force) developed through resistance training into the golf swing (Cronin et al., 2001). Despite the positive association between power-based movements and increased CHS (Hellstrom, 2008; Read, Lloyd, et al., 2013; Read, Miller, et al., 2013; Wells et al., 2009), only one study to date has directed a full training cycle to developing golf specific strength and power. The 18 week intervention used by Alvarez et al., (2012) was broken into three 6 week training blocks (i.e. week 1 -6 strength, week 7 - 12 strength and plyometrics, and week 13 - 18 golf specific training). When compared to previous investigations (Doan et al., 2006; Hetu et al., 1998; Lephart et al., 2007; Thompson et al., 2007), the training repetitions were relatively lower and the training loads were higher and this form of conditioning resulted in significant strength gains in bench press, squat, seated row, and military press (9-30% increase). However, only CHS acceleration improvements (17 m.s^2) were reported (as opposed to changes in maximal velocity) which prevents a comparisons between previous investigations and Alvarez et al. (2012). Fletcher et al., (2004) and Hetu et al., (1998) observed significant CHS increases (0.75 m/s and 1.36 m/s) when investigating the combined effects of strength and power on CHS. However, repetition ranges and loads coincided with hypertrophic conditioning (repetitions >6, intensity < 85% RM, slow movement speed) and as a result the effects of hypertrophy rather than strength were investigated.

High CHS are characterized by a greater range of motion, specifically in the shoulder and trunk (Brown et al., 2011; Healy et al., 2011; Sell et al., 2007). In support of this statement significant increases (4 - 10 m/s) in CHS have been shown to occur following 3-5 weeks of stretch based conditioning (Chen et al., 2010; Fradkin et al., 2004b). Chen et al. (2010) suggested that kinematic variables (i.e. peak upper torso velocity) improved following increases in joint range of motions which positively influenced CHS. However, such conclusions are only speculative as no kinematic measures were taken. This proposed avenue for enhanced performance is supported by previous researchers who showed that improved range of motion is a factor that differentiates high and low CHS golfers (Zheng et al., 2007).

2.8.2 Methodological issues arising from participants

At present, it is difficult to make decisive gender comparisons from the current body of golfing literature due to the paucity of investigations that have involved female participants. In addition, information from a large range of participant ages (i.e. 19 to 76 years old) and experience levels (i.e. <5HCP to >15HCP, trained to untrained) has been documented so when interpreting the results, it is important to take into account the biological age and training experience of the participants. For example, biological age and training age greatly influence the adaptation response to a training stimulus (Skrzek et al., 2012). In untrained or novice trained individuals, early adaptations (i.e. during weeks 1-8) can be attributed to changes in neural recruitment that develop over relatively shorter periods. Such changes are often disproportionate to those seen in later stages of training (≥2 months) (Skrzek et al., 2012). Conversely, in more experienced individuals, strength gains during later stages can be attributed to more peripheral muscle and connective tissue adaptations such as muscular hypertrophy (Seynnes et al., 2007).

To date the research dealing with participants who are aged >39 years have examined CHS as the dependent variable (Fradkin et al., 2004b; Hetu et al., 1998; Lephart et al., 2007; Loock et al., 2012; Thompson et al., 2007; Thompson et al., 2004; Weston et al., 2013). Within these investigations the resistance protocols have targeted hypertrophic (i.e. high repetitions, slow movement speed, low load) and basic movement competency (i.e. functional, rehabilitative, and flexibility type exercises) (Lephart et al., 2007; Thompson et al., 2007; Weston et al., 2013). Collectively the researchers have shown that functional, rehabilitative, and flexibility type training significantly increases CHS. However, when compared to older (>39 years old) participants, younger players (<39 years old) showed greater CHS improvement following such training interventions (i.e. >39 yrs 1.45m/s increase vs. <39 years 2.48m/s increase). Such changes are not unexpected as age-related declines in muscular strength, and to a further extent muscular power, occur from the 4th decade in life and it is also possible that the slow movement, low intensity nature of the employed conditioning protocols was of limited benefit to such cohorts (Macaluso et al., 2004; Skrzek et al., 2012). Although speculative, greater improvement in CHS may be seen with strength and power based conditioning protocols. In addition, greater strength and power increases can be seen in older populations when intensity and movement velocity is higher (>70% RM) when compared to lower intensity protocols (Macaluso et al., 2004). Therefore, in light of these findings, resistance training protocols that are designed for CHS increases in all age groups should include strength (low repetitions <6, high load >70%RM) and power (low repetitions <6, moderate loads, high movement speed) type components.

Another important factor to consider when examining the current literature is the skill level of the participants. As skilled participants exhibit more efficient biomechanics (Zheng et al., 2007) it is likely that resistance training induced morphological adaptations will express themselves as improvements in CHS (Alvarez et al., 2012). However, the potential window of adaptation for these skilled participants (HCP <10) is likely to be smaller when compared to lesser skilled counterparts (Alvarez et al., 2012; Chen et al., 2010; Doan et al., 2006; Kim, 2010; Lamberth et al., 2013). Conversely, higher handicap golfers (i.e. HCP >10) exhibit less efficient swing mechanics, which means that improvements in CHS are likely to arise via a combination of changes in biomechanics, motor pattern, and morphology (Fradkin et al., 2004b; Lephart et al., 2007; Thompson et al., 2007; Thompson et al., 2004; Weston et al., 2013). Thus resistance programs for such athletes should aid in improvement of biomechanics and muscle morphology (Lephart et al., 2007; Thompson et al., 2004).

2.8.3 Length of intervention

Researchers employing interventions less than 8 weeks demonstrated significant increases in CHS (0.75 - 10 m/s. See Table 3) (Chen et al., 2010; Fradkin et al., 2004b; Lamberth et al., 2013). The protocols undertaken were aimed at inducing mechanical muscle changes (i.e. improvements in joint range of motion) and previous research has shown significant improvements in muscular range of motion can occur over periods as short as two weeks (Davis et al., 2005). Thus, the observed CHS increases may be a result of improved ROM as opposed to improved muscular kinetics (Healy et al., 2011).

Several studies employed 8 week interventions with great success (Fletcher et al., 2004; Hetu et al., 1998; Lephart et al., 2007; Thompson et al., 2004; Weston et al., 2013). On average a 1.34 m/s increase was observed across all interventions and two research groups observed concurrent improvements in strength measures and CHS over the course of the 8 week interventions (Lephart et al., 2007; Thompson et al., 2004). Two investigations examined the effects of interventions greater than 10 weeks in duration and observed similar improvements to that of the 8 week interventions (Doan et al., 2006; Kim, 2010). Finally, as previously mentioned, Alvarez et al., (2012) employed an 18 week intervention with elite golfers that was broken into 6 week phases; week 1 – 6 strength, week 7 – 12 strength and plyometrics, and week 13 – 18 golf specific training. Significant increases in CHS acceleration were observed in each phase (weeks 1 - 6 = 7 m/s^2, weeks 7 - 12 = 4.2 m/s^2, weeks 13 -18 = 6.91 m/s^2; total increase of 18m/s^2), which demonstrates that such a periodised approach is effective at improving golf specific performance. From the existing literature it is evident that significant CHS increases can occur following interventions lasting 3-18 weeks in duration. Furthermore, progressive overload and periodization is recommended during longer interventions in order to yield significant increases in CHS (Alvarez et al., 2012; Doan et al., 2006; Lephart et al., 2007). A clear intervention length, training focus, and adaptation (i.e. neural, mechanical, or physiological) interaction exists. However, transference of increased muscular kinetics to CHS may not be immediate as there is likely a “lag time” in which the individual will need to become accustomed to the increased strength/power and learn how to integrate these qualities into a golf swing.

In conclusion, resistance protocols utilized by strength and conditioners should be directed by subject ability. Subjects who demonstrate poor golf mechanics may benefit from stretch based interventions. However, when conditioning for elite golfers, high velocity golf swing type movements should form the foundation of training (Lehman, 2006). Such protocols may improve muscular kinetics such as impulse and peak force that relate to golf swing kinematic CHS predictors (Alvarez et al., 2012; Chu et al., 2010). Thus, practitioners looking to program for an elite cohort should direct specific attention to selecting appropriate movement speeds, movement patterns, sets and repetitions schemes. Low repetitions, high movement velocity, and biomechanically similar exercises are sought. Practitioners may also benefit from tracking specific kinetic changes (e.g. peak force, impulse, velocity) over more traditional strength (kgs) measures as they may provide greater insight into the underpinning mechanisms of CHS increases (Leary et al., 2012). When reporting driving performance CHS should be reported in mph, m/s or kph to allow comparisons between interventional protocols. Finally, future research should look to investigate the impact of full body (upper body push, pull and lower body squat type movements) power protocols on CHS as a paucity of longitudinal literature exists.

Table 4. The effects of resistance training on golf club head speed. Table is ordered by intervention length

Author	Study design	Participants	Protocol	Exercises	Sets	Reps	Results
Chen et al., (2010)	Case study	n = 1M, 19 yrs, 177.8 cm, 78 kg, <10 HCP.	3 week correctional resistance and flexibility program.	Shoulder massage, stretching and resistance band exercises, and vibration training.	3	20	CHS ↑ 4 m/s
Fradkin et al., (2004b)	Control trial	n = 1M, 39.6 yrs, 19.6 HCP.	5 week stretching/warm up type program.	Static and dynamic stretching of all major muscle groups, air swings with golf club.	N/A	N/A	CHS ↑ 7-10 m/s*
Lamberth et al., (2013)	Control Trial	n = 10M, 21.4 yrs, <8 HCP.	6 week hypertrophic intervention.	Compound, free weight, cable and machine exercise covering all major muscle groups.	2-4	6-12	CHS ↓ 1.96 m/s ↑ in bench press and leg press.
Weston et al., (2013)	Control Trial	n = 36M, 47 yrs, 89 kg, 180.8 cm, 11.2 HCP.	8 week isolated core training program.	Isometric and dynamic body weight movement, slow and controlled with 10s holds. No rotational components/lateral bending.	N/A	N/A	CHS ↑ 1.2 m/s
Fletcher et al., (2004)	Control trial	n = 11M, 29 yrs, 76 kg, 179.0 cm	8 week weight and plyometric program.	Free weight resistance work and medicine ball exercise.	3	6-8	CHS ↑ 0.75 m/s*
Thompson et al., (2007)	Control trail	n = 18M, 70.7 yrs,	8 week periodised functional training program.	Body weight type and medicine ball exercise, adapted from sports medicine optimum	1-3	8-15	CHS ↑ 1.47 m/s*

				performance training model.			
Lephart et al., (2007)	Training intervention	n = 15M, 47.2 yrs, 178.8 cm, 86.7 kg, 112.1 HCP.	8 week resistance band and stretching program.	Hip and scapular rehabilitation based, and resisted golf swings. Full body stretching.	3	10-15	CHS ↑ 2.3 m/s* X Factor ↑ 6.8%
Hetu et al., (1998)	Training Intervention no control	n = 12M, 5F, 52.4 yrs.	8 Weeks of strength, flexibility and plyometric training on mature golfers.	Machine, free and free weight exercise for all major muscle groups Flexibility for all major joints Medicine ball and foam ball plyometric exercise.	1-2	6-15	CHS ↑1.36 m/s* Significant ↑ in all strength and flexibility measures.
Thompson et al., (2004)	Control Trial	Trial, n = 19M, 64.3 yrs, 81.2 kg, 177.5 cm. Control; n = 12M, 66.2 yrs, 83.0 kg, 178.3cm.	8 week resistance and stretching intervention on older golfers.	Machine based full body conditioning for all major muscle groups, and weighted golf club swings. Stretching for all major joints involved in golf (shoulders, Hips, Trunk).	1	12	CHS ↑ 0.94m/s * All strength measures ↑ (21.3 – 60.4% increase). ↑ shoulder, and trunk ROM.
Doan et al., (2006)	Longitudinal training intervention	n = 10M, 6F, 19.3 yrs,70.5 kg, 175.3 cm, elite golfers.	11 week conditioning intervention	Traditional resistance (bench press, leg curl, squat, dumbbell and medicine ball exercise.	1-3	7-20	CHS ↑ 0.76m/s*
Kim, (2010)	Control Trial	Trial, n = 9F, 22.9 yrs, 59.07 kg, 164.55 cm Control; n = 8F, 21.75 yrs,	12 weeks of combined flexibility and lower limb/core training.	Deadlift, squat, crunch, back extensions and rotations. Lower limb flexibility	3	12	CHS ↑ 1.35m/s ↑ strength and flexibility

		60.25 kg, 162.91 cm.		exercise.			
Loock et al., (2012)	Pilot intervention study	n = 9M, 17-76 yrs, 10.56 HCP.	12 week intervention using the core power machine.	6 minutes of “Corepower” machine use 3x/week.	2	3 mins	CHS ↓ 0.89 m/s
Alvarez et al., (2012)	Control trial	Control; n = 5M, 23.9 yrs, 70.6 kg, 172.1 cm, 1.6 HCP. Trial; n = 5M, 24.2 yrs, 68.09 kg, 171.9 cm, 2.1 HCP.	18 week comparison between traditional golf conditioning and a three part strength type conditioning.	Full body compound strength + combined strength and plyometric type exercise.	3	5-6 at 70-85% RM	CHS ↑ 17.6m/s^{-2}* Ball speed ↑14.6km/hr

Key: * = reached significance p≤0.05. HCP = handicap, yrs = years old, kg = kilograms, n = number of participants, RM = repetition maximum, M = Male, F = Female. Only resistance training groups are reported in results column.

2.9 Conclusion

Collectively it would seem that resistance training has a strong positive impact on golf CHS. Kinematic data shows higher CHS is characterized by increased range of motion and joint velocities. Furthermore, more skilled golfers who exhibit increased kinematic and kinetic factors during a golf swing also possess greater force and velocity based muscular qualities through specific and non-specific movements, with the highest correlations to CHS being associated with specific downswing movements, and non – specific velocity based movements (Keogh et al., 2009; Wells et al., 2009). Longitudinal data has reported hypertrophic, rehabilitative, and warm up type training protocols increase golf CHS to varying degrees (Alvarez et al., 2012; Chen et al., 2010; Doan et al., 2006; Fletcher et al., 2004; Fradkin et al., 2004b; Hetu et al., 1998; Kim, 2010; Lephart et al., 2007; Thompson et al., 2007; Thompson et al., 2004; Weston et al., 2013). The variation in results are indicative of the training stimulus offered as greater CHS increases are seen when ballistic and power type movements are integrated into the training cycle. Highly skilled participants need to be offered more specific movements, and kinetic outputs to elicit a training effect. To achieve a golf specific training stimulus, training protocols need to mimic the golf swings kinematics (i.e. trunk rotation, hip extension) and allow similar kinetics outputs (i.e. velocity, impulse, peak force). In addition, more specific movements (i.e. medicine ball rotation, cable downswings, jump type movements, upper body pressing, and pulling), with higher movement speeds (ballistic, high velocities) and moderate loads (i.e. maximal power training) should be incorporated. Figure 1 is a deterministic model of factors that influence driving distance. The pathway through which power training likely affects CHS is highlighted in red. Such relationships between singular levels have been previously shown (Fletcher et al., 2004; Ikegawa et al., 2008; Storey et al., 2012a; Wells et al., 2009). However, the relationship between power training stimulus and CHS remains unknown.

2.10 Practical applications

When designing golf specific strength and conditioning programs, the astute strength and conditioner should consider participant age (biological age, and training age), skill level, and flexibility. A progressive periodised program should be employed whereby flexibility components, functional movement patterns and base strength are developed first before undertaking maximal power based movements. The foundation of the program should be rotationally based. Additionally the astute strength and conditioner should track changes in rotational ability. Explosive movements such as Olympic lifts require high levels of joint stabilization and mobility and therefore may not be appropriate for all age and skill levels unless expert coaching is provided. However, maximal power, and ballistic type movements should be integrated into any golf specific program. Finally, fast dynamic stretching and ballistic type jumping should be integrated into golf-specific warmups.

2.11 Future research

Currently a paucity of literature exists on the effects maximal power type training has on CHS and subsequent driving distance. Longitudinal research employing golf specific conditioning (i.e. in relation to movement speed, type, and loading specifics) has yet to be undertaken. Therefore, future research should investigate the influence golf specific conditioning utilizing high movement speeds and golf specific movements to establish if a causal relationship exists. During such interventions, the associated changes in muscular kinetics should be tracked using methods that are specific to golf in terms of postural set up and the contractile windows that are assessed. Additionally, as rotational movement should form the basis of golf specific conditioning, tracking of rotational ability specific to golf is warranted. Thus the development of a test that accounts for rotational specific kinematics is necessary.

Chapter Three

The reliability of isometric mid-thigh pull peak force and early impulse when utilising chain fixation.

3.1 Preface

From the review of the literature it is evident that peak force influences golf club head speed (CHS) within high CHS golfers. In addition, the ability to generate maximal force and force within specific time frames (<200 ms) is of specific relevance to these individuals. At present, the assessment of muscular kinetics is performed using isometric, iso-inertial, iso-tonic and iso-kinetic contraction modes. Previous investigations have reported force expression through an isometric mid-thigh pull to be important to CHS. The isometric mid-thigh pull (IMTP) provides a safe and easily administered measure that can be accurately performed by participants of all strength levels. In addition, both maximal force and force at specific time intervals can be assessed.

Understanding the reliability associated with the measurements utilised by the practitioner are the hallmarks of good practice, and were the focus of this chapter. This was thought particularly important as the force, rate of force development (RFD) and impulse measures of interest were occurring early in the force-time signal of the IMTP, the reliability of which had not been quantified previously. Furthermore we used a new bar fixation method using chains rather than the traditional in-rack methods, additional rationale for the reliability of the measures of interest to be established.

3.2 Introduction

The IMTP has been widely used to quantify the peak force (PF) and RFD capabilities of muscle (Khanna et al., 2010; Leary et al., 2012; McGuigan et al., 2008; Nuzzo et al., 2008; Stone et al., 2004; Stone et al., 2005). The use of isometric testing is becoming more prevalent due to the; 1) high test-retest reliability for peak force (Haff et al., 2005; Kawamori et al., 2006; Leary et al., 2012; McGuigan et al., 2010; McGuigan et al., 2008; Nuzzo et al., 2008; Stone et al., 2004; Stone et al., 2005) and RFD measures (Leary et al., 2012), 2) ease of administration and, 3) low injury risk for a maximal strength assessment (Khanna et al., 2010).

IMTP testing is typically conducted on custom made squat racks where bar height is hydraulically adjusted (Haff et al., 2005; Kawamori et al., 2006; Leary et al., 2012; Nuzzo et al., 2008; Stone et al., 2004; Stone et al., 2005) or in traditional power racks where spotting pins are manually adjusted into pre-set holes (Table 1) (McGuigan et al., 2010; McGuigan et al., 2008). The former allows the bar to be fixed to any height above the floor (Stone et al., 2004), however this equipment is often inaccessible and expensive. Conversely, the traditional power rack and pin height adjustment method depends on the structure and configuration of the power rack. Both apparatus have been shown to be reliable (Table 1) when assessing PF and peak RFD at standardised joint angles between subjects with varying anthropometrics (Leary et al., 2012; McGuigan et al., 2010; Stone et al., 2004). However, the reliability statistics used in these studies are typically intra-class correlation coefficients that provide information on relative reliability (rank order) but provide no real insight into the absolute reliability or typical error associated with a measurement.

Adjustment in bar height and therefore joint angle is an integral part of isometric testing to standardise the protocol. Thus, the apparatus used needs to be accommodating to a wide range of joint angles. At present, only the hydraulically adjusted systems allows for the aforementioned height adjustment (Leary et al., 2012; Stone et al., 2004; Stone et al., 2005), and an alternative method that yields firm bar fixation, similar adjustability, is relatively less expensive and is readily accessible is therefore warranted. With this in mind the use of chains as a means of isometric bar fixation offers potential solutions to all the aforementioned limitations, however, the reliability of such a method is unknown.

Table 5. The reliability of force variables

Author	Method	Apparatus	Variable	ICC	Result
Stone et al., (2005)	IMTP	Custom Rack with hydraulics	PF	ICC	0.99
Nuzzo et al., (2008)	IMTP	Power rack and hydraulic jacks	PF	ICC	0.98
McGuigan et al., (2010)	IMTP	Power rack with pins	PF RFD	ICC	0.96
McGuigan et al., (2008)	IMTP	Power rack with pins	PF RFD	ICC	0.96
Stone et al., (2004)	IMTP	Custom rack with hydraulics	PF PRFD	ICC	0.98 0.81
Kawamori et al., (2006)	IMTP	Custom rack with hydraulics	PF PRFD	ICC	0.97 0.96
Haff et al., (2005)	IMTP	Custom rack with hydraulics	PF PRFD	ICC	0.98 0.81
Leary et al., (2012)	IMTP	Custom rack with hydraulics	PF RFD	ICC	0.98 0.81
Haff et al., (2015)	IMTP	Custom rack with hydraulics	PF RFD time bands	ICC	0.99 0.74

The impulse, which is the magnitude of the force and the time over which that force is applied, determines the momentum of an object. This relationship is an integral part of sporting movements such as golf, weightlifting, and sprinting, where muscular force development must occur in <200 ms against a constant load (Hume et al., 2005; Leary et al., 2012; Storey et al., 2012b; Wilson et al., 1995). As such, it is possible that impulse provides a better measure of sporting performance (Aagaard et al., 2002). Additionally, impulse may provide a more reliable method of force-time analysis within pre-determined time periods (Haff et al., 2015; Thompson et al., 2012). However, currently no researchers have examined the reliability of impulse that occurs in the initial period of a muscular contraction (0-30, 0-50, 0-100, and 0-200 ms) during an IMTP.

Although force variables have previously been shown reliable when IMTP is conducted on custom apparatus and squat and pin racks, the reliability of these measures when using chain bar fixation is unknown. Isometrically quantified impulse is directly proportionate to dynamic limb velocity (Gruber et al., 2007), however impulse has not been considered as a method of early force-time analysis within IMTP literature and the test-retest reliability of early onset impulse has not been established. Given the limitations detailed previously, the purpose of this study was to establish the test-retest reliability of IMTP kinetics (i.e. PF and impulse in certain time epochs 0-30, 0-50, 0-100, 0-200ms) using the chain bar fixation method. It was hypothesised that chain fixation would be a highly customizable and reliable method for IMTP kinetic assessment and would yield similar levels of reliability to traditional IMTP assessment methods.

3.3 Methods

3.3.1 Experimental approach to the problem

Ten participants were recruited for three testing occasions separated by 3-7 days. The three data collection occasions were used to establish test-retest reliability of the protocol as represented by an intraclass correlation co-efficient (ICC), co-efficient of variation (CV) and change in the mean (CM). The participants were instructed to pull "as hard and fast" for three seconds during each trial. Three trials were performed separated by three minutes rest. The average of the three trials were used for statistical analysis. The dependent variables of interest for test-retest reliability were PF and impulse at 0-30, 0-50, 0-100 and 0-200ms.

3.3.2 Participants

Ten male participants (age; 21.8±3.2 yrs, weight; 83.0±10.3 kg, height; 180.0±5.0 cm) were recruited for this investigation. Inclusion criteria for the investigation included; 1) a resistance training history of >3 months and familiar with isometric testing, 2) were free from any acute or chronic injury and, 3) were not or had not taken any banned substances (WADA 2015). All participants signed an informed consent form prior to participation. To ensure the safety of the participants, all testing conditions were examined and approved by the Auckland University of Technology Ethics Committee (AUTEC).

3.3.3 Protocol

Each subject performed a standardized warm-up consisting of three minutes of stationary cycling, dynamic leg swings, arm swings, body weight squats, and push-ups. Following a three minute rest, participants performed three maximal IMTP attempts using a customized chain fixation method (Figure 2A, 2B). All participants attended a familiarization session prior to data collection. Vertical ground reaction force data were collected at 500 Hz using a force board (1030 x 780mm) tri-axial force plate (Objective Design Ltd. Auckland, New Zealand). Force time data was analysed using ForceBoardSW version 1.3.22 software (Sanaxis, 2012). The force plate was turned on ≥30min prior to the start of the session to allow the force plate to equilibrate to the ambient conditions within the laboratory.

Baseline values for the force traces were determined using automated baseline determination consistent with the methods of Thompson et al., (2012). A standard 10 N value above baseline was deemed to be the onset of muscular contraction. The isometric variables analysed were PF and impulse at pre-selected time bands (I30, I50, I100, I200). Peak force was classed as the highest value attained after contraction onset. Finally, impulse was determined as the area under the graph within the pre-determined time period (Storey et al., 2012b).

3.3.4 IMTP chain method:

The chain fixation method involved suspending a standard 20 kg Olympic barbell (Eleiko, Sweden) within the power rack. The bar was secured to the bottom of the rack by a series of chains (8 mm diameter, <800 kg rating) (see Figure 2C) that were attached to shackles (<400kg rating) (see Figure 2C) and rigged in a triangular formation (see Figure 2B). In addition, nylon rigging straps were hung over the top of a power rack and were attached to the sleeves of the Olympic bar. Carabineers (400 kg rating) were clipped into the chain link (see Figure 2), which allowed the bar to sit at the appropriate height (i.e. to enable participant to achieve the required 140° knee angle). The straps were tensioned via the manual ratchets and this was done to inhibit any movement of the bar. Participants were strapped to the bar and were static for three seconds before pulling "hard and fast" for three seconds. Three maximal trials were performed by all participants and three minutes rest was given between trials. Subject weight excluded the weight of the bar as it was held by external pulleys.

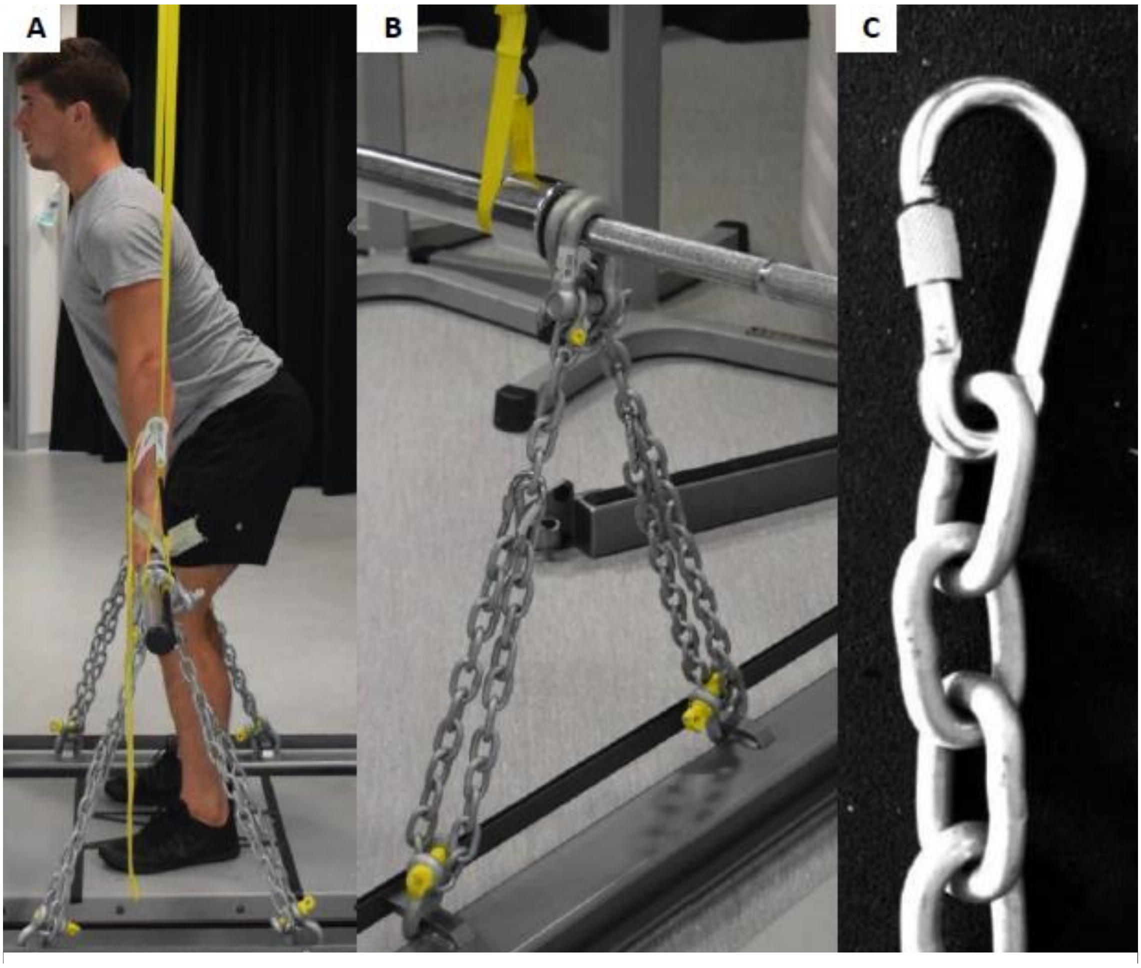


Figure 2. Chain fixation set up (2A), chain configuration (2B), chains and links (2C).

3.4 Statistical analysis

After data collection means and standard deviations were calculated for each load across each data collection occasion. The mean of three maximal trials within each data occasion was used to establish test-retest reliability. Reliability was established via three separate statistical methods; 1) the CM was reported as a percentage fluctuation in mean to establish if average performance increased or decreased across the data collection occasions, 2) the CV was reported to determine typical error as a percentage of each participants mean and, 3) ICC were reported to indicate the consistency of an athletes score in relation to the group. The current investigation set reliability thresholds of; CV ≤ 10% (Atkinson et al., 1998), ICC ≥ 0.70 (Meylan et al., 2012). All reliability data was analysed using Hopkins (2000) reliability excel spreadsheets.

3.5 Results

The results of the reliability analysis can be observed in Table 6. CM ranged from -8.37 – 3.54 %. Between days 1 – 2 mean performance decreased (CM = -3.2 – -8.37%) across all variables, however less variability was observed between days 2 – 3 (CM = -1.71 – 3.54%). CV ranged from 3.11 – 9.68%. Greater variation in CV was observed between days 1 – 2 (3.11 – 9.68%) than between days 2 – 3 (3.29 – 5.74%). ICC ranged between 0.69 – 0.98. Between days 1 – 2 observed relatively lower ICC (0.69 – 0.98) when compared to days 2 – 3 (0.85 – 0.98). These results suggest that all kinetic variables are reliable (CV ≤ 10%, ICC ≥ 0.70), however following a single testing the magnitude of reliability further increases.

Table 6. Reliability of IMTP peak force and early impulse kinetics.

	Mean ± SD			Change in the mean (%)		Coefficient of variation (%)		Intraclass correlation	
Variables	Day 1	Day 2	Day 3	Days 1 - 2	Days 2 -3	Days 1 - 2	Days 2 - 3	Days 1 -2	Days 2 - 3
IMTP PF (N)	2807±502	2724±549	2711±593	-3.82	0.72	3.11	4.02	0.98	0.98
IMTP I30 (N·s)	19.2±2.8	18.1±2.3	18.4±2.1	-7.86	3.54	5.88	3.81	0.77	0.89
IMTP I50 (N·s)	32.0±5.0	29.9±4.1	30.5±3.4	-8.37	2.61	6.91	3.29	0.71	0.91
IMTP I100 (N·s)	71.4±12.9	66.3±10.9	67.1±7.6	-8.09	0.16	9.34	4.68	0.69	0.85
IMTP I200 (N·s)	169±33	159±29	159±21	-6.17	-1.71	9.68	5.74	0.79	0.86

Key: IMTP = isometric mid-thigh pull, PF = peak force, I30 = impulse 0 - 30, I50 = impulse 0 - 50, I100 = impulse 0 - 100, I200 = impulse 0 - 200, N = Newton, N·s = Newton second.

3.6 Discussion

The underlying rationale behind this investigation was to establish the reliability of early IMTP force time kinetics and PF when employing a chain fixation method. It was hypothesised that chain fixation would be a highly customizable and reliable method for early IMTP impulse and PF and the results of this investigation confirmed our hypotheses. The primary findings of this investigation were that IMTP PF, I30, I50, I100 and I200 are reliable (CM = -8.37 – 3.54 %, CV = 3.11% - 9.68, ICC = 0.69 – 0.98) variables when assessed via the chain fixation method. In addition, the reliability of all measures (PF, I30, I50, I100, I200) increased following one testing occasion (CM = -1.71 – 3.54%, CV = 3.29% – 4.02%, ICC = 0.85 – 0.98) which indicates that a thorough familiarisation session is required prior to data collection. To the best of the author's knowledge this is the first IMTP investigation to demonstrate the reliability of impulse through a range of pre-determined early time periods (0-30, 0-50, 0-100, 0-200).

The majority of researchers studying the IMTP literature have reported PF to be highly reliable (ICC = 0.96 – 0.99) (McGuigan et al., 2010; McGuigan et al., 2008; Nuzzo et al., 2008; Stone et al., 2003; Stone et al., 2004). The current PF reliability findings (ICC = 0.98) are consistent with the aforementioned IMTP PF reliability literature. Additionally, the typical error as a CV was reported in this research giving far greater insight into the reliability of IMTP PF (CV = 3.11% – 4.02%). Previously ICC has been noted as a weak measure of reliability when reported in isolation, the inclusion of CVs add a great deal of value to understanding the stability of a measure (Atkinson et al., 1998).

Rapid force-time capabilities are important to sports performance as explosive sports have narrow contractile windows (Aagaard et al., 2002). All impulse time periods analysed in this study (I30, I50, I100, I200) were found to be reliable, in addition the reliability of impulse increased over testing occasions. Many researchers have been concerned with the reliability of IMTP RFD measures (Haff et al., 2005; Haff et al., 2015; Kawamori et al., 2006; McGuigan et al., 2010; McGuigan et al., 2008; Nuzzo et al., 2008; Stone et al., 2004; Stone et al., 2005). However, the use of impulse over pre-specified time periods may offer a solution to the concern around rapid force production. The reliability of impulse over brief time epochs for the most part remain unreported, which is surprising given the impulse-momentum relationship (f x t = m x

v) that explains the velocity of athletic movement. Given that contractile windows associated with sporting movements can be quantified and therefore improved (Aagaard et al., 2002; Leary et al., 2012; Storey et al., 2012b), we advocate that early onset impulse may be a better and more reliable measure to quantify changes in rapid force development and may have greater application to explosive movement (Baechle et al., 2008; Storey et al., 2012b). However, this contention needs to be validated via cross-sectional and longitudinal research.

Chain fixation was opted for as the method of bar fixation within the current investigation due to the bar movement observed during IMTP using the available rack and pin apparatus. The reliability of PF (CM = -3.82 – 0.72%, CV = 3.11% – 4.02%, ICC = 0.98) when chain fixation was employed is consistent with that of rack and pin (ICC = 0.96) (McGuigan et al., 2010; McGuigan et al., 2008) and custom hydraulic fixations (ICC = 0.97 – 0.99) (Haff et al., 2005; Haff et al., 2015; Kawamori et al., 2006; Leary et al., 2012; Nuzzo et al., 2008; Stone et al., 2004; Stone et al., 2005). In house investigations comparing rack and pin and chain fixations revealed no significant difference between protocols when measuring PF, however significant difference existed between early impulse measures (I30, I50, I100, I200). Therefore, methods of bar fixations should not be interchanged and need to be taken into consideration when interpreting results. There are a number of distinct advantages of chain fixation over rack and pin and custom apparatus set up; 1) the adjustability of chains is greater (<1cm) than rack and pin (dependant on manufacturer of rack), 2) bar height could be tracked via individual chain loops to give a standardised bar height between testing occasions that is referenced against a joint angle (140°) and, 3) the accessibility to chain set ups is greater than that of custom apparatus. Therefore, it can be concluded that the chain fixation method may offer an alternative assessment method as it displays a similar level of reliability to that of other more traditional methods for assessing PF and impulse.

Finally, the inter-day analysis revealed that there was improved reliability between days 2 – 3, for all measures (PF, I30, I50, I100, I200) as compared to the Day 1 – 2 analysis. These results are indicative of a learning effect taking place so it is recommended that all participants undergo a familiarisation session prior to testing. Another testing occasion would have been beneficial to observe if performance had plateaued, which would have given some insight to the quantity of familiarisation needed.

3.7 Conclusion

Isometric mid-thigh pull PF, I30, I50, I100, and I200 are reliable methods of quantifying early force time characteristics. However, 1 – 2 familiarisation sessions should be employed to increase the reliability of this method. Chain fixation offers a more flexible option of bar fixation to that of rack and pin, and is relatively more affordable than that of assessments using custom designed apparatus. In addition, the reliability of PF measures is similar between all methods of bar fixation however the different methods should not be used interchangeably. The chain method may allow for efficient testing of large groups over repeated occasions as the number of chain loops from the bar can be recorded against the referenced knee angle for each individual. The authors recommend the chain fixation method for quantifying PF and impulse at pre-determined time periods. As such the current protocol should be included in longitudinal literature to track pre to post change in early impulse and peak force characteristics.

Chapter Four

The reliability of the cable downswing load velocity spectrum

4.1 Preface

Based on examination of the literature it was concluded that a standardised rotational assessment covering both velocity and strength was absent. Previously, either fixed load ballistic type or non-specific machine based assessment have been conducted. Therefore, the purpose of this paper was to determine the cable downswing (CDS) load velocity spectrum and to quantify the CDS load velocity spectrum test-retest reliability. Specific reference to golf is employed as the current method is integrated into the proceeding chapter. Such a method allows for the assessment of golf specific rotation through high force (high load) and high velocity (low load) scenarios. Therefore, this method can be adapted into other sports specific movements that involve a rotational component.

4.2 Introduction

The ability to create rotational velocity is required for golf, racquet sports, throwing, hitting and some paddling type events. Therefore, the ability to test and monitor rotational ability is of importance to coaches and strength and conditioning practitioners who are involved with rotational type sports. Currently, the assessment of rotational ability is somewhat unstandardized and varied. Methods of rotational testing involve medicine ball throws (Gordon et al., 2009; Read, Lloyd, et al., 2013), rotational based machines (Sell et al., 2007), and seated cable rotations (Andre et al., 2012). However, such methods are restricted in their sporting application, that is, the medicine ball assessments can be sports specific but provide limited kinematic and kinetic feedback, whereas the latter two rotational methods are not sport specific but can give an abundance of kinematic and kinetic feedback. Previous researchers have suggested that physical assessments need to be specific to the primary task of interest (Keogh et al., 2009) and as such both kinematics and kinetics should mimic those required in sports performance. For the purpose of this paper, the golf swing is referred to as the primary task of interest.

Testing methods should be reliable and sensitive to changes in muscular kinetics across various loads. The reliability of rotational machine based, cable based, and medicine ball testing has previously been noted (Table 1) (Andre et al., 2012; Gordon et al., 2009). However, the latter was only shown to be reliable at low loads (3 - 6kg) with no previous researchers reporting test-retest reliability across various loads within one protocol. In addition, such investigations have employed arbitrary loads with no concise reasoning given (Gordon et al., 2009; Ikeda et al., 2007; Ikeda et al., 2009). For example, Andre et al., (2012) investigated peak power at 9%, 12% and 15% bodyweight and each respective load was deemed light, moderate, and high. However, such assumptions disregard the maximal force capabilities of the individual and anthropometric factors associated with power development (e.g. lean body mass) (Markovic et al., 2014; Pennington et al., 2010). In contrast, Keogh et al., (2009) accounted for absolute force via a predicted one repetition maximum during a golf specific cable downswing (CDS). However, peak force capacity has a hierarchical relationship to increasing velocity of movement (Cronin et al., 2001; Henricks, 2014) and therefore, maximal force may have a diminishing relationship as the force generation window of the associated sporting movement decreases (Storey et al., 2012b; Wilson et al., 1995). In addition, it is important to note that peak force is typically reached during maximal contractions lasting ≥300ms (Aagaard et al., 2002; Storey et al., 2012b) whereas a golf downswing lasts ≤230ms (Leary et al., 2012). Thus, peak force during the CDS may not be applicable to the primary sport of interest (golf). Rotational sports performance (such as golf) are dictated by the resultant velocity of an external object (i.e. golf club) with a constant mass irrespective of body weight. Therefore, we believe that the assessment of peak velocities of absolute loads through a load - velocity spectrum is more applicable for the sport of golf as it accounts for both the force and velocity capabilities of the participant relative to a constant external load.

Table 7. Reliability of rotational assessments

Author	Movement	Assessment	Load	ICC
Ikeda et al., (2009)	Side Medicine ball throw	Medicine ball velocity	2, 4, and 6kg	0.89 – 0.97
Ikeda et al., (2007)	Side Medicine ball throw	Medicine ball velocity	2, 4, and 6kg	0.89–0.95
Gordon et al., (2009)	Medicine ball rotation*	Distance thrown	3kg	0.89
Andre et al., (2012)	Seated cable rotation	Peak power	9, 12, 15% BW	0.97, 0.94, 0.95
Sell et al., (2007)	Biodex dynamometer torso rotation*	Torque at 60°/s	isokinetic	0.96 – 0.89

Key: * = included in golf specific research

During the transition from the backswing to the downswing in golf, the production of high force in the form of torque is required to overcome the rotational forces generated during the backswing. Once this transition period is complete, the production of high velocities against a low load (i.e. the typical golf club is <800 grams) is required to produce a high rotational velocity through to the point of impact (Nesbit et al., 2005). Therefore, a golf specific rotational assessment that considers both high load and low load peak velocity is warranted and further investigation is required to determine the reliability of such a load – velocity spectrum.

Interestingly, previous golf related literature has used fixed low load medicine ball throws (3kg), cable rotations and biodex machine rotational movements to gain sports specific feedback (Gordon et al., 2009; Loock et al., 2013; Read, Lloyd, et al., 2013; Sell et al., 2007; Wells et al., 2009). However, none of these test options enable any sports specific positions that are appropriate for golf loading. Furthermore, the testing loads have previously been dictated by investigator discretion and no concise reasoning has been given for these load selections (Gordon et al., 2009; Sell et al., 2007). In addition, although Keogh et al., (2009) employed a predicted one repetition maximum CDS which provided peak force specific data, no velocity data was presented. Furthermore, a rope cable attachment was employed which may have limited grip feel, grip width and therefore golf familiarity for the participants. As such, the use of a golf club specific cable attachment is warranted during the CDS movement to provide golf grip familiarity. To ascertain the participant's maximal load, Keogh et al., (2009) set technique parameters which included; 1) the maintenance of ideal golf swing mechanics and, 2) finishing with the cable rope past where impact would be during a golf swing (Keogh et al., 2009). Interestingly, the observed relationship between CDS peak force and golf club head speed (CHS) only accounted for 51% (r^2) of the variance in CHS, and no test-retest reliability was reported. In order to account for the aforementioned limitations of rotational testing, further investigation of a load - velocity spectrum integrating the CDS movement criteria as previously described by Keogh et al., (2009) is warranted. Thus, the purpose of this paper was to determine the CDS load velocity spectrum and to quantify the CDS load velocity spectrum test-retest reliability. It was hypothesized that a fixed load CDS load velocity spectrum would be a reliable method of assessing golf specific rotational ability.

4.3 Methods

4.3.1 Experimental approach to the problem

Ten participants were recruited for testing over three separate testing occasions separated by 3-7 days between testing occasions. The participants were instructed to perform a golf downswing accelerating through to impact as they would in a normal golf shot. All participants rotated forcefully down followed by a controlling rotation back to the stationary starting position. Three trials were performed at each load ranging from 1.25kg to 18.75kg. The maximal load was determined by the technique thresholds defined by Keogh et al., (2009) and golf specific technique parameters. The dependant variable for test-retest reliability was cable stack peak velocity (m/s) as measured by a linear position transducer attached to the weight stack.

4.3.2 Participants

Ten male participants (age 21.7±3.0 yrs; weight 84.6±9.8 kg; height 180.7±4.7 cm; Handicap; -0.5±0.6) were recruited for this investigation from local golf clubs. The inclusion criteria for the current investigation stated that the participants; 1) held a New Zealand Golf association handicap of <5, 2) had a resistance training history of >3 months, 3) were free from any acute or chronic injury and, 4) were not or had not taken any banned substances (WADA 2015). All participants signed an informed consent form prior to participation. To ensure the safety of the participants, all testing conditions were examined and approved by the Auckland University of Technology Ethics Committee (AUTEC).

4.3.3 Protocol

All participants reported to the AUT Millennium Institute for three testing occasions. Session 1 included the recording of descriptive data (height, weight) along with a familiarisation of the CDS protocol. Prior to the familiarisation session, all participants performed a standardized warm-up which consisted of three minutes of stationary cycling, dynamic leg swings, arm swings, push-ups lunge with a rotation, and golf swings. Following a three minute rest, participants performed 10-15 non-fatiguing cable downswings on the lightest load and all subjects had prior experience with loaded cable rotations. Following the familiarisation, data collection took place and participants were required to perform three maximal CDS at incremental loads of 2.5 kg ranging from 1.25 kg to 18.75 kg. Each trial was separated by approximately 10 seconds of stationary rest with 3 minutes rests between loads. Testing occasions one, two and three were conducted at the same time of day but were separated by a minimum of three days and a maximum of seven days. Prior to all testing occasions, the participants were instructed to maintain a normal diet and daily routine with the exclusion of stimulants 12 hours prior to testing. Vertical cable stack velocity was collected at 50 Hz via a GymAware linear position transducer (LPT) (ACT, Australia) which has previously been reported a valid and reliable method of position encoding (Youngson, 2010).

4.3.4 CDS method.

The GymAware linear position transducer was calibrated and fixed to the cable. The set-up position employed was similar to that reported by Keogh et al., (2009). The participant was positioned one meter away and slightly anterior to the cable pulley, with the body rotated 15-20° anticlockwise (right handed attempt). The cable height was set slightly above standing shoulder height; a golf grip cable attachment (Figure 3) was gripped in the same fashion as a golf club. Participants were instructed to assume a 6 iron golf posture and rotate back to a position that would mimic left arm parallel during the back swing. From this positon the participants were instructed to downswing maximally through an impact position stopping in a position where the left arm was at 4 o'clock. Consistent with the protocol of Keogh et al., (2009), golfers were instructed to maintain proper golf kinematics during the movement. Therefore, visually observed technique parameters were set which included; 1) the hips leading the movement (i.e. towards the lead foot) (Keogh et al., 2009), 2) no substantial loss in starting posture, 3) maintenance of starting stance foot position with no visual sliding of the feet (Smith, 2008) and, 4) finishing the movement with the golf grip attachment past where impact would be during a golf swing (Keogh et al., 2009). The previously defined technique parameters were set as they were associated with golf swing flaws (Smith, 2008). To ascertain the maximal load to be used for the ensuing load velocity spectrum, pilot testing revealed that 18.75 kg was observed as the technical maximum within participants of varying strength levels. During trials with loads above 18.75kg, there was substantial loss of foot position, loss of posture, and/or an inability to move the golf grip attachment to the impact position. Average velocity was obtained from the three maximal CDS at each incremental load. The correct sequence during a CDS can be observed in Figure 4.

Figure 3. Cable golf grip attachment

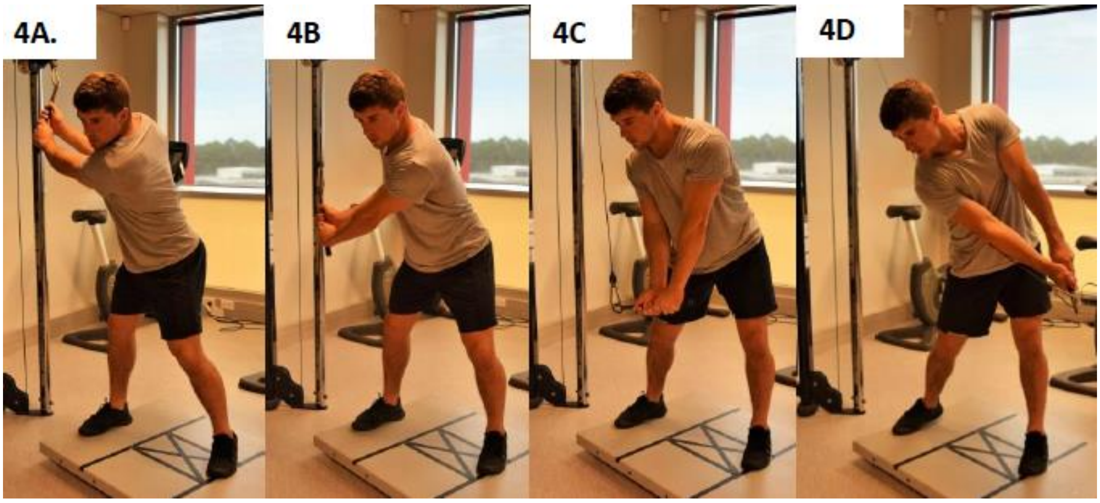


Figure 4. Correct golf cable downswing technique**.**
Start position (2A), rotated back as in golf swing. Mid-downswing (2B), hips are leading the movement. Acceleration (2C), trunk rotating through impact. Impact/just post (2D) posture and normal golf mechanics maintained

4.4 Statistical analysis

After data collection means and standard deviations were calculated for each load across each testing occasion. The mean of three maximal trials within testing occasion was used to establish test-retest reliability. Reliability was established via three separate statistical methods; 1) the change in mean (CM%) was reported as a percentage fluctuation in mean to establish if average performance increased or decreased across the data collection occasions, 2) the co-efficient of variation (CV) was reported to determine typical error as a percentage of each participants mean and, 3) intraclass correlation co-efficient (ICC) were reported to indicate the consistency of an athletes score in relation to their ranking in the group. The current investigation set reliability thresholds of; CV ≤ 10% (Atkinson et al., 1998), ICC ≥ 0.70 (Meylan et al., 2012). All reliability data was analysed using Hopkins (2000) reliability excel spreadsheets.

4.5 Results

The variables found to be reliable can be observed in table 1. Downswing velocity across all eight loads was extremely reliable (CM = -5.1 – 2.9%, CV < 10%, ICC ≥ 0.70). Change in mean of < %5.0 was observed across 15 of 16 inter session comparisons. The Day 1 – 2 1.25kg comparison was observed to have an ICC = 0.70, CV = %6.4, CM = %5.1 which was the least reliable of all loads. However, 1.25kg can still be reported as being a reliable testing load. Reliability increased with increasing trials as ICC, and CV during trials 2 – 3 increased and decreased respectively.

Table 8. Reliability of the cable downswing velocity across varying loads.

Variables	Mean ± SD			Change in the mean (%)		Coefficient of variation (%)		Intraclass correlation	
	Day 1	Day 2	Day 3	Days 1 - 2	Days 2 -3	Days 1 - 2	Days 2 - 3	Days 1 -2	Days 2 - 3
CDS 1.25kg (m/s)	2.8±0.4	2.7±0.2	2.8±0.3	-5.1	2.9	6.4	3.3	0.70	0.91
CDS 3.75kg (m/s)	2.6±0.2	2.6±0.3	2.6±0.2	-0.8	-0.5	4.1	3.7	0.88	0.92
CDS 6.25kg (m/s)	2.4±0.2	2.3±0.2	2.4±0.2	-1.3	1.8	4.4	2.4	0.83	0.97
CDS 8.75kg (m/s)	2.1±0.2	2.1±0.2	2.1±0.2	1.2	0.9	1.5	1.8	0.98	0.97
CDS 11.25kg (m/s)	1.9±0.2	1.9±0.2	1.9±0.2	0.3	1.9	2.7	2.5	0.95	0.96
CDS 13.75kg (m/s)	1.7±0.2	1.7±0.2	1.7±0.2	-2.2	1.3	3.0	2.4	0.92	0.96
CDS 16.25kg (m/s)	1.5±0.2	1.5±0.2	1.6±0.2	-1.7	1.7	3.3	1.6	0.93	0.98
CDS 18.75kg (m/s)	1.4±0.2	1.4±0.2	1.4±0.2	-0.1	-0.6	3.3	3.2	0.93	0.95

*CDS = Cable downswing, kg = kilograms, m/s = meters per second

4.6 Discussion

The purpose of this investigation was to quantify the reliability of the CDS load velocity spectrum. An acceptable level of reliability was observed across all tested loads (1.25 – 18.75kg, ICC = 0.70 – 0.97, CV = 1.5% – 6.4%, CM = -5.1% – 2.9%) (Table 8). Such findings are in agreement with previous investigations where the reliability of rotational assessments have been reported (ICC = 0.89 – 0.97) (Andre et al., 2012; Gordon et al., 2009; Ikeda et al., 2007; Ikeda et al., 2009; Sell et al., 2007). However, the ICC as a stand-alone measure has been reported as a weak measure of reliability (Atkinson et al., 1998) and therefore, this investigation was the first to report full reliability statistics within a rotational assessment (ICC, CV, CM) across various loads (Table 1). In addition, this investigation was the first to report the reliability of a golf specific rotational assessment.

Previously golf related investigations have demonstrated the importance of rotational ability where high golf swing rotational velocities have differentiated high and low CHS golfers (Brown et al., 2011; Chu et al., 2010; Okuda et al., 2010; Vena et al., 2011). Furthermore, significant correlations have been reported between rotational speed (r = 0.67) (Read, Lloyd, et al., 2013), power (r = 0.54) (Gordon et al., 2009), and strength movements (r = 0.71) (Keogh et al., 2009), and CHS. In line with these findings, Nesbit et al., (2005) demonstrated the need for golfers to exhibit high levels of rotational strength, power and speed during the golf swing. Therefore, golf specific rotational velocity assessments should include assessment of velocity at high loads (strength) through to velocity at low loads (power) as a load velocity spectrum does. Therefore, a CDS load velocity spectrum can be considered as a golf swing specific rotational assessment of downswing velocity.

Prior to this investigation, in house pilot testing revealed the upper load limit to be 18.75 kg, as greater loads resulted in substantial disruptions in golf kinematics. The aforementioned load is significantly lower than 68.9kg 1RM load that was reported by Keogh et al., (2009). This discrepancy between CDS loads may be attributed to the following; 1) the accuracy of the predicted 1RM equation used by Keogh et al. (2009) through a sequential rotational motion is unknown thus, an over estimation of the 1RM load may have occurred, 2) additional movement criteria were set in the current investigation in addition to that of Keogh et al., (2009) and, 3) different cable pulley machinery used between investigations may alter the resulting resistance and hence the kinematic and kinetic outputs, making inter-investigations comparisons problematic. Therefore, individual apparatus and participant upper limits should be established per the apparatus used in respective assessments. Furthermore, only within cohort comparisons can be made unless the methods are standardised between investigations.

Figure 5. A sequence of cable downswing and golf swing attempts to show movement similarity.

4.7 Conclusion

The current investigation has found the CDS load velocity spectrum to be a reliable method of assessing golf specific rotational ability. Therefore, the current protocol should be integrated into longitudinal golf resistance training literature as a means of quantifying pre to post change in rotational ability. When applied in a practical setting the astute strength and conditioner should establish an upper load relative to the apparatus and participant. In addition, pre to post data collection should be undertaken on the same cable apparatus. The current protocol can be adapted for various rotational movements, however, definitive and standardised movement criteria should be determined and the reliability of the assessment needs to be established as was reported in the current study.

Chapter Five

The effects of power type conditioning on club head speed and accuracy in professional male golfers: a single subject research design

5.1 Preface

The review of the literature revealed that the vast majority of golf specific resistance training programs utilised hypertrophic type training parameters and the effects of maximal power type training on club head speed (CHS), remain unknown. Furthermore, changes in muscular force capabilities have not been tracked in conjunction with CHS over the course of any intervention. Of specific relevance is the need to track changes in golf specific rotation and lower body ground reaction forces within the contractile window that are specific to the golf downswing (i.e. <200 ms). As such, this chapter aimed to provide evidence for the inclusion of power type resistance training when CHS improvement is sought. The isometric mid-thigh pull (IMTP) and cable downswing (CDS) were included as pre and post neuromuscular performance assessments as they have previously been established as reliable assessment methods (Chapter 3 and 4). In addition, driver CHS and accuracy were included as golf performance measures to answer the overarching question, "what are the effects of power type training on the CHS of professional male golfers?" In order to address this research question, a six week power type resistance training protocol was undertaken involving two male professional golfers, while tracking pre to post changes in CHS and accuracy.

4.2 Introduction

In recent years, the ability to drive the ball long and straight in professional golf has gained a lot of attention as this skill allows professional golfers to make a greater number of birdies and therefore increases their potential earnings (Fradkin et al., 2004a; PGATOUR, 2015). Driving a golf ball long and straight requires a golfer to apply high forces in short time frames to the golf club through a biomechanically efficient golf swing (Nesbit et al., 2005). This allows the driver head to collide with the golf ball at the highest velocity, with the club head "square" to the target in both path and orientation (Newell, 2001). In doing so the golfer maximizes standard launch mechanics to create maximal horizontal displacement, with low lateral dispersion (Hume et al., 2005).

Previous researchers have suggested that maximizing biomechanical factors will lead to an increase in CHS (Chu et al., 2010; Zheng et al., 2007). Such factors include an enhanced "x factor stretch" (an increasing relative orientation of the pelvis and thoracic spine during the downswing) and a delayed release of the wrists leading into impact (Brown et al., 2011; Chu et al., 2010; Hume et al., 2005; Vena et al., 2011). However, once such technical traits are mastered there are limited options for further performance improvements via enhanced kinematics. Therefore, alternative methods to improve CHS are sought which include golf specific resistance training. Popularity for resistance training grew with the rise of Tiger Woods as this form of training formed an integral part of his development (Johnson, 2007). Furthermore, squatting, pressing, pulling, ballistic and rotational type activity have shown moderate to strong correlations to CHS (Gordon et al., 2009; Hellstrom, 2008; Keogh et al., 2009; Loock et al., 2013; Read, Lloyd, et al., 2013; Wells et al., 2009). This interaction between increase in strength and increase in CHS has been supported by longitudinal research. In addition, hypertrophic (i.e. moderate intensity, slow-moderate velocity, high volume training), rehabilitative, and warm up type training protocols have been shown to increase CHS following 6-18 week long training interventions (Alvarez et al., 2012; Chen et al., 2010; Doan et al., 2006; Fletcher et al., 2004; Fradkin et al., 2004b; Hetu et al., 1998; Kim, 2010; Lephart et al., 2007; Thompson et al., 2007; Thompson et al., 2004; Weston et al., 2013).

It has previously been suggested that endurance and strength/power are independent qualities (Cronin et al., 2001). However, the majority of previous investigations have utilized endurance type protocols (1-3 sets, 10-20 repetitions) (Chen et al., 2010; Doan et al., 2006; Hetu et al., 1998; Kim, 2010; Lephart et al., 2007; Thompson et al., 2004).

This seems counterintuitive as strength and power training have been associated with increasing force producing capabilities that are likely to increase golf driver CHS (Blazevich et al., 2002a; Jones et al., 2001; Storey et al., 2012b). Such force capabilities are impulse, which is a function of force x time, and peak force (PF). Impulse is important to golf due to the angular impulse – momentum relationship. During isolated joint movements (i.e. hip extension) the equation $Tt = H (I\omega)$ applies. Where T, t, H, I and ω represent torque, time, angular momentum, moment of inertia and angular velocity, respectively (Aagaard et al., 2002). Within the golf swing the greater accumulative impulse (Tt) from all joints (torso, thoracic, shoulder girdle) before impact the greater the CHS as represented by greater angular velocity ($H = I\omega$).

Increasing force kinetics requires structured manipulation of training variables (i.e. load, intensity, volume) over a training cycle (Baechle et al., 2008). However, only one paper in the current golfing literature has made an attempt to do so, integrating a strength, power, and golf specific speed protocol to great affect within a periodised 18 week program (Alvarez et al., 2012). Although, large strength increases were observed (10-26% increase in bench press, back squat, triceps push down, and military press), poor reporting of CHS increases (i.e. club head acceleration was reported as opposed to CHS) makes conclusions on the effect of the training intervention on CHS difficult.

Due to the paucity of literature quantifying the effects of power type resistance training on golf performance, more research utilizing power type protocols is warranted. Thus, the purpose of the current study was to determine the effects of a 6-week power type conditioning protocol on rotational and lower body kinetics, CHS and driver accuracy in two professional male golfers. It was hypothesized that significant increases in muscular kinetics, CHS, and driver accuracy would be observed following six weeks of maximal power type conditioning.

5.3 Methods

5.3.1 Experimental approach to the problem

To determine the effect of maximal power type resistance exercise on golf drive CHS and accuracy in professional golfers, two professional golfers undertook a six week, three times per week periodised training intervention. Pre and post physical measures

(IMTP and CDS) and golf specific (CHS, and accuracy) results were visually analysed for trend, variability and change in level. In addition, the results were statistically analysed via the ±2 x standard deviation band method (±2SD) (post mean above/below pre mean ±2SD) to identify substantial pre to post change.

5.3.2 Participants

Two competitive male professional golfers volunteered to participate in this study. Due to the national and international travel requirements of professional golfers only two resistance trained golfers could commit to a six-week training block. Thus, the current study was adapted into a single subject research design. The mean age, mass and height of the participants were 24.5±2.1 yrs, 100.4±3.2 kg and 180.2±0.6 cm. To qualify as resistance trained, participants must have completed two or more resistance based sessions per week for the past six months. All participants had appropriate joint mobility (determined through over-head snatch squat technique) to allow them to safely perform the prescribed Olympic lifting movements. Each subject had the risks of the investigation explained prior to signing the informed consent form. All procedures and protocols were approved by the Auckland University of Technology Human Subject Ethics Committee.

Both participants exhibited proper swing mechanics, as per the methods of Smith (2008) and Newell (2001). This was important for the purpose of this investigation as it decreased the possibility for changes in CHS being attributable to improvements in swing mechanics.

5.3.3 Equipment

Participants performed three separate tests; 1) golf drive ability on radar, 2) cable down swing (CDS) with a linear position transducer (LPT) and, 3) isometric mid-thigh pull (IMTP) on force plate.

1) Golf drive ability

Participants hit 5 golf balls down a 300 meter long driving range. A Trackman (Trackman, Denmark) doplar radar was positioned three meters posterior to the golf ball in line with the intended target line. Artificial astro turf was used as the surface on which participants hit the golf balls from. Participants used their own driver to avoid unfamiliarity with changing equipment and changes in CHS associated with the structural properties (i.e. stiffness, weight and length) of the golf club (ICC = 0.88) (Keogh et al., 2009).

2) Cable down swing (CDS):

A cable cross over machine (LifeFitness, USA) with adjustable pulleys was used for the CDS. A custom made cable attachment was used which consisted of a custom steel handle with a standard diameter golf grip fixed onto it (refer to Figure 6). A Celesco PT5a linear positional transducer (LPT) (Chatsworth, USA) was fixed to the cable stack.

Figure 6. Cable golf grip attachment.

3) Isometric mid-thigh pull:

An IMTP was performed in a chain system that allowed an Olympic barbell to be fixed to any height. A force plate (Objective Design Ltd. Auckland, New Zealand) was placed within the squat rack where the participants stood.

5.3.4 Testing procedures

Participants were involved in an IMTP and CDS familiarization session three days prior to the first testing occasion as the reliability of early impulse was previously shown to increase proceeding a familiarisation session (refer to Chapters 3 and 4). Within this session a full introduction to all assessments was given. Pre intervention anthropometric baseline data and pre and post intervention physical (IMTP and CDS) baselines were established at the same time of day over three separate testing occasions that were separated by three days (Figure 7). On all occasions, both participants were instructed to follow their normal daily nutritional routine and they arrived at the testing facility in a fed and rested state following a 24 hour break from exercise. A five-minute rest was given to participants between testing protocols.

Finally, golf driver CHS and accuracy data was collected at the same time of day over two separate occasions separated by three days. Two sessions were deemed appropriate due to the level of experience (elite) of the participants and the low SD observed over 2 sessions.

Day	1	2	3	4	5	6	7	8	9	10
Physical testing	■				■				■	
Golf testing				■				■		

Figure 7. Schedule of events**.**

Key: Physical testing involved IMTP and CDS. Golf testing involved CHS and accuracy measures

5.3.4.1 Anthropometric data

Only standard descriptive anthropometrics were gathered for the purpose of this investigation. Body mass was determined to the nearest 0.01kg using a calibrated electronic scale. Stature was measured to the nearest 0.1cm using a stadiometer fixed to a wall.

5.3.4.2 Pre-testing warmup

All participants were required to perform a standardized warm up consisting of 5 minutes of light cardiovascular exercise followed by dynamic stretching. Dynamic stretching included leg swings (medial-lateral, anterior-posterior), arm flexion-extensions, horizontal ab/adductions, body weight squats, and oblique plane trunk rotations. Additionally, preceding the golf drive performance testing, participants were allowed to hit 15-20 5 irons or drivers at a submaximal exertion.

5.3.4.3 Golf testing

Club head speed was determined using Trackman Radar which is specifically designed for golf use. Previous researchers have stated the validity and reliability of radar swing and launch characteristic analysis (ICC = 0.97) (Loock et al., 2012; Thompson et al., 2007). Following the standardized pre testing warm up, participants were given 5 minutes of passive rest. Participants were then given 10 practice golf shots using the Trackman with their own driver. Following the completion of the practice swings participants rested a further 3 minutes before completing 5 maximal attempts for accuracy and distance. Participants aimed at a target that the Trackman radar was aligned to via a camera within the Trackman that projects the surroundings through the Trackman software (Trackman, 2014). Trackman is a Doplar radar that tracks golf club and ball flight characteristics in 3D (Trackman, 2013). During all trials an experienced golfer observed each swing to assess technical proficiency. Further trials were given when a participant acutely exhibited poor technical mechanics until 5 reliable trials were completed as reported in previous investigations (Fletcher et al., 2004; Thompson et al., 2004). An average of the five trials was used for analysis.

5.3.4.4 Isometric force time analysis

Force time curves were analysed using ForceBoardSW version 1.3.22 software during IMTP. Force time baselines were determined using automated baseline determination consistent with the methods of Thompson et al., (2012). The isometric variables analysed were IMTP PF and IMTP impulse at 0-30 (I30), 0-50 (I50), 0-100 (I100), and 0-200 (I200). The reliability of IMTP chain PF (ICC = 0.98, CV = 4.02%, CM = -3.82 – 0.72%) and early impulse at pre-determined time periods have previously been noted (ICC = 0.85 – 0.91, CV = 3.29% – 5.74%, CM = -8.37 – 3.54%)

5.3.4.5 IMTP testing

The IMTP was employed as a neuromuscular assessment as the mid-thigh pull position (140° knee angle as assessed via a goniometer) is consistent with joint angles experienced during downswing where peak ground reaction forces occur (Haff et al., 2015; McNitt-Gray et al., 2013; Meister et al., 2011). For the purposes of the IMTP protocols, the bar height restriction was set at a position that allowed the participants to achieve the recommended 140° knee angle. The bar was secured to the bottom of the rack by a series of chains (<1000kg rating) that were attached to shackles (<400 kg rating) and rigged in a triangular formation. In addition, nylon rigging straps were hung over the top of a power rack and were attached to the sleeves of the Olympic bar. Carabineers (400 kg rating) were clipped into the chain link, which allowed the bar to sit at the appropriate height (i.e. to enable participant to achieve the required 140° knee angle). The straps were then maximally tensioned via the manual ratchets and this was done to mitigate any movement of the bar. Participants were strapped to the bar (see Figure 8) and were static for three seconds before pulling “hard and fast” for three seconds. Three maximal trials were performed by all participants and three minutes rest was given between trials. An average of the three trials was used for analysis. Subject weight excluded the weight of the bar as it was held by external pulleys.

Figure 8. Method used to strap participants to the bar during IMTP.

5.3.4.6 Cable downswing testing

An LPT (Chatsworth, USA) was fixed and calibrated to a commercial gym cable stack in a similar fashion to the set-up position used by Keogh et al., (2009). The subject was positioned one meter away and slightly anterior to the cable pulley, with the body rotated 15-20° anti-clockwise (right handed attempt). The cable height was set slightly above standing shoulder height and a golf grip cable attachment was attached to the cable stack (Figure 6). Subjects were instructed to assume a 6 iron golf posture and rotate back to a position that would mimic a left arm parallel position during the back swing. From this positon the subject was instructed to perform a maximal downswing through an impact position (i.e. left arm perpendicular to floor) stopping in a position where the left arm was at approximately 4 o’clock. Instructions to lead with the hips and maintain proper golf swing mechanics were given throughout (Keogh et al., 2009). A load velocity spectrum was established pre and post and the assessed loads were 1.25, 3.75, 6.25, 8.75, 11.25, 13.75, 16.25 and 18.75kg. To ascertain the maximal load to be used for the ensuing load velocity spectrum, pilot testing revealed that 18.75 kg was observed as the technical maximum within participants of varying strength levels.

During trials with loads above 18.75kg, there was substantial loss of foot position, loss of posture, and/or an inability to move the golf grip attachment to the impact position. An average of three attempts at each load was used for analysis. The test retest reliability of the CDS velocity load spectrum was previously established (ICC = 0.91 – 0.98, CV = 1.6% – 3.7%, CM = -5.1 – 2.9%). The reliability was observed to increase with increasing trials therefore, a full familiarisation session as employed in the current intervention was undertaken.

5.3.4.8 Conditioning protocol

A specific golf conditioning program was implemented through the 2014 New Zealand Professional Golf Association competitive season (November – December). Prior to undertaking the program, both subjects were involved in a one-week Olympic weightlifting technique program consisting of power snatch specific coaching from an experienced Olympic lifting coach. During the course of the intervention (familiarization and testing to post-testing), participants were instructed to maintain their current golf practice and tournament schedule. Participants were instructed to refrain from all other forms of resistance training or cardiovascular training that may have influenced the results. During the six-week intervention subjects were informed about hydration and nutritional requirements however, no specific dietary plans were given. All resistance sessions were supervised by the lead researcher with specific attention given to correct exercise technique. Technical feedback was given by way of video and knowledge of performance. In addition, motivation was given to move the loads as fast as possible throughout each training session.

5.3.4.9 Program structure

Both participants completed three supervised power-type resistance training sessions per week. The sessions included hang power snatch, bench throw, bench pull, push press, and seated barbell (BB) rotation or medicine ball (MB) ballistic rotation. The bench throw was performed on a standard bench press set in a squat rack with spotting bars level with the chest. Subjects lowered the weight to the chest before ballistically pressing the bar up in an attempt to “throw” the bar. Spotters were used to guide the bar back to the hands once it had been released in preparation for the next repetition.

Exercise order was kept constant throughout. However, following week two the seated BB rotation was replaced with a MB ballistic rotation. Lower back injury occurrence has been attributed to poor recruitment of abdominal musculature at velocity (Horton et al., 2001), thus the first two weeks of relatively low velocity BB training was implemented to ready the participants core musculature for the higher velocity MB loading (Cabri et al., 2009; Newton, 2007; Thompson et al., 2007). Repetitions, sets, loading, and rests are noted in Table 8. Such loading schemes allowed all exercises to be performed in an explosive manner. Snatch loads were set at 60% of predicted back squat maximum. However, the degree of technical mastery was the major criteria. All other loads were prescribed as a percentage of predicted one repetition maximum (RM); both participants had completed a three to five repetition maximum for bench press, squat, and push press within the previous three weeks.

Within a training week (3 days), intensity was cycled to allow for a changing load stimulus. Furthermore, weeks one to five were structured moderate, light, and heavy within a week. Light days were categorized by submaximal intensity which corresponded with snatch loads of 75-90% RM and upper body press and pull loads of 35-50% RM. Moderate days corresponded with loads of 85-95% RM and 45-55% RM for the snatch and upper body press and pulling exercises, respectively. Finally, heavy days worked up to maximal or near maximal intensity (85-100%) when snatching and 45-60% RM when upper body pressing and pulling. Changes in programmed % RM influenced total training volume (sets x repetitions x load). Due to the influence on % RM on training volume, fluctuations in daily volume were present. A light day was given on training day 2 which enabled the participants to maximize the two heavier sessions (sessions 1 and 3) due to lower residual fatigue from day 2. In conjunction to daily fluctuations in training volume, weekly fluctuations were also implemented. Weeks 1 – 6 were categorized and structured as light, moderate, heavy, light, heavy, light (Table 8). Training days 1-3 were separated by one day of rest; training weeks were separated by two days of rest.

Table 9. Program periodisation, sets, repetitions and loads

	Week 1			**Week 2**			**Week 3**			**Week 4**			**Week 5**			**Week 6**		
Day	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Snatch (%RM)	85	75	85	85	75	90	90	85	95	85	75	85	95	90	100	80	75	70
Bench throw (% RM)	45	35	45	45	35	50	50	45	55	45	35	45	55	50	60	40	35	30
Bench pull (% RM)	45	35	45	45	35	50	50	45	55	45	35	45	55	50	60	40	35	30
Push press (% RM)	45	35	45	45	35	50	50	45	55	45	35	45	55	50	60	40	35	30
Seated BB rotation (kg)	20	20	20	30	30	30												
Ballistic MB rotation (kg)							6	6	6	5	5	5	10	10	10	6	6	6
Repetitions	4	4	4	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2
Sets		4			5-6			5-6			3-4			4-5			3-4	
Rest period (mins)		2-3			2-3			2-3			2-3			2-3			2-3	

5.4 Data analysis

All statistical analysis was performed in Microsoft Excel (Microsoft, 2010). Standard descriptive statistics (mean and standard deviation) for both participants were collated (height, age, and weight). Golf specific CHS was reported via direct measurement of actual club head velocity (mph) via a Trackman (Trackman, Denmark) doplar radar. Lateral dispersion (accuracy) was calculated as lateral displacement of the golf ball with reference to a straight line between ball and intended target. Left (negative values) and right (positive values) were reported in meters (m), where straight drives are equal to zero. The data for each golf-specific testing occasion was an average of 5 trials.

Raw force time data was transferred to a pre-programmed excel spreadsheet to automatically calculate contraction onset (average of 230 pre contraction samples + 10 N). Automated onset has previously been stated as the optimal method of contraction onset determination (Thompson et al., 2012). Peak force was determined as the highest N value obtained proceeding contraction onset (3 seconds). Impulse was calculated over pre-determined time bands (0-30, 0-50, 0-100, 0-200). Each data point for both IMTP and CDS was an average of three maximal trials.

5.5 Statistical analysis

Traditional longitudinal research typically relies on t-tests and ANOVAs to establish statistically significant change in means. Both methods produce P values that lead the researcher to establish if a likely change or training effect has occurred following the longitudinal training interventions. However, the preferred method for single subject research is mixed statistical and visual analyses where researchers are concerned with determining the change (Kromrey et al., 1996). Previous reports have argued that visual analysis methods are insensitive to small changes and that a more quantitative method should be employed. However, others have stated that single subject research design should only be concerned with large, visually recognized changes as these may be more applicable to practitioners (Nourbakhsh et al., 1994). Single subject statistical analysis methods include; split method of trend estimation, the C statistic, and the two band standard deviation (SD) method. It has been suggested there are large variations in results between methods of analysis (Nourbakhsh et al., 1994). For the purpose of this investigation the two band SD method was chosen due to its agreement to the C statistic and split method of trend estimation (Nourbakhsh et al., 1994). This method allows for ease of data interpretation as numerical changes are tracked via graphing with clear set rules to establish substantial change. Two bands are shown on the graph; upper and lower bands are calculated by pre mean ± 2SD. A substantial change is noted when post-test data points on the graph fall outside either band and these changes are further strengthened when consecutive or numerous data points fall outside the SD lines. Figure 8 provides an example of further visual analysis undertaken when substantial changes were not achieved.

In addition to the visual analysis, the mean pre (mean of three data points) to post (mean of three data points) changes are provided (raw and % change). Thus, a statistical representation of change is quantified. However, as visual analysis is primarily concerned with large visually observed change (Nourbakhsh et al., 1994), only measures that exceed the ±2SD threshold are of primary importance (listed in red). Therefore, when analysing and interpreting the complete data set, conclusions should be based on ±2SD graph observations as misrepresentation of data points can exist when interpretation is based solely on numerical tabulated data.

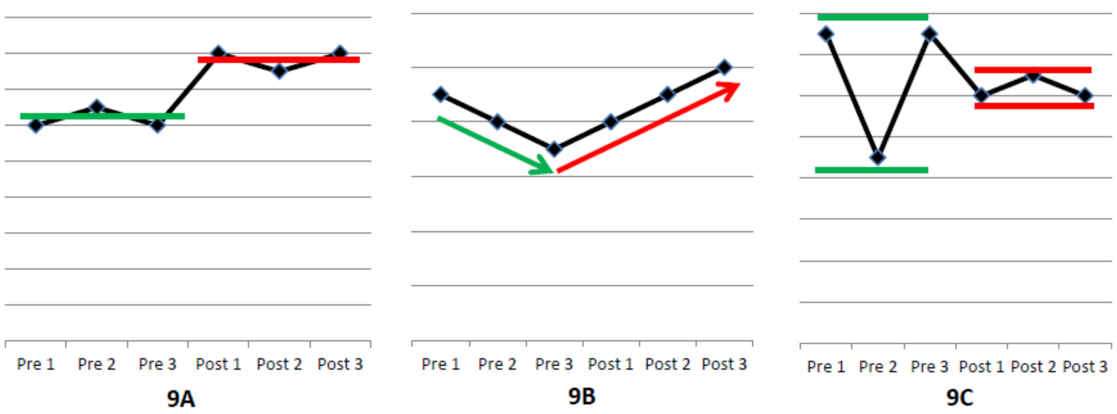


Figure 9. Visual statistical analysis.

Adapted from Backman et al., (1997). **Change in Level (9A):** Post testing mean (red) appears to be clearly higher than pre testing values (green), therefore a change in level exists. **Change in trend (9B):** A change in trend exists when post testing (red) data opposes the pre testing (green) trend. **Change in variability (9C):** A change in variability exists when post testing data points (red) appear to have less/more dispersion than pre testing (green).

5.6 Results

5.6.1 Driver CHS and Accuracy

Participant one

Visual analysis revealed no change in trend, level or variability for CHS. However, a decrease in variability of accuracy was observed. The 3.1% increase in CHS exceeded the ±2SD threshold thus a substantial increase in CHS was noted. In addition, a change in accuracy was reported where subject one tended to land the golf ball closer to the target (pre = 7.76 m, post = -2.69 m) line following the training intervention.

Participant two

Visual analysis revealed no change in variability, however a change in CHS level was noted. Furthermore, accuracy improved and trended towards 0. Both CHS post testing data points exceeded the ±2SD threshold resulting in an increase in CHS of 3.9%. Accuracy trended towards straighter drives as the ball finished on average close to the target line (pre 11.24 m, post = 7.92 m).

Table 10. Mean pre to post club head speed and accuracy change

Participant One				
	Pre	**Post**	**Raw change**	**% change**
CHS (mph)	114±1.5	117±1.3	3.6	3.1%
Side (m)	7.76±12.5	-2.69±16.3	-10.4	
Participant Two				
	Pre	**Post**	**Raw change**	**% change**
CHS (mph)	103±0.94	107±1.02	4.2	3.9%
Side (m)	11.24±14.6	7.92±19.0	-3.3	

Red = substantial change </> mean ±2SD as determined via the statistical analysis method.

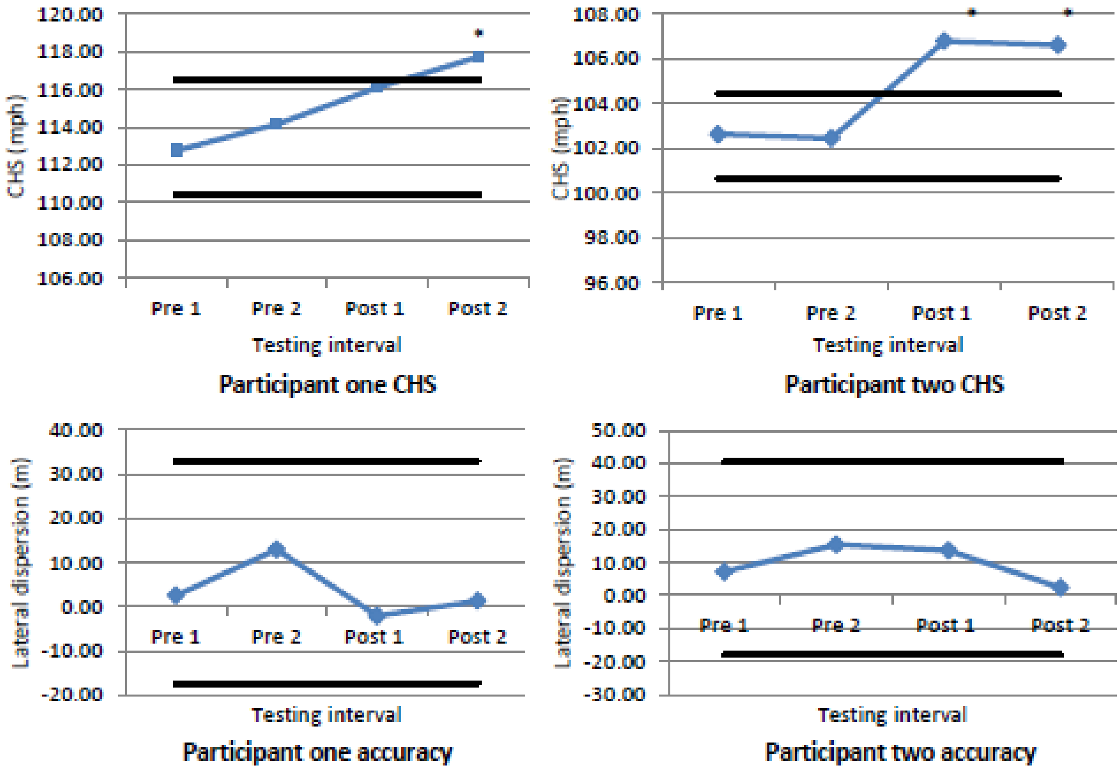


Figure 10. Participant driver launch characteristics pre to post.

* = substantial change observed

5.6.2 IMTP PF

Participant one

No change in level, variability or trend was visually observed. Furthermore, no data points exceeded the ±2SD threshold and no mean percentage change occurred.

Participant two

No change in variability or level was visually observed, however a trend towards increases PF was observed. No data points exceeded the ±2SD threshold however a mean increase of 2.7% was reported.

Table 11. Mean pre to post IMTP PF change

	Pre	Post	Raw change	% change
Participant One				
	Pre	**Post**	**Raw change**	**% change**
IMTP PF (N)	3533±79	3533±89	-0.1	0.0%
Participant Two				
	Pre	**Post**	**Raw change**	**% change**
IMTP PF (N)	2812±82	2892±59.1	79.3	2.7%

Red = substantial change </> mean ±2SD as determined via the visual analysis method.

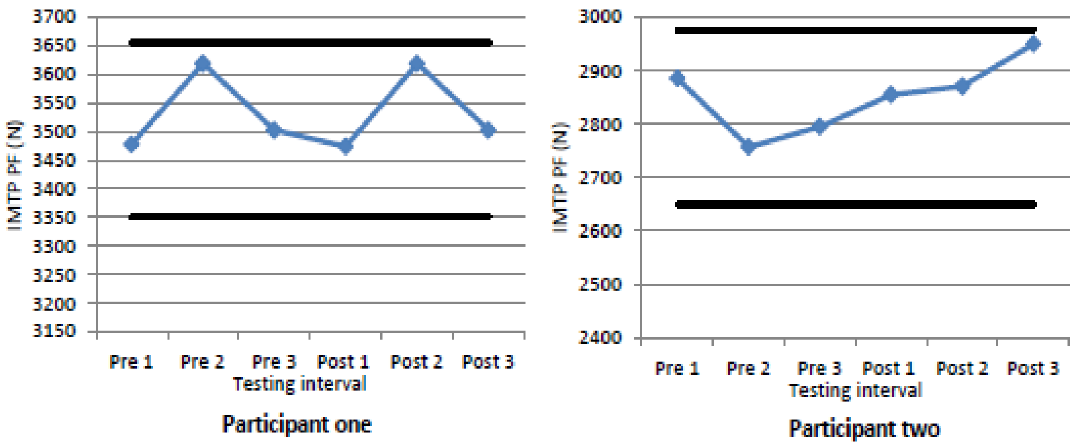


Figure 11. IMTP PF pre to post change.

* = Substantial change observed.

5.6.3 IMTP Impulse

Participant one

Visual analysis revealed an increase in variability and therefore any change in the level observed is likely due to the increased variability. Only one of the post testing occasions exceeded the ±2SD threshold. However, the increased variability makes any changes observed equivocal. Changes ranged from - 8.81 to 6.87%, with the positive changes associated with early time brackets (I30, I50).

Participant two

Visual analysis revealed no changes in trend, level, but a slight decrease in variability. No data points exceeded the ±2SD threshold, in addition changes ranged from -2.3 to -8.1%. However, such change is associated with the decrease in variability.

Table 12. Mean pre to post IMTP impulse changes

Participant One				
	Pre	**Post**	**Raw change**	**% change**
IMTP I30 (N·s)	20.6±1.1	22.2±2.1	1.5	6.87%
IMTP I50 (N·s)	34.3±2.2	36.6±4.6	2.3	6.17%
IMTP I100 (N·s)	78.9±6.8	78.6±14	-0.3	-0.36%
IMTP I200 (N·s)	197±15.7	181±35	-15.9	-8.81%
Participant Two				
	Pre	**Post**	**Raw change**	**% change**
IMTP I30 (N·s)	20.2±2.4	18.7±1.5	-1.5	-8.1%
IMTP I50 (N·s)	33.7±4.1	32.0±2.5	-1.7	-5.3%
IMTP I100 (N·s)	75.0±9.9	73.2±5.0	-1.8	-2.4%
IMTP I200 (N·s)	175±18.2	171±9	-4.0	-2.3%

Red = substantial change </> mean ±2SD as determined via the visual analysis method.

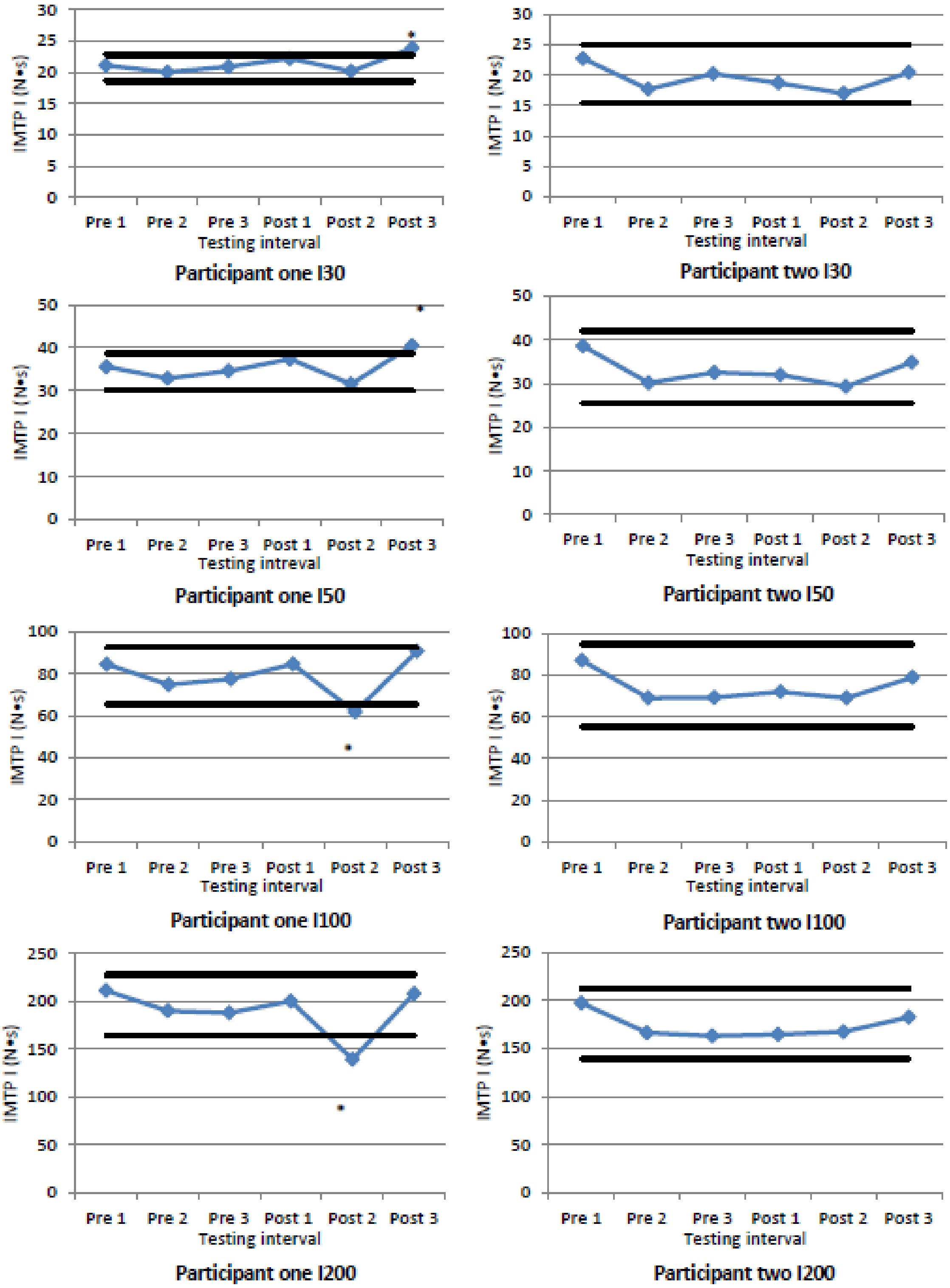


Figure 12. IMTP Impulse pre to post change (N·s).

* = substantial change observed.

5.6.4 CDS load spectrum

Participant one

No change in variability or trend was observed. However a clear change in level across the majority of loads was visually observed. All CDS loads exceeded the ±2SD threshold thus substantial change is noted. 5.2% - 20.1% increases in CDS velocity were reported with the greatest change associated with lighter loads.

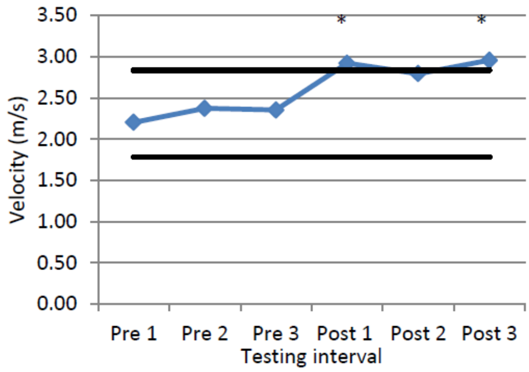
Participant two

No change in variability or trend was observed, however a change in level across all loads was visually observed. All CDS loads exceeded the ±2SD threshold. Increase in CDS velocity ranged from 14.0% – 17.6%.

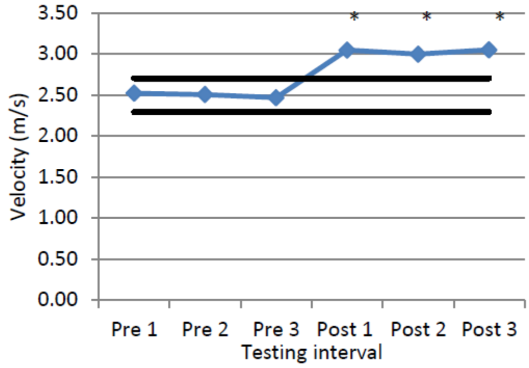
Table 13. Mean pre to post CDS velocity change

	Pre	**Post**	**Raw change**	**% change**
Participant one				
CDS 1.25kg (m/s)	2.31±0.26	2.89±0.11	0.58	20.1%
CDS 3.75kg (m/s)	2.28±0.15	2.63±0.08	0.35	13.2%
CDS 6.25kg (m/s)	2.16±0.06	2.41±0.10	0.25	10.5%
CDS 8.75kg (m/s)	1.94±0.11	2.18±0.05	0.25	11.3%
CDS 11.25kg (m/s)	1.81±0.06	2.02±0.06	0.21	10.3%
CDS 13.75kg (m/s)	1.66±0.06	1.81±0.07	0.16	8.6%
CDS 16.25kg (m/s)	1.53±0.05	1.66±0.03	0.12	7.4%
CDS 18.75kg (m/s)	1.45±0.04	1.53±0.06	0.08	5.2%
Participant two				
	Pre	**Post**	**Raw change**	**% change**
CDS 1.25kg (m/s)	2.50±0.10	3.03±0.06	0.53	17.6%
CDS 3.75kg (m/s)	2.25±0.13	2.69±0.07	0.43	16.1%
CDS 6.25kg (m/s)	2.06±0.06	2.39±0.04	0.33	14.0%
CDS 8.75kg (m/s)	1.86±0.06	2.17±0.05	0.31	14.3%
CDS 11.25kg (m/s)	1.68±0.04	1.97±0.06	0.30	15.0%
CDS 13.75kg (m/s)	1.51±0.06	1.80±0.04	0.28	15.8%
CDS 16.25kg (m/s)	1.40±0.05	1.63±0.04	0.24	14.5%
CDS 18.75kg (m/s)	1.28±0.06	1.49±0.06	0.21	14.1%

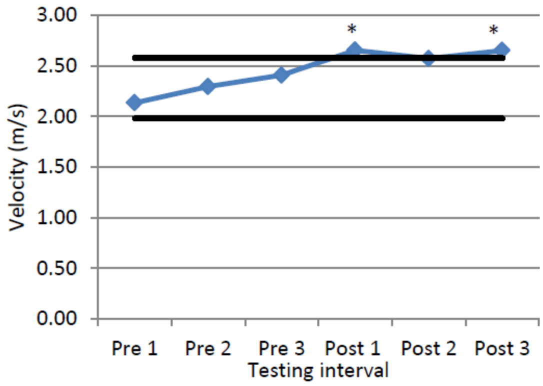
Red = substantial change </> mean ±2SD as determined via the visual analysis method.



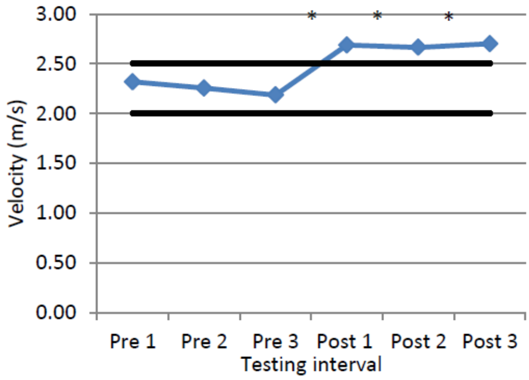
Participant one CDS 1.25kg



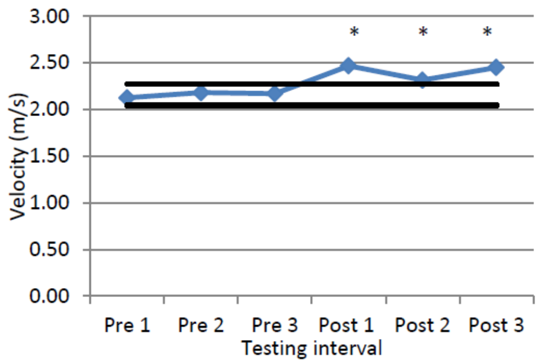
Participant two CDS 1.25kg



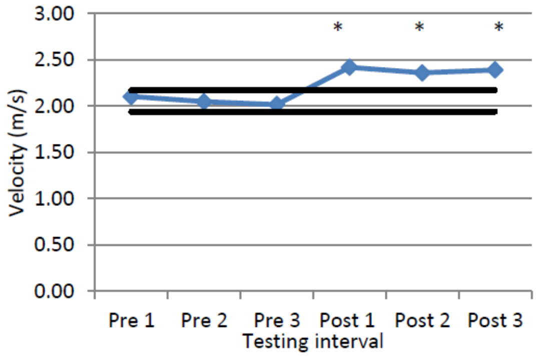
Participant one CDS 3.75kg



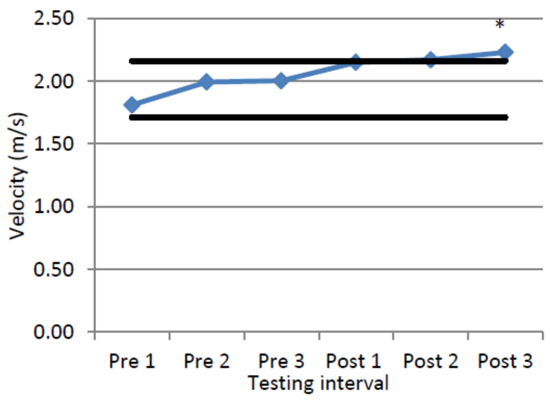
Participant two CDS 3.75kg



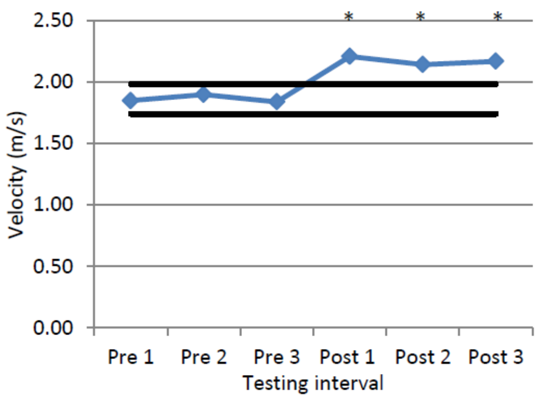
Participant one CDS 6.25kg



Participant two CDS 6.25kg



Participant one CDS 8.75kg



Participant two CDS 8.75kg

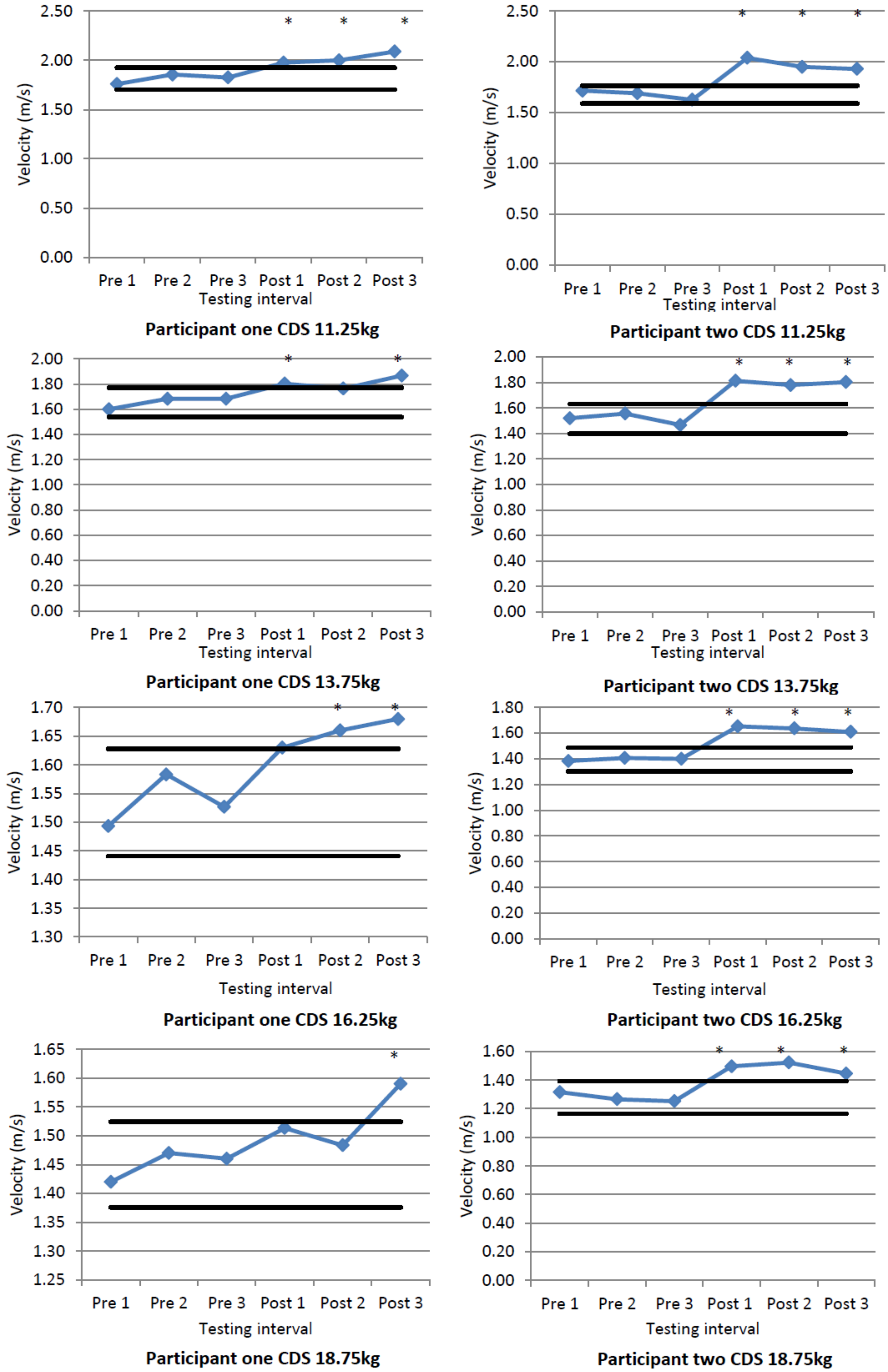


Figure 13. CDS velocity pre to post change (m/s).

* = Substantial change observed

5.7 Discussion

The major finding of this study was that CHS substantially increased following a 6 week maximal power training protocol; a percentage change of 3.1% and 3.9% was observed from participants one and two, respectively. Furthermore, substantial increases in CDS velocity also occurred (participant one = 5.2% – 20.1%, participant two = 14.0% - 17.6%). To our knowledge this is the first paper to investigate the effects of maximal power type training on golf CHS. Furthermore, it is the first to assess kinetic changes in the muscular ability of professional golfers in both an isometric fashion and through a sports specific load-velocity spectrum. Thus, the findings of our research add to the current body of golf literature providing evidence for the inclusion of power based resistance protocols in golf conditioning.

5.7.1 Changes in launch and distance characteristics

The IMTP was chosen as the preferred non-specific force measure within the current investigation as the safety and reliability of isometric testing has previously been noted (Ignjatovic et al., 2009). In addition, the mid-thigh pull position (140° knee angle) is consistent with the joint angles during downswing where peak ground reaction forces occur (Haff et al., 2015; McNitt-Gray et al., 2013; Meister et al., 2011). Furthermore, the associated kinetics can be tracked in time periods that correspond with the downswing which makes this assessment highly relevant to golf (Leary et al., 2012).

Time periods of 0-30, 0-50, 0-100, and 0-200 were used for the IMTP impulse analysis as Leary et al., (2012) reported force time measures <250ms to be optimal when analysing golf force generating capacity through the IMTP. Furthermore, as high CHS golfers can apply greater force rapidly, impulse measures beyond 200ms were deemed not applicable for the calibre of participants in our study (Meister et al., 2011).

As previously mentioned, impulse is important to CHS due to the impulse – momentum relationship. Within the golf swing the greater accumulative impulse from all joints (i.e. torso, thoracic, shoulder girdle) within the downswing until impact, the greater the momentum of the club head (Aagaard et al., 2002; Callaway et al., 2012; Chu et al., 2010; Okuda et al., 2010; Zheng et al., 2007).

However, as there were no substantial changes in impulse it would seem that the impulse as measured by the IMTP explained little of the variance associated with the increase in CHS. That is, 6 weeks of power training had little influence on IMTP and any change in performance are unlikely due to the isometric measures assessed in this study. It is likely that the lack of change in lower body maximal force expression was due to the high-power, whole-body nature of the training stimulus. Previous researchers have shown that the lower body works predominantly in the first phase of the downswing (Burden et al., 1998; McHardy et al., 2005; Nesbit et al., 2005), where lower body (hip, knee) extension creates hip rotation that elicits X factor stretch through the trunk (Burden et al., 1998; Leary et al., 2012; Nesbit et al., 2005). However, the current findings reveal increases in CHS can occur with no change in lower body force expression.

Rotational specificity in golf has shown moderate to strong correlations to CHS (Keogh et al., 2009; Read, Lloyd, et al., 2013). Furthermore, all longitudinal data to report significant increases in CHS have included ballistic medicine ball rotations or high velocity golf swings (Doan et al., 2006; Fletcher et al., 2004; Hetu et al., 1998; Thompson et al., 2007). However, only one longitudinal study has employed rotational protocols in conjunction with tracking changes in rotational ability (Lephart et al., 2007). The current study reported substantial increases in velocities across a full load – velocity spectrum during a CDS (1.25kg to 18.75kg) in conjunction with increased CHS. It is likely that such a movement has the greatest cross over to CHS due to the biomechanical similarities to the sporting movement in question. Previous reports have alluded to ballistic medicine ball and CDS rotations being more beneficial to CHS increases, when compared to more traditional strength movements (squat, bench press) (Earp et al., 2010; Keogh et al., 2009) and the findings of this study certainly support such a contention. Low load barbell and moderate load medicine ball rotation exercises (i.e. 5-10 kg) were used through the training period. The current study observed changes through all CDS loads (1.25 – 18.75kg) and the changes in high load (CDS 18.75kg) velocity were unexpected as previous researchers have suggested a load-velocity specific adaptation exists (Jones et al., 2001). However, such findings are not uncommon in trained participants and it appears that the intent to move the load a fast as possible can influence force – velocity adaptation (Blazevich et al., 2002b).

Similar improvements in CHS have been noted in previous papers (Hetu et al., 1998; Kim, 2010; Lephart et al., 2007; Thompson et al., 2007; Weston et al., 2013). However, none of which have had participants with starting CHS above 45 m/s. Elite athletes have smaller “windows of adaptation” as their ability is closer to their genetic potential

(Newton et al., 2002). Professional golfers (as in the current investigation) exhibiting high swing speeds (>45 m/s) are viewed as elite thus their window to improve CHS is thought low. Lamberth et al., (2013), Fletcher et al., (2004) and Doan et al., (2006) all recruited participants with CHS velocities greater than 45 m/s. However, these previous investigations reported significant CHS increases of 0.76m/s, 0.75m/s and non-significant decrease of 1.96 m/s over 6, 8, and 11 weeks, respectively, following low velocity, hypertrophic type conditioning. In contrast, the current study noted substantial 0.93m/s, and 1.49 m/s increases over a 6-week training period, when movement velocity was high, repetitions low, and loading was moderate – heavy (35 – 100% RM). Participants who exhibit high CHS are likely to need very specific stimuli to generate further increases in CHS. Such stimuli should target specific kinetics (PF, impulse and velocity) and kinematics that have evidential support for greater CHS improvement (Alvarez et al., 2012; Leary et al., 2012; Okuda et al., 2010; Zheng et al., 2007).

To the authors knowledge no other interventional paper had previously reported changes in accuracy which is another novel aspect of our investigation. Interestingly, accuracy trended towards improvements as variability decreased which indicated that the participants were able to hit the ball with greater consistency. Increased accuracy is of particular importance to golf professionals as long, accurate drives decrease the remaining distance to the hole which increase birdie chances and the corresponding earning potential of the player (PGATOUR, 2015).

5.7.2 Changes in IMTP kinetics

We can only speculate as to why substantial increases in IMTP PF and IMTP impulse were not observed in the current study. As previously mentioned, it is likely that the lack of change in lower body maximal force expression was due to the high-power, whole-body nature of the training stimulus. With regard to increases in IMTP impulse, it is likely that the skill of weightlifting is too complex to teach in 7 weeks (1 week introductory period followed by a 6 week intervention) thus reducing any muscular force adaptation as measured by the IMTP. Suchomel et al., (2015) suggested the use of weightlifting pulling derivatives (e.g. snatch pull, clean pull, jump shrug) for sports conditioning as they display the same kinetics and triple extension as traditional full movements but are less complex. Such movements may have yielded greater muscular adaptation in the current study leading to more conclusive increases in both early and late impulse (Aagaard et al., 2002).

With regards to IMTP PF, it is possible that the volume and intensity of the current protocol was relatively low to what was normally experienced by the participants, therefore, increases in IMTP PF were not observed (Rhea et al., 2003). Although previous investigations have reported greater increases in 1RM (PF) performance, the subjects in these investigations were relatively untrained compared to our participant cohort which is likely to have contributed to the greater strength gains reported by previous authors (Alvarez et al., 2012; Hetu et al., 1998; Lamberth et al., 2013; Rhea et al., 2003). Finally, it is possible that the use of a maximal isometric testing measure failed to detect any significant increases in dynamic lower body PF producing ability. Although the use of a maximal dynamic test (e.g. 1RM back squat) may have detected changes in dynamic strength, a key focus of our investigation was to examine what effect power type training had on early onset impulse (as determined via IMTP) given its relevance to the golf swing (Hume et al., 2005; Leary et al., 2012).

5.8 Conclusion

The current study provides evidence that power-type training is an effective means of resistance training for CHS improvement in professional male golfers. When designing golf specific programs, golf specific rotation exercises should be the primary concern as sports specific movements offer the greatest performance enhancement. In addition, the intent of such movement should be maximal velocity regardless of load. Changes in the IMTP force variables were inconsistent and as such, further research is needed to establish a relationship between force time variables and CHS increase. Strength and conditioners looking to integrate Olympic lifting movements (i.e. power snatch, power clean) into golf specific resistance training for novice trained individuals should consider the cost benefit. Such movements are technically complex and therefore lengthy learning times can be expected. A relatively less complex alternative to Olympic lifting are derivatives such as snatch pull, clean pull, or clean pull jumps. Such movements can be used to teach technique while still improving muscular kinetics (Suchomel et al., 2015).

Finally, it is vital for professional golfers to maintain normal practice and tournament schedule through golf specific conditioning. Therefore, strength and conditioners need to consider the residual fatigue of the employed protocol. In addition, the safety of physical assessment should be considered. Physical preparation should never detract from sports specific practice or performance thus efficient protocols need to be implemented.

When interpreting the current results, it is important to acknowledge the limitations that are associated with the single subject research design. Firstly, as only professional golfers participated in the current study the results cannot be generalised to amateur populations. Furthermore, as the conclusions were based on statistically observed substantial change (change outside mean ± 2SD) and visually interpreted trends, changes in variability and level, we acknowledge that such results have a high degree of variability based on individual interpretation. Therefore, it is important that research using traditional null hypothesis testing (t-tests), greater subject sizes, and a control group is undertaken. It is therefore difficult to compare the increases in CHS from current intervention to those observed through hypertrophic or stretching protocols. Finally, prior to the intervention, no attempt was made to track the participants' current resistance training or practice volume. However, both participants completed the intervention during the same portion of the golf season and met the previously stated resistance training inclusion criteria.

Further research is required to understand the exact golf specific kinetic and kinematic changes that take place following high-power and high-intensity resistance training. Furthermore, a case controlled intervention employing power, strength and traditional type resistance training is need to establish a comparison between resistance protocols. Such research should integrate the current muscular kinetic testing protocols however, iso-inertial tests should be included in a full testing battery. In addition, the inclusion of three dimensional golf swing analysis would help establish a relationship between muscular kinetics changes and golf swing kinematics changes.

Chapter Six: Summary, practical applications and future research designs

6.1 Summary

Resistance training to increase CHS has grown in popularity as golfers are seeking increases in driving distance to combat longer golf courses. Currently, the vast majority of golf specific resistance training programs consist of hypertrophic type training parameters. In contrast, no intervention to date had investigated the effects of a solely power type conditioning protocol on CHS over a longitudinal period. Furthermore, no conditioning protocol had tracked kinetic changes related to high CHS players through specific and non-specific movements over an interventional period. Therefore, this Masters thesis sought to investigate the question, "what are the effects of power type training on the CHS of professional male golfers?"

Power training in professional golfers and the impact it has on CHS formed the central focus of this thesis. The major conclusion of this thesis is that power type resistance is effective in increasing CHS within two male professional golfers. In reaching this conclusion several other key findings were made.

The literature review revealed rapid force development and rotational velocity to be paramount to high CHS (Gordon et al., 2009; Keogh et al., 2009; Leary et al., 2012; Nesbit et al., 2005). The relationship between early IMTP force time kinetics and CHS was noted by Leary et al., (2012), thus IMTP was chosen as a method of tracking the muscular force capabilities. However, the reliability of early impulse measures had not been established and no study had opted to fixate the bar with chains during an IMTP. Thus, the first investigation (Chapter 3) sought to quantify the reliability of IMTP PF and impulse through predetermined time periods when fixating the bar with chains. As a result IMTP PF and early (≤200ms) impulse were found to be reliable kinetic variables (CM = -8.37 – 3.54 %, CV = 3.29% – 4.02%, ICC = 0.85 – 0.98) when the bar was fixated with chains. In addition, the IMTP PF reliability (CM = -3.82 – 0.72, CV = 3.11% – 4.02%, ICC = 0.98) assessed during the chain fixation method was shown to be consistent with IMTP PF as assessed by other more traditional methods (ICC = 0.96 – 0.98) (Leary et al., 2012; McGuigan et al., 2010; McGuigan et al., 2008; Stone et al., 2004). IMTP impulse was shown to improve between testing occasions and this information was another novel aspect of our research. Impulse has particular relevance to explosive movement due to its contribution to the momentum of an object. Measuring impulse over pre-determined time periods allows for analysis of force expression with specific relevance to sporting performance (Aagaard et al., 2002). When referring back to the relevance of IMTP impulse within the context of the current thesis, Leary et al., (2012) suggested that IMTP force expression within 200 ms is of importance to golf due to the time course of the downswing being ≤230ms (Hume et al., 2005). As such, the chain fixation protocol was integrated into the proceeding training intervention to quantify force expression with a particular emphasis on the early time frames (i.e. <230 ms) that are specific to golf. Based on the current findings it is recommended that a full familiarisation session should be employed to increase the reliability of IMTP measures. In addition the inclusion of the chain fixation provides a reliable and relatively inexpensive means of bar fixation. Thus, practitioners integrating the IMTP as a means of force – time analysis should look to integrate the aforementioned protocol.

As previously mentioned rotational velocity is paramount to high CHS (Brown et al., 2011; Chu et al., 2010; Read, Lloyd, et al., 2013). However, it was also identified that no reliable golf specific rotational assessment had been reported in the literature. Therefore, Chapter 4 sought to provide a means of assessing golf specific rotational velocity in a reliable fashion. The CDS load velocity spectrum was proposed as a novel assessment method and was found to be highly reliable (CM = -5.1% – 2.9%, CV = 1.5% – 6.4%, ICC = 0.70 – 0.97). The reliability of this method increased with increasing trials (days 2 – 3, CM = -0.6 – 2.9%, CV = -0.6% – 2.9%, ICC = 0.91 – 0.98), so it is recommended that a full familiarisation session should be employed with new participants. Resistance based rotational movements have previously been identified as an integral part of golf resistance training (Alvarez et al., 2012; Doan et al., 2006; Fletcher et al., 2004; Keogh et al., 2009; Thompson et al., 2004). Furthermore, speed, power and strength had been reported to differentiate high and low CHS players (Gordon et al., 2009; Keogh et al., 2009; Nesbit et al., 2005; Read, Lloyd, et al., 2013). With this in mind, the proposed CDS load velocity spectrum accounts for low load velocity, moderate load velocity and high load velocity through a kinematically golf specific movement (Keogh et al., 2009). As the CDS load velocity spectrum was reported to a reliable method of assessing golf specific downswing velocity, it was integrated into the proceeding training intervention as means to quantify changes in golf specific rotational ability. Strength and conditioning coaches seeking to quantify rotational velocity should also look to integrate the current protocol into their practise. Practitioners may reduce the number of assessed loads, however such a new assessment required all loads to be assessed within the present research. In addition, the current protocol can be adapted to fit the kinematics of several rotational sports however, the reliability of movements that vary from the CDS will need to be established.

The fourth part of this thesis involved a 6 week power type resistance training intervention. Although previous researchers have been concerned with correlational analysis and associations with strength and power type adaptations, muscular kinetics and CHS (Brown et al., 2011; Chu et al., 2010; Gordon et al., 2009; Hellstrom, 2008; Okuda et al., 2010; Read, Lloyd, et al., 2013; Wells et al., 2009), no longitudinal interventions have investigated the effects of a power type training protocol. Furthermore, no study had tracked changes in muscular kinetics (IMTP PF, IMTP impulse and CDS velocity) pre to post intervention. Chapter 5 aimed to provide evidence for the inclusion of power type resistance training (i.e. loads 45-80%RM, 1-3 repetitions, and 4-6 sets) protocols within a male professional golfer's schedule who is looking to further increase their CHS. Thus, this chapter specifically sought to address the overarching research question of, "what are the effects of power type training on the CHS of professional male golfers?"

This chapter utilised a single subject research design where two male participants undertook a periodised six week power type resistance training program. Following the six week training intervention, substantial increases in CHS (3.1 and 3.9% increase) were noted for both participants. In order to make the current findings more applicable to golf performance, a measure of golf drive accuracy was also included. Interestingly accuracy was seen to trend towards improvement where the ball finished closer to the target line. No substantial change in any IMTP variable was observed. However, CDS load velocity spectrum showed substantial increases in velocity across all tested loads (1.25 – 18.75kg). Thus, the substantial increases in CHS were attributed to increased rotational velocity through the downswing phase as measured by the CDS. It was concluded that maximal power training is an efficient means of increasing CHS in competitive professional male golfers. However, the inclusion of Olympic type lifting should be done so with caution. The complexity of Olympic movements may negate the targeted muscular adaptions from occurring in novice Olympic lifters. Thus, pulling derivatives (i.e. snatch pull and clean pull) are recommended instead as they yield similar kinetic outputs with a relative decrease in movement complexity. Furthermore, the foundation of golf specific resistance training should revolve around a ballistic loaded golf specific rotation.

6.2 Future research

Future research should look to employ similar methods of testing and training to the interventional study with the exclusion of Olympic lifts and the inclusion of pulling derivatives due to the high levels of technical mastery that the Olympic lifts require. As such, it is recommended that a sound degree of technical mastery should be reached before Olympic lifts are employed as a conditioning movement for golfers. Tracking muscular adaptation for golfers should include specific kinematics and kinetics (PF, impulse, CDS velocity) through both specific (i.e. driving performance, CDS) and non-specific movements (squat, upper body pressing and pulling). In addition, tracking golf performance variables should include CHS, accuracy and golf swing kinematics tracked via three dimensional analysis. Thus the current golf performance and physical assessments should be employed in conjunction with iso-inertial movements to provide a more rounded physical testing battery. Three dimensional pre to post analysis will provide a greater understanding the role adapting muscular force variables has on CHS and golf.

6.3 Limitations

The current studies have several limitations. The only limitation of the CDS protocols was standardisation of cable pulley apparatus when looking to compare between investigations. The manufactures specifications of each cable apparatus dictate the arrangement of the pulleys and therefore the resulting load at the handle. It is therefore likely loads across apparatus will vary making between investigation comparison of velocity inaccurate.

As competitive golfers regularly travel internationally for tournament purposes, recruiting a large cohort for longitudinal periods provided challenges. To overcome this situation, a single subject research design was opted for where two professional golfers were recruited. In order to combat the single subject design limitations multiple pre and post data collection occasions were included to account for error and change associated with; measurement (random change, technological error, biological error), learning effect (systematic change), and daily variation in kinetic outputs (systematic change) respectively. Thus, the substantial pre to post changes can be associated with increased muscular output rather than testing error and change. In addition, a mixed visual and statistical analysis method was employed to further strengthen our findings.

As CHS testing was undertaken in a driving range situation, visual factors (trees, rough, fairway width, lakes) that influence golf driving accuracy and distance were not accounted for. Furthermore, no kinematic data was taken thus the exact kinematic changes that underpin CHS improvements cannot be reported.

Prior to participation in the current investigation the researchers did not track the participant's current resistance training volume or practice volume (i.e. the number of balls hit per week). As a result the current study had difficulty explaining the resulting muscular adaptations or lack thereof. However, previous golf related resistance based interventions have also failed to report resistance training volume prior to the intervention (Alvarez et al., 2012; Doan et al., 2006; Fletcher et al., 2004; Hetu et al., 1998; Lephart et al., 2007; Thompson et al., 2004).

As a result of the previously stated limitations the current interventional results must be interpreted with caution and the outcomes can only be generalized to an adolescent male professional cohort. Further research is sought utilizing large cohorts using conventional statistics.

Appendices

Appendix 1. Participant information sheet.

Participant information sheet

Project title:

"The effects of maximal power training on CHS in professional male golfers."

You are invited to participate in the above named research that will be conducted by Mr. Michael Schofield and supervised by Dr. Adam Storey and Professor John Cronin. Your participation in this investigation is completely voluntary. Your decision to participate or not participate will not affect any relationships with the researchers or supervisors now or in future.

What is the purpose of this research?

Exercise is widely regarded within the golfing community as a means to decrease injury potential and increase golf club head speed (CHS). It has been established that hypertrophic (i.e. moderate intensity, slow-moderate velocity, high volume resistance training), rehabilitative, and warm up type training protocols increase golf CHS to some extent. In addition, previous researchers have shown strong associations between power type exercises and golf CHS, although interestingly, such exercises are rarely integrated into golf conditioning programmes. Therefore the purpose of this investigation is to investigate the effects of maximal power training on CHS in professional male golfers. The results will add to the current body of golf conditioning literature, while contributing towards a Masters. All results will be published in a thesis and journal article which may include a conference presentation.

Am I eligible to participate?

You are eligible to participate if you; 1) are a male aged 18-30 years, 2) currently a member of the NZPGA (New Zealand professional golf association, 3) have no current acute or chronic injuries and/or medical conditions, 4) are not using any performance enhancing or banned substances (World Anti-Doping Agency 2014), 5) have been involved in regular resistance type training for the past six months and, 6) have appropriate joint mobility to perform the Olympic lifts (e.g. snatch and clean and jerk related movements).

Your participation in this study is voluntary; you have the right to withdrawal at any time without reason.

What will happen in this research?

Familiarization and testing session:

If you are eligible and have given voluntary consent you will be required to participate in a familiarization session three days prior to the pre-intervention testing session. During the familiarization session you will be shown correct exercise technique regarding the specific testing protocols of this investigation and you will become familiar with all the testing equipment.

The pre-intervention testing will involve a combination of golf specific tests (5 maximal drives on a speed radar) and physical tests that will assess your muscular kinetics (isometric mid-thigh pull, Isometric bench press and golf specific cable downswing).

Training

All participants will be required to complete 3 supervised sessions per week across the 6 week training period. Each session will last 60 – 90 minutes. The Olympic type and power type movements will be performed in an explosive fashion. The exercises involved in this investigation have been chosen due to their strong correlations with golf swing speed (e.g. pushing, pulling, squatting and rotational movements). The level of training intensity (% repetition maximum lifted) will differentiate heavy and light days during a training week. In addition, total training volume (i.e. reps x sets x load) will separate heavy and light weeks. A "deloading week" (i.e. a reduction in training volume) will be implemented every fourth week to allow recovery. Between training sessions you will be encouraged to partake in your normal golf practice although you will need to keep a golf training log. You are advised to exclude any intense cardiovascular type exercise for the duration of the study.

What are the discomforts and risks?

As with any physical activity and/or training program each session has the potential to cause fatigue. Furthermore, it is possible that transient muscle soreness may occur 12-48 hours following testing and training, however this is only an acute response and will subside. This response to resistance exercise is no different to what would be experienced when resistance training outside of this investigation.

What are the benefits?

You will receive a full golf CHS profile, and physical data regarding your strength and power. It is also likely that you will improve your golf CHS. In addition you will have expert Olympic and resistance training coaches improving technique through all exercises.

What compensation is available for injury or negligence?

In the unlikely event of a physical injury as a result of your participation in this study, rehabilitation and compensation for injury by accident may be available from the Accident Compensation Corporation, providing the incident details satisfy the requirements of the law and the Corporation's regulations.

How will my privacy be protected?

All information collected for the purpose of this investigation will be stored on a secure database accessible by only Michael Schofield (researcher), Dr. Adam Storey (Primary Project Supervisor), and Professor John Cronin (Secondary Project Supervisor). All data that is used will be encoded in such a way that the identity of the subject is protected.

Present and future studies will use the encoded data therefore it will be impossible to be able to uncover the identity of any subject involved in this investigation.

Future data storage and use

All data collected from this study will be kept indefinitely in the Sport Research Institute New Zealand (SPRINZ) database (AUT University). We feel it is important to keep all data for future investigations and publications or until such stage that no further research is warranted in this area. All data will be held in an encoded state thus protection of privacy will be maintained.

What are the costs of participating in this research?

There are no financial costs associated with participating in this investigation. However there is a time cost. You will be required to attend 3 supervised sessions (approximately 60-90min per session) per week for 8 weeks along with familiarization, testing and technique sessions.

How do I agree to participate in this research?

If you do choose to participate in this investigation you will be required to fill in an Informed Voluntary Consent form, which you can obtain from Michael Schofield. Following your signing of the Informed Voluntary Consent form you will also be required to complete a Participant Questionnaire which will provide the researcher with general information regarding your contact details, health, resistance training background and golfing status.

What do I do if I have concerns about this research?

Any concerns regarding the nature of this project should be notified in the first instance to the Primary Project Supervisor: Dr. Adam Storey, adam.storey@aut.ac.nz, 021 2124200.

Concerns regarding the conduct of the research should be notified to the Executive Secretary of AUTEC Kate O'Connor, ethics@aut.ac.nz, 921 9999 ext 6038.

Whom do I contact for further information about this research?

Researcher	**Michael Schofield** BSr, PGd, (Masters Student) AUT-Millennium, 17 Antares Place, Mairangi Bay 021325550 mike@burnfitness.co.nz
Project supervisor	**Dr. Adam Storey** AUT-Millennium, 17 Antares Place, Mairangi Bay 0212124200 adam.storey@aut.ac.nz
Second research supervisor	**Professor John Cronin** AUT-Millennium, 17 Antares Place,

Mairangi Bay

john.cronin@aut.ac.nz

Approved by the Auckland University of Technology Ethics Committee on 14/07/2014
AUTEC Reference number 14/191

Appendix 2. Consent form

# Consent Form	AUT UNIVERSITY TE WĀNANGA ARONUI O TAMAKI MAKAU RAU

Project title: "The effects of maximal power training on CHS in two professional male golfers."

Project Supervisor: Dr. Adam Storey

Researcher: Michael Schofield

- ○ I have read and understood the information provided about this research project in the Information
- ○ I have had an opportunity to ask questions and to have them answered.
- ○ I understand that I may withdraw myself or any information that I have provided for this project at any time prior to completion of data collection, without being disadvantaged in any way.
- ○ I am not suffering from any acute or chronic injuries
- ○ I am not using any performance enhancing or banned substances (World Anti-Doping Agency 2014)
- ○ I agree to take part in this research.
- ○ I understand and allow for the data collected within this study may be used in future research.
- ○ I wish to receive a copy of the report from the research (please tick one): Yes○ No○

Participant's signature: ....

Participant's name: ....

Participant's Contact Details (if appropriate):

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Date:

Approved by the Auckland University of Technology Ethics Committee on 14/07/2014 AUTEC Reference number 14/191

Note: The Participant should retain a copy of this form.

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