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The Effect of a Seven Week Exercise Program on Golf Swing Performance and Musculoskeletal Screening Scores

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The Effect of a Seven Week Exercise Program on Golf Swing Performance and Musculoskeletal Screening Scores

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Abstract

Golf has traditionally been a sport where the focus of coaching and development programs has been on perfecting the technical aspects of the golf swing. Recent systematic reviews have given coaches and players the opportunity to see the physical and on-course performance benefits of performing exercise programs as part of their development programs [1, 2]. Typically, golf exercise studies have implemented programs of 6 – 18 weeks, 2 – 3 sessions per week and involved a variety of forms of exercise focusing on improving muscular strength, power and endurance, as well as range of motion and stability [1, 2]. Despite these studies reporting positive outcomes in golf swing performance and musculoskeletal measures (e.g. muscular strength, power and endurance and joint flexibility) as a result of these exercise programs, many golfers may be unwilling or unable to complete such a frequent amount of sessions per week due to work, family and/or study commitments. Subsequently, the question then remains, what is the minimum dosage of exercise required to elicit positive changes in golf swing performance and musculoskeletal measures?

The aim of Study one was to investigate the effects of a once per week strength and conditioning program conducted over a seven week period on golf swing performance and musculoskeletal screening measures. Forty three participants (37 males and 6 females), enrolled in a Diploma of Golf Management at the Professional Golfers Association International Golf Institute volunteered to take part in the study. Golf swing performance measurement such as Club Head Speed (CHS), driving distance, ball speed, smash factor (ratio of ball speed and club speed), carry side (lateral deviation from target line), as measured with the TrackMan system, and the Ten Test-On Range Protocol involving 10 musculoskeletal screening tests that examined abdominal muscular endurance, movement competency and range of motion, were performed on separate days before and after the 7-week exercise program. Several significant improvements were found for the musculoskeletal screening measures, namely left leg bridging, thoracic extension, right thoracic rotation, and right and left single leg squat. In contrast, no significant changes were found for any golf swing performance measures. These results add to the current golf science literature in that they indicate that once a week training for seven weeks is sufficient to produce a number of significant improvements in musculoskeletal screening performance but insufficient to elicit changes in golf swing performance.

Study two focused on the quantifying the relationship between changes in musculoskeletal screening measures and golf swing performance that occurred after the seven week exercise program described in Study one. Pearson correlational analysis was performed on the change scores (difference between pre-and post-test)

between the musculoskeletal measures and TrackMan golf swing variables with statistical significance set at $p < 0.05$. Although the majority of correlations were non-significant, there were a number of exceptions. Moderate negative correlations between right bridging leg lift and driving distance ($r = -0.354$, $p = 0.040$), left thoracic rotation and ball speed ($r = -0.358$, $p = 0.037$), driving distance ($r = -0.393$, $p = 0.021$), side ($r = -0.381$, $p = 0.026$) right thoracic rotation and smash factor ($r = -0.340$, $p = 0.049$), right single leg squat and ball speed ($r = -0.407$, $p = 0.017$) and left single leg squat and ball speed ($r = -0.411$, $p = 0.016$). The only significant positive correlation was found between right side bridge and Combine test score ($r = 0.356$, $p = 0.039$). Overall, these results suggest that changes in individual musculoskeletal measures may only predict a relatively small proportion of the improvement in golf swing performance with short term exercise programs.

The current thesis adds to the current literature on the effectiveness of exercise programs in golf in several ways. It demonstrates that a once a week, seven week exercise program can be successful in improving a number of musculoskeletal screening measures, although no significant changes were detected for any golf swing performance measure. However, results of this thesis also provide some insight into what aspects of the exercise prescription may most contribute to improved golf swing performance. Results supported the importance of the trunk with improved trunk rotation range of motion and lateral trunk flexion endurance significantly related to accuracy and overall Combine test score, respectively. Collectively, these results suggests that golfers can obtain benefits with reduced strength and conditioning frequency and duration and that increases in trunk range of motion and muscular endurance may contribute to improved golf swing performance.

Declaration

This thesis is submitted to Bond University in fulfilment of the requirements of the degree of Masters by Research. This thesis represents my own original work towards this research degree and contains no material which has been previously submitted for a degree or diploma at this University or any other institution, except where due acknowledgement is made.

Mico Hannes Olivier

Sign:

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1. Olivier, M. H., Horan, S. A., Evans, K. A. and Keogh, J. W. L. (2016). The Effect of a Seven-Week Exercise Program on Golf Swing Performance and Musculoskeletal Measures. *International Journal of Sports Science and Coaching,* Vol. 11(4), pg. 610-618.

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Abbreviations

CHS	Clubhead Speed
3-D	3 – Dimensional
FMS	Functional Movement Screen
IMTP	Isometric Mid-Thigh Pull
LBP	Low Back Pain
ROM	Range of Motion
COR	Centre of Rotation

Chapter One: Introduction

Golf is a popular sport played worldwide with recent estimates suggesting 55 million people participate in this activity [2, 3]. Traditionally golf has been portrayed as a relatively low impact, low intensity sport requiring little physical fitness. However, research conducted over the last two decades has provided valuable insight into the importance of physical fitness for maximising performance and reducing injury risk in golf. Players typically walk 10km during a round, hit 2000 shots per week, with each of these shots involving a complex, coordinated, powerful movement requiring adequate flexibility, power and strength [4]. Not surprisingly, a number of cross-sectional studies have shown positive relationships between several strength measures and golf swing parameters such as club head speed (CHS) and driving distance [5-10]. This greater understanding of the physical requirements of the game have allowed strength and conditioning coaches and sport scientists to work with golfers with the aim to improve their performance and/or reduce their injury risk by developing specific exercise programs for each individual golfer. Results of the peer-reviewed literature indicates that the use of strength and conditioning programs can significantly improve musculoskeletal measures and aspects of golf swing performance [11-17].

As a result of more abundant research in this area, Torres-Ronda et al. [2] and Smith et al. [1] have conducted recent reviews of the effects of exercise program implementation on golf performance, highlighting the many benefits such programs provide for a golfers swing performance. Recent studies have involved golfers of different skill levels (handicaps) and ages, with most exercise studies demonstrating significant improvements in golf swing performance as assessed by greater CHS [12-17] and in some cases driving distance [13, 15]. In order to maintain ecological validity through the controlling of environmental factors, many of these exercise studies have quantified golf performance by devices including launch monitors, with most of these devices demonstrating adequate validity and reliability to quantify variables such as CHS [12-17]. A more recent device, Trackman (TrackMan™, ISG A/S, Denmark), is becoming a popular golf swing device as evident by its use in the PGA, USPGA and Australian PGA (TrackMan™, ISG A/S, Denmark) [18]. The TrackMan is a 3-D ball flight analysis tool which gives coaches instant access to extensive and accurate golf swing data, such as CHS, ball speed, driving distance, smash factor and accuracy, which could potentially prove critical to a golfer's performance.

The literature has outlined most golf exercise studies as utilising exercise program durations of 8 – 18 weeks, with most of these programs eliciting not only improved physical characteristics such as muscular strength and power, but also golf swing performance [11-13, 15-17]. The exercise programs performed in this literature have also varied substantially on the actual exercise prescription, with some studies including a variety of flexibility, muscle endurance, movement competency (quality of movement), muscular strength and muscular power exercises. Furthermore, these exercise programs typically involved 2-3 sessions per week. As there still exists some uncertainty regarding the actual exercise prescription as well as the minimal frequency and duration of the exercise program that can improve musculoskeletal measures and golf swing performance, more research needs to focus on addressing these issues within this literature. Part of the reason for this uncertainty may be due to the variation in participants, with two studies [11, 13] utilising highly trained athletes, with other studies involving recreational golfers [12, 14, 15, 17, 19].

Most amateur golfers are limited in the time they can devote to exercise due to other commitments such as work, family and study, thereby constraining their ability to perform an exercise program 2-3 times a week. As such, incorporating one session a week might be more feasible for many golfers. The efficacy of such a dosage needs to be further investigated in the golfing population, but previous studies [20, 21] have established the usefulness of implementing such a frequency of exercise in older adults. Specifically, DiFrancisco-Donoghue and colleagues [21] demonstrated that one set of strength exercises once a week is equally as effective in improving strength as one set of exercises twice a week. Such information is valuable to researchers as it provides a rationale for implementing a once a week exercise program that has potential to improve selected musculoskeletal measures and golf swing performance.

Prior to providing any exercise program to an athlete, it is recommended that the athlete perform some musculoskeletal screening assessments. Musculoskeletal screening is becoming increasingly more popular in sports, with physiotherapist and strength conditioning coaches using such assessments with new clients or at the start of a new season in an attempt to assess the movement competency and subsequent risk of injury of each golfer. Through the use of these screening tools, practitioners are better able to provide exercise programs which will appropriately address any movement abnormalities, subsequently allowing for greater strength and endurance gains to be made that may ultimately improve sporting performance and/or reduce the risk of injury. Typically, musculoskeletal screening assessments examine joint range of motion, muscular endurance and movement control, as all of these variables are considered crucial for optimal performance whilst playing a role in reducing an athlete's risk of injury [22, 23]. To date, there has been little published data supporting the use of musculoskeletal screening tests for golfers. Evans et al. [24] looked at predictors of low back pain (LBP) in young elite golfers and found that those athletes who performed poorly on the right side bridge endurance test were more likely to suffer LBP. Furthermore, Evans et al. [24] suggested that those golfers who had tight hip flexors, although not predictive of LBP, were more likely to report that LBP affected their performance. With previous studies finding LBP as one of the most common injuries amongst golfers [25, 26], it seems useful to assess hip flexor range of motion (ROM) and abdominal muscular endurance in order to identify modifiable risk factors that can be altered with exercise program. Therefore, a number of items included in any musculoskeletal screening assessment should focus on the joints and muscles proximal and distal to the most common injury sites as well as those that play a crucial role in sporting performance [27-31].

Murray and colleagues [31] further investigated the incidence of LBP and if there was any association with hip rotation range of motion. Their results revealed that in a group of 64 amateur golfers, the 28 in the LBP group had significantly reduced lead (nearest the hole) hip medial rotation in comparison to the golfers without LBP. Lindsay and Horton [28] observed that those golfers with LBP produced greater trunk rotation range of motion during their swing compared to the maximum range of motion they achieved from a neutral posture during range of motion testing. Lindsay and Horton [28] interpreted these results to suggest that these golfers with LBP had to supramaximally rotate their spines during the golf swing to compensate for the lack of flexibility in their torso. Although only a limited number of studies have effectively utilised musculoskeletal screening in golf [24], review studies of injury rates amongst golfers have shown that LBP is very common amongst golfers and usually results in long periods away from the sport [25, 26, 32]. Risk factors for LBP in golf include overuse (repetitive practice), which may be secondary to poor swing mechanics, poor trunk musculature endurance, and poor flexibility [33, 34]. Adding more complexity to this condition, the golf swing is asymmetrical, dynamic and repetitive, and with compressive loads exceeding 6100 N measured in the lumbar region, proper swing mechanics should be reinforced to reduce the potential for pain and injury to the lower back region [35]. As such, by utilising information such as presented above, practitioners will be more able to assemble musculoskeletal assessment batteries which are more reflective of the demands of the sport whilst also reducing injury risk.

While considerable evidence now demonstrates that exercise programs are effective in improving various aspects of golf swing performance, there are still many gaps in the literature. Specifically, can a golf exercise program involving a reduced frequency and duration of exercise significantly increase musculoskeletal and golf swing performance measures; and what aspects of the golf exercise program actually underlie these changes?

Project Aims

Therefore, the aim of this thesis was to:

1. Investigate the effects of a seven week, one day a week exercise program on selected musculoskeletal screening test scores and golf swing performance parameters such as CHS, ball speed, driving distance, smash factor, accuracy and total Combine test score, as assessed by the Trackman system;
2. Gain greater insight into what physical qualities impact on golf performance by quantifying the relationship between changes in musculoskeletal measurement scores and golf swing parameters resulting from the exercise program.

It was hypothesised that;

1. The seven week, once a week exercise program will result in significantly ($p < 0.05$) improved musculoskeletal screening scores and golf swing parameters;
2. Changes in a number of musculoskeletal screening tests scores and golf swing parameters will be significantly correlated ($p < 0.05$) with one another.

Chapter Two: Literature Review

Literature Search

The literature reviewed in this thesis was sourced using SPORTDiscus and Pubmed databases. Key words used during the search included; golf, testing, Trackman, injuries, exercise programs and musculoskeletal screening. Articles were searched up to July 2016, obtaining full text articles. Articles that matched key words in the abstract were included for review. Further articles were sourced after reviewing the reference list of the included articles.

Golf Swing Technical Performance Determinants

The golf swing is a highly complex sporting activity that involves a sequential pattern of muscle activation with the aim to make contact between the club head and ball in order to hit the ball the required distance and direction. Compared to other sports, this complexity is further heightened by the fact that golfers have to be skilled at striking the ball with a myriad of clubs from their driver to their pitching wedge and putter, with such shots occurring over different distances and with different task goals. As a result of the technical complexity of the golf swing, the considerable number of clubs that they have to utilise and decisions they need to make before taking each shot, golfers spend considerable time practising their goal swing on the practice range, in the bunker and on the putting green. As illustrated in Figure 2.1, the golf swing consists of technically complex sequences of movements, involving linear and angular motion across a large number of the body's joints.

Figure 2.1. An illustration of the Different Phases of the Golf Swing.

Golf Performance Testing

Golf performance testing is becoming more prevalent in recent years in an attempt to gain more insight into the golf swing and to assist golfers improve their performance. However, there has traditionally been a divide between sports scientists (biomechanists) and coaches in how these performance measures are obtained. Biomechanists have traditionally assessed the golf swing using 3-D motion capture, force plates and/or electromyography in purpose-built biomechanical laboratories, in which the golfers hit the ball into a net located a few metres away [5, 12, 14-17, 36]. Such an approach allows the quantification of an extensive number of biomechanical factors that may relate to golf swing performance and/or injury risk. Unfortunately, this approach could be criticised for its lack of ecological validity whereby the golfers are not able to obtain task relevant perceptual information during and prior to the golf swing. Alternatively, golf coaches typically work with their athletes on the golf course during practice and tournament play. During tournament play, golfers are able to access a range of statistics that reflect their ball striking and putting performance. Examples of these statistics include strokes gained from tee-to-green and off-the-tee, approach the green, greens in regulation, around the green and so forth. When working with their golfers, golf coaches will utilise their "skilled eye" or video to qualitatively assess the golfer's movements and based on the outcome of each shot, provide some feedback on ways in which the golfers can improve their performance. More recently, golf coaches are also utilising technology to provide their golfers quantitative feedback, so to bridge the gap between the laboratory based in-depth biomechanical analysis and the notational analysis provided by tournament providers.

Field-Based Biomechanical Golf Swing Parameters

As stated previously, the sport of golf requires the golfer to precisely control the distance and direction of their shots with the ultimate goal to put the ball in the hole in as a few shots as possible. Golf swing performance devices have therefore been developed to be used on the golf course so to provide the golfer and golf coach biomechanical information relating to the distance and accuracy of the golf shot as well as how the clubhead makes contact with the ball. These two levels of performance information are crucial as if there are some errors in ball distance and accuracy, an understanding of the nature of ball contact is crucial if the golfer is to improve the distance and direction of the golf shot. The literature has presented several variables which may be predictive of golf swing performance, although CHS and driving distance have been most commonly measured [5, 7, 9, 11-17, 37]. While driving distance is more ecologically valid than CHS in terms of where the ball comes to rest after being hit, the assessment of driving distance may be more affected by variations in environmental conditions between testing sessions. This has resulted in CHS becoming the preferred performance measure in the golf research literature that relates to the distance of the golf shot. This research has often indicated a strong association between CHS and handicap [36], whereby golfers with a lower handicap generally have a higher CHS. Thompson & Osness [16] illustrated that a higher CHS, with sufficient accuracy, generally results in greater driving distances, reducing the distance to the hole, subsequently resulting in fewer shots needed to reach the hole [11, 12]. The following section will describe some of the common field-testing biomechanical devices used by golf coaches and the actual golf swing performance parameters that these devices provide.

Testing Equipment

Numerous performance measuring devices has been utilised, both indoors and for field testing, most notably various brands and versions of Launch Monitors, with the predominant variables measured being CHS and driving distance [7, 9, 11-17, 37, 38]. Previously, authors have identified these two measures to be both reliable and valid due to their strong associations with performance parameters such a handicap [36]. Table 2.1 lists some of the previous studies which have utilised various golf swing measuring devices.

Table 2.1. Literature Overview of Previous Golf Swing Performance Devices

Testing Equipment	**Radar (speed) Gun**	**Launch Monitors**	**Swing Mate**	**Swing Analyser**	**TrackMan Pro**
Studies	Alvarez et al. [11] and Keogh et al. [7]	Doan et al. [12], Wells et al. [9], Lephart et al. [15] and Kim	Gordon et al., [5], Hellstrom [6] and Thompson et al., [17]	Thompson & Osness [16] and Fletcher & Hartwell [13]	Robertson et al. [18],Robertson et al. [40] and Schofield [38]

	[39]

As can be seen in Table 2.1, there have been a variety of systems used in the literature to assess biomechanical aspects of performance on the golf course. Radar guns, as used by Keogh et al. [7] and Alvarez et al.[11], typically only provide measures of CHS and ball speed. A range of launch monitors have also been used in this literature. By placing these devices behind the golfer, coaches and researchers are able to gain detailed information regarding the swing and launch parameters of each golf swing in close to real time, whereby the golfer and coach can access this information directly after each golf swing. Examples of these devices have included the GolfAchiever [12], Titleist Launch Monitor [9], Accusport [15], Swing Dynamics Launch Monitor [39]. These launch monitors may provide additional measures to CHS and ball speed, such as the direction and distance of the golf shot. A number of these launch monitors have been compared to standard measures such as 3-D motion capture and have been reported to have sufficient levels of validity and reliability [15].

A recently developed launch monitor that is being more commonly used amongst coaches and players in the PGA and tours is the TrackMan (TrackMan™, ISG A/S, Denmark). A Doppler radar based Launch Monitor, Trackman provides instant feedback to coaches, with the manufacturers reporting an error of measurement of less than one foot at 100 yards (0.33% error) (TrackMan™, ISG A/S, Denmark). A list of some selected golf performance variables which the TrackMan can measure, along with their definitions is provided in Table 2.2. The definitions were gathered from the My TrackMan website (TrackMan™, ISG A/S, Denmark), detailing the importance of each of these variables in relation to golf swing performance. While the TrackMan measures the most commonly assessed golf swing variables currently found in the literature, i.e. CHS, driving distance and ball speed, other variables including smash factor and carry side (accuracy) may also provide valuable information regarding the outcome of a golf swing. The smash factor is the ratio between ball speed and club head speed. Therefore, it can be presumed that by having a higher smash factor, a golfer ultimately makes more efficient impact between club head and ball, which should hypothetically increase driving distance. Robertson et al. [18] included the use of "carry side", a measurement of how close the ball landed to the left or right of the target line. Having access to such a broad range of data may prove useful in that it may provide additional information to the golfer and the coach in their quest to improve their performance.

Table 2.2. Selected Golf Swing Parameters as measured by the TrackMan.

Golf performance variables	Definitions
Club head speed (CHS)	The speed at which the club head is moving before impact
Ball Speed	The speed of the ball after impact is made
Carry Distance ("flat")	Distance of the ball travelling through the air
Carry Side (accuracy)	Measurement of the point where the ball lands in relation to the target line, either left or right of it.
Smash Factor	Ball speed divided by the club speed (ratio between the two)

Although aspects of the validity of the Trackman remains to be fully demonstrated in the peer-reviewed literature across all golfing activities, a number of studies have utilised the system. Specifically, Robertson et al. [18] developed the 'Nine-Ball Skills Test' to discriminate between elite and amateur golfers and used the Trackman to assess golf swing performance in these golfers. Furthermore, Robertson and colleagues [40] utilised the TrackMan to validate the "Approach Iron Skill Test". The aforementioned studies and subsequent outcomes prove vital as it presents coaches and researchers with the freedom to reliably measure golf swing performance, whilst simultaneously allowing for accurate feedback to be provided during practice sessions on the driving range or golf course [18, 40].

A popular assessment tool undertaken by many professional golfers utilising the Trackman device is the 'TrackMan Combine test'. The TrackMan Combine test is a golf swing performance assessment that takes into account accuracy and consistency of golf shots using multiple golf clubs and targets. Such information may enable players to evaluate their accuracy, strengths and weaknesses in hitting targets at varying distances (TrackMan™, ISG A/S, Denmark). Such a test allows amateur golfers to compare their total Combine test scores to those of PGA tour golfers, with a score of ≥ 80 reported to indicate a player who could be playing on the PGA tour (TrackMan™, ISG A/S, Denmark).

Golf Swing Physical Performance Determinants

While it is acknowledged that golf is a highly technical sport, like any sport it has its own unique physical requirements. Traditionally, golfers may spend considerable time developing and maintaining flexibility across many trunk and upper body muscles so to facilitate a long backswing and follow-through. More recently, golfers are also spending more time performing a range of other exercise activities with the aim to increase muscular strength, power and endurance. The aim of such training has been to increase golf performance (e.g. ball striking distance) and to reduce the risk of injury, most commonly overuse injuries. The following sections will briefly describe the muscle activation patterns and flexibility requirements of the golf swing.

Muscle Activation during the Golf Swing

A review by McHardy and Pollard [41] summarised the literature to determine the most active muscles during the different phases of the golf swing; backswing, forward swing, acceleration, early and late follow through. This review indicated moderate to high degrees of activation of a variety of large muscles including the pectoralis major, gluteus, quadriceps, erector spinae and hamstring muscle groups as well as several smaller muscle groups including the rotator cuff, trapezius, internal and external oblique and adductor magnus muscles. Indicative of the complexity of the golf swing, these electromyography (EMG) results however indicated quite specific coordinative patterns of muscle activation that reflected their various roles during the backswing, downswing and follow-through.

A review by Smith [4] and a study by Sell, Tsai, Smoliga, Myers & Lephart [8] found the more skilled golfers to have superior strength in their hips, legs and trunk muscles compared to their lower skilled counterparts. Such results appear consistent with many correlational studies [5-7, 9, 10] that have demonstrated significant positive correlations between physical strength characteristics and golf swing performance such as CHS and driving distance. For example, Read et al. [10] found that performance in seated medicine ball chest throws and medicine ball rotational throws were significantly correlated to CHS ($r = 0.67$ and $r = 0.63$), respectively. Similar results also obtained by Wells, Elmi, and Thomas [9] and Hellstrom [6] who reported strong positive correlations between the number of pull ups in 60 seconds, dominant arm grip strength and a range of golf performance measurements, i.e. CHS, ball speed and carry distance. Collectively, the results of these cross-sectional comparative studies and those of the McHardy and Pollard’s comprehensive review on EMG muscle activity [41] support the view that developing muscular strength is an important component of training for improved golf swing performance.

Many researchers have aimed to determine the role the abdominal muscles play during the golf swing and the subsequent importance of incorporating them into an exercise regime. Wells et al. [9] examined the role of abdominal muscles golfers and found that the endurance of the abdominals on the dominant side of women correlated with driving distance. Based on these results, Wells et al. [9] proposed that the activity of the external & internal obliques and the transverse abdominus is crucial for golf swing performance, while also speculating that they play important roles in reducing the risk of injury to the lower back. The findings of Wells et al. [9] along with the EMG review by McHardy and Pollard [41] has led to a large emphasis on the abdominal and lower back muscles in many exercise programs for golfers [42, 43].

Numerous studies have also looked at the contribution and importance of leg strength and power during the golf swing [5, 6, 8, 9, 11-13, 15, 44, 45]. The common feature amongst these studies is that possessing high levels of leg strength provides greater stability whilst allowing for an efficient transfer of ground reaction forces to the club head. These studies are consistent with previous EMG studies, in that a number of lower body muscles including the right gluteus maximus are highly active during the golf swing, and as such may play an important role in the development of high CHS.

Flexibility Requirements in the Golf Swing

As the golf swing is a dynamic action requiring a large ROM across many joints, having adequate flexibility is thought to play an important part in being able to produce an optimal golf swing. As proposed by Keogh et al. [7], possessing adequate flexibility around the shoulders, hips, torso and wrist may all be beneficial characteristics for golfers due to the larger ROM exhibited at these joints during the full golf swing. High degrees of ROM around these joints will allow for more mechanical work to be completed on the club head during the golf swing, resulting in a greater period of time over which the club head can accelerate during the downswing [5, 7]. With this in mind, a number of investigators have further attempted to identify the importance flexibility plays in the golf swing through both correlational and longitudinal studies.

In order to establish the effectiveness of flexibility training in the sport of golf, several investigators have conducted correlational analyses with golf swing performance indicators, such as CHS, handicap and driving distance [7-9]. Keogh et al. [7] quantified a range of flexibility measures including wrist adduction, abduction, trunk rotation and hip internal and hip external rotation, to determine how they may be related to CHS. The authors surprisingly reported no significant correlations between any flexibility measures and CHS, even more so, there were no significant differences between high handicap golfers and the low handicap golfers in the flexibility measures. While somewhat surprising, these results are consistent with Gordon et al. [5] who also reported no statistically significant correlation between rotational flexibility and CHS. Such results are inconsistent with Joyce et al. [46] who reported lower trunk flexion/extension at the top of the backswing, lower trunk flexion/extension at ball impact, and lateral bending of the trunk at the top of the backswing to be strongly associated with CHS. Possible reasons for these inconsistencies amongst authors include the means by which flexibility was measured, where Keogh et al. [7] and Gordon et al. [5] used musculoskeletal assessments and Joyce et al. [46] used three-dimensional using motion analysis.

Longitudinal studies have incorporated flexibility exercise programs into golfers' routines in an attempt to successfully improve golf swing performance. Jones [37] prescribed an 8-week PNF stretching routine for 16 recreational golfers. The author reported a statistically significant improvement in CHS of 7.2% at the conclusion of the training program. Other studies have also showed significant improvements in both flexibility measures and CHS in a group of 31 [16] and 18 [17] middle-aged/older men who play golf recreationally.

Considering the evidence provided by these correlational and longitudinal studies, it seems plausible for researchers to assume that greater CHS, and thus ball speed, is a possible outcome if an athlete can improve their flexibility around the trunk and shoulder regions [7, 8, 12, 47]. This information has implications for practitioners to thoughtfully design an exercise or flexibility program which may equally lower the risk of injury, i.e. improve musculoskeletal measure scores, and improve golf performance variables.

Golf Injury Epidemiology

Due to the repetitive and asymmetrical nature of the golf swing, golfers may be at some risk for a number of injuries as well as joint and muscular pain. The following section describes some of the most common injuries found in the sport of golf and the risk factors associated with these injuries. This information is most relevant for strength and conditioning coaches and physiotherapists who are working to improve the physical capacities and reduce the injury risk of golfers.

Common Injuries in Golf

Golf is commonly seen as a sport which is of low impact to the body, however research has shown that the repetitive, asymmetrical nature of the golf swing leads to injury risks to a number of anatomical locations such as the lower back, wrist and elbow regions [31, 48]. The golf swing is a rotational movement in which large forces are generated and/or absorbed by many of the body's muscles and joints [29, 31, 32, 44, 48-50]. As this intense asymmetrical muscle activity may be repeated thousands of times per week, this may ultimately lead to fatigued core muscles and altered spinal posture that may increase the risk of low back pain (LBP) [51].

An examination of several injury studies reveals that LBP is the most common injury in both amateur and professional golfers [29, 31, 50, 51]. Perhaps due to the large ROM and forces produced by the upper body during the golf swing, the upper limb may also experience a relatively high proportion of golf-related injuries [25, 29, 32]. These injuries may be seen across the shoulder, elbow and wrist [25, 26, 34, 52], and may reflect a mixture of acute and chronic injury mechanisms. A better understanding of the aetiology of these injuries is important for the strength and conditioning coach and sports physiotherapist working with golfers, so that the exercise prescription may maximise performance benefits and reduce the risk of injury. Due to LBP typically being the most common injury reported in golf, the following section which describes the aetiology of injury in golf will focus upon LBP.

Aetiology of Injuries in Golfers

A survey study conducted by Batt [25] aimed to locate and examine the mechanism of common injuries amongst golfers. An examination of the available evidence suggested that overuse and poor golf swing mechanics were the primary causes of the majority of golf related injury. These findings can be found throughout the golf science literature, with more recent findings focusing on LBP, its mechanism of injury and more effective ways to reduce the risk of this disorder [26, 29, 31, 34, 48, 50, 51]. McHardy and colleagues [34] did a follow-up study, focusing on the location, mechanism and phases of swing during which LBP occurred. Their results suggested that 46.2% of LBP injuries were caused by overuse, i.e. repetitive golf swing practice. Grimshaw [53] reported similar findings with LBP being the most prominent injury site (30%). From their findings, Grimshaw [53] proposed that LBP arises from either poor swing mechanics and overuse, with these overuse-related cases of LBP more typical of the professional golfer. Batt [25] also presented an argument that one of the reasons underlying the high prevalence of LBP in amateur golfers was that they tended to generate greater lower back torques than was perhaps required during the golfer swing. Thus, Brandon and Pearce [54] recommended that coaches focus on correcting the golf swing mechanics of those amateur golfers. This was considered important as the amateur golfers' poor swing mechanics may contribute to LBP regardless of their much smaller number of golf swings per week compared to golf professionals. As professional players will typically have a more refined golf swing technique than amateurs, they should be at reduced risk of LBP. However, the professional players perform a greater number of swings per week, meaning that they may require input from coaches and health professionals to implement preventative measures to reduce their risk of LBP, i.e. management of their golf swing loads and addressing any trunk muscular endurance deficiencies [25, 26, 44, 48-51]. Therefore, a strength and conditioning program may need to focus on the abdominal and lower back region if professional golfers wish to reduce their risk of LBP [24, 55, 56].

Although injury occurrence is an area which is not directly focused on in this thesis, an awareness of these injuries and how they occur is crucial in order to choose a set of musculoskeletal screening tests that might be most specific to the sport of golf. Moreover, by knowing the aetiology of the injuries, strength and conditioning coaches as well as sports physiotherapists who work with golfers can take appropriate rehabilitation and physical conditioning steps to reduce the likelihood of further injury.

Musculoskeletal Screening

A pre-assessment screening protocol, also known as musculoskeletal screening, often involves a series of muscular endurance, flexibility and movement competency tests. These assessments are typically conducted by physiotherapists or strength and conditioning coaches prior to an exercise or rehabilitation program across a number of sport and athletic endeavours [57, 58]. Tests included in screening must have sufficient reliability and validity [57] if the musculoskeletal screening tests are to identify performance limitations and/or injury risk factors for a particular sport [59]. Prior to conducting the musculoskeletal screening process, it is imperative for practitioners to become acquainted with the sport, in particular the primary determinants of performance and the mechanisms of common injuries. In many cases, exercise programs are developed based on the outcomes of these musculoskeletal screening tests in an attempt to eliminate side-to-side asymmetries and improve muscular strength and endurance of the primary muscles.

Common Musculoskeletal Screening Assessments

In recent years, the Functional Movement Screen (FMS) system has become the most popular musculoskeletal assessment tool that is purported to assess an athlete's functional movement capacities [22, 60-64]. Multiple authors [22, 60, 62, 63] have stated that the FMS system is intended to detect any deficits in functional movement patterns. As such, the FMS system is not proposed as a diagnostic tool [23], rather a method of identifying any asymmetrical or dysfunctional movement patterns which may affect an athlete's performance or predispose them to an injury [60, 62].

To the author's knowledge, only three studies [60, 63, 65] have examined a FMS specific exercise program and its ability to elicit changes in FMS scores. Kiesel, Plisky & Butler [63] and Cowen [65] demonstrated improved movement competency as assessed by FMS scores after the performance of exercise programs that were developed based on initial FMS scores. These findings could pave the way for future research that seeks to examine potential relationships between these scores, improved physical performance and a decrease in risk of injury. Frost, Beach, Callaghan & McGill [60] have also utilised the FMS system to analyse the effectiveness of a 12 week exercise program for firefighters. According to the authors, their results showed a surprisingly lack of changes in FMS scores after the 12 week exercise program, even though significant improvements in a range of other physical fitness qualities were observed. This led the authors to question the ability of the FMS to detect any significant changes in movement competency as a result of a specifically designed exercise program targeting movement deficiencies. These conflicting conclusions could plausibly be due to the variations in the intervention programs utilised. Frost et al. [60] implemented a training program not specific to the FMS, Cowen et al. [65] implemented yoga classes amongst beginners whereas Kiesel et al. [63] developed a training program based on the FMS score outcome of every participant. Beside the opposing results, these studies may still support the benefits of using musculoskeletal screening assessment tools in the strength and conditioning process. However, if these musculoskeletal screening assessments are to optimally inform the exercise prescription, such screening protocols need to be specifically tailored to the athlete's sport in order to obtain relevant data regarding the athlete's current physical capabilities and how they may contribute to performance and/or risk of injury.

Musculoskeletal Screening Assessments in Golf

There are currently very few studies which have utilised musculoskeletal screening approaches in golf. Of these studies, most of which utilised a very limited number of assessments in their screening protocols. Keogh et al. [7] investigated the relationship between several musculoskeletal screening assessments (including measures of abdominal muscular endurance as well as upper and lower body ROM) and CHS in 10 low and 10 high-handicap golfers. Keogh et al. [7] reported non-significant correlations of $r = 0.43$ between abdominal muscular endurance and CHS; with similar non-significant correlations of $r = 0.00 – 0.34$ found for the ROM measures and CHS. Parchmann and McBride [66] utilised a more comprehensive musculoskeletal screening assessment (FMS) with the aim to predict athletic ability or CHS in 25 National Collegiate Athletic Association Division I golfers. However, none of the FMS assessments were able to predict athletic ability or CHS in this cohort.

Previous studies have thoroughly investigated injury patterns in golfers, with most studies reporting LBP as one of their most common injuries [26, 34, 52, 67, 68]. As a result, several studies have utilised musculoskeletal screening assessment techniques in an attempt to identify risk factors for LBP in golfers [24, 29, 66, 69]. Evans et al. [24] used a number of musculoskeletal screening assessments (abdominal muscle endurance, upper and lower body ROM and body composition) in an attempt to identify risk factors for LBP in 14 trainee professional golfers. Their results demonstrated high BMI and reduced muscular endurance of their right relative to left lateral trunk flexors were the strongest predictors of a LBP episode. There was also some evidence to suggest that golfers with tight hip flexors were also more likely to report that LBP affected their performance. Further, Evans et al. [24] emphasised the strong relationship between right side deficit on the side bridge test and LBP, suggesting that the correction of this deficit may reduce LBP. Evans and Oldreive [56] also observed that those golfers who have a history of LBP had significantly reduced transverse abdominis muscular endurance than those golfers with no history of LBP. Such findings warrant the assessment of the trunk region prior to engaging in any golf strength and conditioning programs or before an increase in golf practice volume is considered. Vad et al. [29] quantified hip and lumbar ROM with the aim of establishing whether these variables may be associated with a prior history of LBP in 42 professional golfers. The authors reported that the 14 symptomatic golfers had significantly reduced lumbar extension and reduced hip internal rotation ROM of the lead leg than asymptomatic golfers [29].

Collectively, the results of these four musculoskeletal studies provide some insight into the risk factors of LBP in golf, allowing for researchers to assemble a battery of musculoskeletal screening tests to assess the current status of individual golfers. However, further refinement and clarification of these musculoskeletal screening assessments need to be performed so to assess the specific requirements of golf. From a research design perspective, these four musculoskeletal golfing studies have utilised samples of between 14 and 42 participants, suggesting the use of larger samples of more homogenous golfers may be required to more clearly describe the relationships between musculoskeletal screening, golf swing performance and injury risk.

On this basis, a more "golf specific" musculoskeletal measurement protocol would appear required to better inform strength and conditioning and sports physiotherapy practice in golf. An attempt to achieve this has been performed, with this protocol referred to as the *Ten Test On Range* (The Golf Athlete, Brisbane, Australia). The *Ten Test On Range* screening tool involves a series of tests designed to assess physical parameters thought to be important for golf (see Table 2.3). As such, this protocol will be adopted in this thesis. This protocol is commonly used by many Australian golf professionals and physiotherapists, with many of the assessments in this battery reported to have good intra-and inter-rater reliability when conducted by inexperienced and experienced testers [69].

Table 2.3. A Description of the *Ten Test On Range* Musculoskeletal Screening Tests

Musculoskeletal Screening Test	Structures Assessment	Rationale of Importance to Golf Performance or Injury Risk
Side bridge (seconds)	Challenges the muscles of the anterolateral chest wall (lateral trunk flexors), the quadratus lumborum, external and internal obliques.	McGill and colleagues [70] outlined the importance of developing sufficient muscular endurance around the torso, specifically the quadratus lumborum to reduce the risk of LBP. These lateral trunk muscles may play an important role in stabilising the spine as well as contributing to the development of trunk angular velocity during the golf swing.
Front plank (seconds)	Challenges the muscles of the anterior abdominal muscles.	McGill and colleagues [70] outlined the importance of developing sufficient muscular endurance around the torso region. The muscles of the anterior abdominal wall contribute to the production of adequate stability as well as transferring forces from the lower to upper body during the golf swing.
Combined elevation (thoracic extension)	Global measure of the flexibility of the upper back and thoracic spine	The ability to elevate the upper limbs overhead and effortless manner ease would seem relevant to maximising range of motion in the backswing.

(cm)		
Hip Internal Rotation (degrees)	Global measure of hip internal rotation movement	The mobility of the hip rotators would appear to be important so to effectively summate the joint angular velocities during the golf swing LBP [29]. The literature has found that those golfers who lack sufficient hip internal rotation are more likely to "over-rotate' their spines during the golf swing, increasing the subsequent spinal load and likelihood of suffering a LBP episode [28]
Hip External Rotation (degrees)	Global measure of hip external rotation movement	Several authors have noted how important it is for golfers to have adequate hip mobility due to the strong correlation between a lack of hip ROM and LBP [29]. Greater hip external rotation will theoretically allow for the golfer to increase the length of their backswing and follow-through, which may contribute to golf swing performance and a reduction in injury risk.
Straight Leg Raise (degrees)	Global measure of the flexibility of the hamstring muscle group	Several investigators [71, 72] have linked a reduced hamstring range of motion and the incidence of LBP. Incorporating a test such as the Passive straight leg raise test may provide valuable information to golf coaches regarding the athlete's hamstring muscle length and how this may be a potential risk of LBP [71].
Thoracic	Global measure of the flexibility of	The X-Factor or X-Factor stretch both relate to the relative range of motion of

Rotation (degrees)	the cervical & thoracic spine	the trunk compared to hip rotation during the golf swing has been identified as a potential predictor of CHS in golf. [47].
Overhead squat (1-5)	Global measure of upper back, hip and ankle mobility	The overhead squat test is a reliable, global assessment of mobility and ROM around the ankles, hips, thoracic and shoulder region [73]. A relatively low score on this test could identify limited mobility at a particular joint, which has consequences for the golfer's ability to generate and transfer power during the golf swing.
Single leg bridging lift (1-5)	Global measure of hip strength and weight transference	The bridging leg lift test subjectively measures gluteal and hip strength and stability. McHardy and Pollard [41] commented on the high activity of the gluteals during the downswing, so to reinforce correct recruitment and activation of the hip stabilising muscles.
Single leg squat (1-5)	Global measure of hip &thigh muscle strength and control	The single leg squat is a challenging movement requiring high degrees of stability around the ankle and hip joint as well as intense muscular contractions of the knee and hip extensors. This has some similarities to the muscular demands associated with weight transfer during the golf backswing and downswing [74, 75].

Table 2.4. Inter-tester Reliability of the *Ten Test On Range* Musculoskeletal tests

	ICC (95% Confidence Interval)	
Musculoskeletal Screening Tests	**Inexperienced**	**Experienced**
Single leg squat	0.44 (0.29 – 0.62)	0.41 (0.25– 0.59)
Single leg bridge	0.32 (0.19 – 0.50)	0.30 (0.16 – 0.49)
Seated trunk (Thoracic) rotation	0.60 (0.45 – 0.75)	0.50 (0.33 – 0.68)
Lift off (Thoracic Extension)	0.67 (0.54 – 0.81)	0.71 (0.54 – 0.84)
Overhead squat	0.85 (0.76 – 0.92)	0.84 (0.75 – 0.91)

Table 2.5 Intra-tester Reliability of the Ten Test On Range Musculoskeletal tests

	ICC Range	
Musculoskeletal Screening Tests	**Inexperienced**	**Experienced**
Single leg squat	0.55 – 0.96	0.28 – 0.92
Single leg bridge	0.86 – 1.00	0.34 – 0.95
Seated trunk (Thoracic) rotation	0.73 – 0.98	0.58 – 0.97
Lift off (Thoracic Extension)	0.28 – 1.00	0.63 – 0.98
Overhead squat	0.95 – 1.00	0.69 – 0.99

Reprinted from Horan S. Evans, K. and Dalgleish, M. (2014). Reliability of a Standardised Golf Specific Musculoskeletal Screening Protocol Designed for use by Golf Professionals.

Exercise Programming for Golf

An effective exercise program for golf should look to provide movement control across multiple joints, as well as strengthen and lengthen the relevant primary muscles that contribute to performance and/or may be at risk of injury. It is imperative that the exercise programs adhere to the principle of specificity, ensuring that the relevant muscles and movement patterns to be trained resemble the actions of the golf swing. As such, having an understanding of the primary muscles involved in the golf swing, how these muscles are coordinated, the joint ROM required and the muscles, joints etc. that may be at risk of injury is fundamental to the exercise prescription process.

Commonalities and Differences in Golf Exercise Programs

As can be seen in Table 2.4, there are a number of commonalities and differences in the exercise programs performed in the golf literature. A majority of these studies utilised relatively small samples sizes (N < 20) [11-17, 37, 39, 76, 77]. There was however much greater between study heterogeneity in terms of factors such as age, with both middle to older [15-17] and younger adults [11, 12, 14, 38] involved as participants. There was also substantial variation between and sometimes within studies in relation to the level of golfing performance (i.e. handicap) of the participants. Finally, there was often considerable differences in the exercise prescription across the studies. Such heterogeneity within the literature makes it somewhat difficult to provide overall generalisations on the efficacy of exercise for golf performance. For example, you may look to compare the studies of Alvarez et al. [11] and Lephart et al. [15]. Lephart et al. [15] reported the mean age ± SD of golfers to be 47.2 ± 11.2 , whereas Alvarez et al [11] had a mean age ± SD group of 23.9 ± 6.7 and 24.2 ± 5.4 for the control and treatment groups, respectively. Alvarez et al. [11] focused more on assessing the effects of an exercise prescription incorporating maximal, explosive and golf-specific strength exercises divided into 3 x 6 week blocks, respectively. Alternatively, Lephart et al. [15] used considerably less strength focused training, and more resisted golf swing movements in addition to some stability and flexibility exercises, yet both studies still managed to elicit improvements in both musculoskeletal measures and CHS. Despite improvements observed in both studies, it is of utmost importance to recognise the different subject demographics, and therefore consider the requirements and abilities of those respective age groups when prescribing an exercise program as their adaptations may largely depend on both the length and type of stimulus applied.

Gender differences is another key factor to consider when incorporating an exercise program due to the potential for different physiological characteristics and adaptations that occur between males and females [78]. As females may have greater flexibility but reduced muscular strength and power as well as limb lengths than males, the potential benefits of different exercise prescriptions on male and female golfers may differ to some extent. The current literature appears to have utilised samples that have been completely male or a mixture of genders that still favoured male participants. Therefore, it is almost completely unknown if male and female golfers may respond somewhat differently to the same exercise prescription.

The wide variety of exercise prescriptions used in the golf literature also make it somewhat challenging to determine what aspects of these exercise programs were most crucial in increasing musculoskeletal measures and golf swing performance. A vast majority of these studies prescribed exercises which were reflective of hypertrophic and strength based protocols, typically not representative of the explosive, maximal velocity movement of the golf swing. Throughout the literature, however, attempts have been made to utilise exercises which not only mimic the golf swing action but also its movement velocity and muscle activation sequencing [13, 15, 38]. As mentioned before, the golf swing is a rapid predominantly rotational movement with the aim often being to maximise velocity in the shortest amount of time to make contact with the ball. Schofield [38] recently successfully implemented a power type exercise protocol amongst two golfers with the aim of better understanding the usefulness of performing exercises which more accurately reflect the movement speed of the golf swing. The results of the aforementioned study showed a statistically significant improvement in CHS for both participants after the 6-week exercise program. To the author's knowledge, Schofield [38] and Alvarez et al. [11] may be the first two studies to investigate the effectiveness of a maximal power type training protocol in improving CHS in golfers. Conducting more of these explosive type exercise programs would seem to be just as beneficial as the general hypertrophic, strength based protocols generally utilised in the literature. Furthermore, these findings can enable investigators to have greater access to variables which may play vital roles in predicting successful golfing performance [38].

There has also been various research designs utilised in the literature, for example, when participants are randomly divided into control and treatment groups in what is known as a randomised controlled trial. This has the benefit of comparing the treatment group to the control group, i.e. the true effect the program had on the subject could then be shown without bias. In contrast, a single group pre–post design has been used in a number of these studies, whereby all participants received the exercise program, with no participants included in the control group. Such single group, pre—post-test designs are more prone to a range of biases that contribute to the level of evidence being less than that obtained from a randomised controlled trial.

Table 2.6. Summary of Golf Exercise Trials

Study	Sample (Age, Hcp, N)	Type of training	Duration	Frequency	Change in strength	Change in flexibility	Change in club head speed	Change in driving distance	Change in accuracy
Westcott et al. [77]	Age = 57 yr, N = 17 (13 M, 4 F) N = 3 (Con)	ST & FT	8 Wk	3d / wk	LE: 56%*	Ave. Hip & Shoulder 24%*	6%*	NA	NA
Hetu et al. [76]	Age = 52.4 ± 6.7 yr, N = 17 (12 M, 5 F)	ST, FT, Plyo (med ball rotations)	8 wk	2d /wk	LE: 18.1%*, BP: 14.2%*, GS: 6.2%*	SR: 38.8%*, TR: 47.3%*	6.3 %*	NA	NA
Jones [37]	Age = 58 ± 9 yr, Hcp = 18 ± 7, N = 16	FT	8 wk	3d / wk	NA	HF: 7.1%, HE: 35.3%, SA: 8.6%, SER: 8.9%, TRR: 23.5%, TRL: 25.1%	7.2 %*	NA	NA
Fletcher and	Age = 29 ± 7.4 yr, Hcp	ST and Plyo	8 wk	2d /wk	NA	NA	1.5%*	4.3%*	NA

Hartwell [13]	= 5.5 ± 3.7, N = 6 M (Exp) N = 5 M (Con).								
Thompson and Osness [16]	Age = 64.8 ± 6.1 yr, Hcp = all levels, N = 19 M (Exp) N = 12 M (Con)	ST (1 set of 12 reps on each ex.) and FT	8 wk	3d / wk	BP: 35.6%*, AC: 28.9%*, SP: 38.3%*, SRO: 36.9%*, LPL: 21.3%*, BC: 60.4%*, BE: 27.7%*, LC: 27.3*, LP: 41.1%*, LE: 38.5%*,	TR: 34.4%*, SA: 16.5%*, ISR: 24.2%*, ESR: 18.2%*, TF: 18.7%*.	2.7%*	NA	NA
Doan et al. [12]	Age = 19.3 ± 1.5 yr, Hcp (M) = 0, Hcp (F) = 5 – 10, N	ST (trunk), FT	11 wk	3d / wk	Total = (TR: 14.8%*, GS: 7.3%*, BP: 10.2%*, SQ:	Total; TRBS: 14.8%*, TRFT: 9.7%*	Total = 1.62%*, M = 0.61%, F = 3.36%	NA	PDC: (Total = - 20.44%, M = - 29.56%*, F

	= 16 (10 M, 6 F)				13.3%*, LPL: 12.6%*, SP: 23.6%*7-24%)				= -6.76%*)
Lephart et al.[15]	Age = 47.2 ± 11.4 yr, Hcp = 12.1 ± 6.4, N = 15 M	ST, FT, BT	8 wk	3-4d /wk	LT 60°/s: 8.9%*, RT 60°/s: 7.5%*, RT 120°/s: 13.3%*, ILHA: 8.6%*, IRHA: 9.9%*	All ROM variables improved significantly	5.2%	7.7%	NA
Thompson et al. [17]	Age = 70.7 ± 7.1 yr, Hcp = NA, N = 11 M (Exp) N = 7 M (Con)	ST, BT, SS	8 wk	3d /wk	TUG: 8.5%, STEP: 23.1%. CHAIR: 11.8%	SR FLEX: 64.5%*	4.5%	NA	NA
Kim et al. [39]	Age (Exp) = 22.9 ±	CT, FT	12 wk	3d /wk	BE: 55.6% SQ: 18.4%	FF: 8.97% BF: 9.38%	3.48%*	2.5%*	NA

	3.69 yr, (Con) = 21.75 ± 4.37 yr, Hcp = NA, N = 9 F (Exp), N = 8 F (Con)				ILBS: 11.48%				
Alvarez et al. [11]	Age (Con) = 23.9 ± 6.7 yr, (Exp) = 24.2 ± 5.4 yr, Hcp ≤ 5, N = 5 M (Exp), N = 5 M (Con)	ST	6 wk	2d / wk	IGSR: 5.1%, IGSL: 3.9%, BP: 6.6%, SQ: 11.6%, SRO: 16.5%, TCP: 11.1%, SC: 16.1%, MP: 14.1%	NA	4.1%	NA	NA
Alvarez et al. [11]	Age (Con) = 23.9 ± 6.7 yr, (Exp) =	PT	6 wk	2d / wk	IGSR: 0.5%, IGSL: 2.9%, BP: 7.4%, SQ:	NA	2.7%	NA	NA

	24.2 ± 5.4 yr, Hcp ≤ 5, N = 5 M (Exp), N = 5 M (Con)				17.8%, SRO: 13.3%, TCP: 14.9%, SC: 13.1%, MP: 8.2%				
Alvarez et al. [11]	Age (Con) = 23.9 ± 6.7 yr, (Exp) = 24.2 ± 5.4 yr, Hcp ≤ 5, N = 5 M (Exp), N = 5 M (Con)	GST	6 wk	2d / wk	IGSL: -0.3%, IGSR: 0.04%, BP: -2.9%, SQ: 2.6%, SRO: -2.8%, TCP: -4.6%, SC: 0.6%, MP: 1.6%	NA	4.3%	NA	NA
Lamberth et al. [14]	Age = 21.4 ± 2.3 yr, Hcp ≤ 8, N = 10 M	ST, PT	6 wk	NA	BP: 8.8%*, LP: 9.5%*	SR: 6.1%	3.9%	NA	NA
Schofield [38]	Age = 24.5 ± 2.1 yr,	PT, ST, Plyo	6 wk	3d / wk	NA	NA	3.1% - 3.9%	NA	LD: -29.5% - (-)

Hcp = NA, N = 2 M.	136.6%*

Con = Control; Exp = Experimental; M = Male; F = Female; Hcp = handicap; AC: Abdominal Curl; BC: Bicep Curl; BE = Back Extension; BF = Back Flexion; BP = Bench Press; BT = Balance Training; CHAIR: 30-s Chair stand test; CG = Control Group; CT= Core Training; ESR = External Shoulder Rotation; FF = Forward Flexion; FT = Flexibility Training; GS = Grip Strength; GST = General Strength Training; HF = Hip Flexion, HE = Hip Extension; IGSR = Isometric Grip Strength Right Hand; IGSL = Isometric Grip Strength Let Hand; ISR = Internal Shoulder Rotation; ILBS = Isometric Low Back Strength; LC = Leg Curl; LD = Lateral Dispersion from target line (Trackman); LE = Leg Extension; ILHA = Isometric Left Hip Abduction; LP = Leg Press; LPL = Lat Pull-down; LT 60°/s = Left Torso Rotation at 60°/s; MP = Military Press; NA = Not Applicable/Provided; PDC = Putting Distance Control test – 15 puts from 4.6m; Plyo = Plyometric Training; PT = Power Training; IRHA = Isometric Right Hip Abduction; RT 60°/s = Right Torso Rotation at 60°/s; RT 60°/s = Right Torso Rotation at 120°/s; SA = Shoulder Abduction; SC = Seated Calf Machine; SER = Shoulder External Rotation; SP = Shoulder Press; SQ = Squat; SR = Sit and Reach; SR FLEX = Chair sit and reach; SRO = Seated Row; SS = Spinal Stabilisation; ST = strength training; STEP = 2 minute step test; TCP = Tricep Cable Pushdown; TF = Trunk Flexion; TG = Treatment Group; TR = Trunk Rotation; TRBS = Trunk Rotation Backswing; TRFT = Trunk Rotation Follow Through; TRR = Trunk Rotation Right; TRL = Trunk Rotation Left; TUG = 8-ft timed up-and-go test; wk = week(s); yr = year; * = significant ($p < 0.05$).

Effectiveness of Exercise Interventions on Golf Performance

Longitudinal exercise studies in the golf literature have been designed with a focus on developing muscular strength and flexibility, typically written as a hypertrophic based protocol, with less of an emphasis on physical determinants such as muscle power. In general, these exercise programs have been found to be effective in improving aspects of musculoskeletal measures crucial to the sport of golf. For example, studies that performed resistance training reported improvements in the ranges of 7.3-60.4% for the primary strength tests [12, 14-17]. Similarly, studies that involved flexibility training found improvements of 7-39% for the range of motion tests [15-17]. When these exercise studies have measured CHS, many studies reported small but significant increases in CHS of up to 7.2% [12-17, 37, 38, 76, 77]. Thus, the prescription of relatively non-specific strength and conditioning programs to facilitate increases in muscular strength, range of motion, and golf swing performance, i.e. CHS, are recommended performance enhancing strategies. However, it is imperative to examine the demographics of the involved participants as well as the nature of the strength and conditioning program so that appropriate generalisations and subsequent recommendations can be made.

As has been stated, most exercise prescriptions have been relatively non-specific, hypertrophy and strength based training protocols with the aim of increasing muscular strength, i.e. scores on Repetition maximum (RM) and flexibility tests [11, 12, 14-17, 38, 76, 77]. The duration of these programs have been variable, with most studies utilising durations of 8–18 weeks. In contrast, one author suggested that only 6 weeks of resistance training is needed to see improvements in physical characteristics, such as maximal and explosive strength [11]. Perhaps as a result of such a statement regarding the potential of six weeks resistance training to elicit significant benefits, Lamberth et al. [14] examined the effects of a six week strength and functional training program on golf swing performance, with the focus on CHS changes. Although significant improvements were reported in several strength measures, i.e. bench press and leg press, no significant changes were observed for CHS in either control or treatment groups. With many studies finding pronounced changes in golf swing performance after 6-8 week exercise programs [13, 15-17, 37, 76, 77], such results may infer a minimum duration of 6-8 weeks of training is required to see such adaptations.

The minimum duration required to elicit significant physical benefits may also reflect other aspects of the actual exercise prescription, whereby most golf exercise programs have focused on slow movement speed hypertrophic/strength based exercise protocols, involving 2-4 sets of 6-12 reps. In contrast, Alvarez et al [11] conducted an 18 week exercise program in which they divided the program into 6 week blocks of maximal strength (weeks 1-6), explosive strength/power (weeks 7-12) and golf-specific strength training (weeks 13-18). The authors noted significant changes in maximal strength after the first 6 weeks of maximal strength training, whereas the golfers needed another 6 weeks of training (involving explosive strength) to convert these changes into improvements in golf swing parameters such as ball speed and club mean acceleration. While such a periodised training program may be indicative of typical resistance training periodisation used in other sports, its design does not necessarily answer the question of what form of training resulted in the greatest change in golf swing performance. It remains somewhat unknown if the explosive strength/power was solely responsible for the improvements in golf swing performance or if it was the combined effect of the strength (Week 1-6) and explosive strength/power (Week 7-12) phases. Nevertheless, this was one of the first studies whereby explosive, ballistic exercises were incorporated in a periodised progressive order to simulate the movement specificity of the golf swing. Recently, Schofield [38] examined the effects of a power type training program in an attempt to replicate the movement velocity and muscle activation sequencing of the golf swing over a 6 week period. Across the two exercising participants, Schofield [38] reported significant increases in Cable Down Swing (CDS) test performance across the load range of 1.25kg - 18.75kg (5.2% - 20.1% and 14.0% - 17.6%, for participants, respectively) that were associated with the statistically significant increases of 3.1% and 3.9% in CHS. Such improvements in CHS may reflect the movement specificity of the CDS test, as it closely replicates the action and muscle activation patterns of the golf swing. Furthermore, it was noted that no significant changes was found in the Isometric mid-thigh pull (IMTP) testing after 6 weeks of power training, suggesting that isometric assessments of non-golf specific movements may explain little of the changes that occurred in CHS. The two aforementioned studies have thus successfully utilised power-type, explosive resistance training programs, warrant future studies to investigate the usefulness of more long-term strength and conditioning programs.

Chapter Three: The Effect of a Seven Week Long, One Session per Week Exercise Program on Golf Swing Performance and Musculoskeletal Measures

Introduction

Golf has traditionally been viewed as a skill based sport that is not overtly physical and has a low risk for injury. However, this view is in contrast to elite golf practice with recent reviews finding high levels of lower body, trunk and upper body muscle activity during the golf swing [41], relatively high physiological stress during match play [3] and relatively high injury rates to areas such as the lower back, shoulder and wrist [25, 26, 32]. Most golf-related injuries are thought to result from the large number of practice hours golfers perform, the asymmetrical nature of the golf swing or biomechanical-related swing inefficiencies.

Several exercise studies have looked at the effects of strength and conditioning programs on physical characteristics and found significant improvements following the programs in muscular strength, power, endurance and range of motion in golfers of various ages and skill levels [12, 13, 15-17, 79, 80]. The study by Doan et al., [12] assessed highly skilled golfers before and after 11 weeks of resistance training, assessing their golf performance, muscular strength and flexibility. They reported significant improvements in all strength, power and flexibility measurements, with relative strength gains and flexibility ranging from 7-24% and 7–16% respectively. Similarly, Lephart et al., [15] investigated the effects of an eight-week exercise program on less skilled and older athletes in comparison to the above mentioned study. Their results showed statistically significant increases in all ROM tests as well as for club head velocity, ball velocity, carry distance and total distance. The majority of previous exercise studies have ranged between 8-18 weeks and typically involved 2-3 exercise sessions per week. In contrast, the training programs of Larkin et al. [79] and Reyes [80] only went for three and seven weeks, respectively. Following on from this, a recent study by Lamberth et al., [14] utilised a 6-week combined resistance and functional training program with the aim of eliciting improvements in golf swing performance. Lamberth et al., [14] found significant improvements in one-repetition maximum bench press and leg press, but no significant change in club swing speed.

Despite growing evidence that exercise offers golfers significant performance benefits [12, 13, 15-17], the specific type and frequency of physical conditioning programs to achieve optimal outcomes is still unknown. Adhering to time-intensive exercise programs may be challenging for collegiate golfers who are studying full-time, working part-time and trying to maintain relatively high amounts of golf practice and match play. These demands may mean that it is difficult for these golfers to apportion enough time to be able to perform 2-3 supervised sessions per week as has been performed in previous exercise studies [12, 13, 15-17, 36]. Additionally, with the collegiate golf programs requiring students to pass academic, playing and industry components away from the course, program instructors need to be mindful of student load when scheduling exercise sessions into the program. As very little research has examined the effects of a reduced physical conditioning training duration and/or frequency on collegiate golfers, such research appears warranted. Previous studies that have examined reduced training frequency [21, 81, 82] have demonstrated that relatively untrained older adults can significantly improve muscular strength, power and/or endurance with one exercise session per week. Furthermore, significant body composition and physical performance gains can be observed in as little as four weeks of training in professional rugby union players [83]. It would therefore appear feasible that even one resistance exercise session per week may induce significant improvements in muscular strength, power and endurance that may subsequently improve musculoskeletal screening test outcomes and/or golf swing performance in collegiate golfers with little to no physical conditioning experience.

Strength and conditioning coaches and physiotherapists frequently employ musculoskeletal screening assessments [22, 60, 61, 64, 84, 85] to assess physical fitness deficiencies and movement dysfunctions thought to contribute to reduced performance or an increase injury risk in athletes. Screening protocols, such as the Functional Movement Screen (FMS) [22, 60-64], Movement Competency Screen (MCS) [85] and the Conditioning Specific Movement Tasks (CSMT) [84] have gained substantial attention over recent years because of their proposed potential to identify dysfunctional movement patterns that may reduce performance and predispose athletes to greater risks of injury. From a performance perspective, Parsonage et al. [84] investigated elite adolescent rugby players and divided them into 3 groups based on four CSMT. Results showed that the two groups who performed better on movement competency tests, thought to be specific for rugby, were significantly faster over 10, 20 and 40m, jumped significantly higher, and covered significantly greater distances on the Yo-Yo intermittent recovery level 1 than the group who scored lower on these movement competency tests. Kiesel et al. [63] and Cowen et al. [65] have also observed significant improvements in FMS scores after an exercise program designed to improve the movement deficiencies identified by baseline assessments.

However, some limitations still exists with the common screening assessments. Firstly, there is currently limited evidence as to the efficacy of these screening protocols in reducing the risk of injury. Secondly, these screening approaches appear quite generic and appear to be focused on athletes competing in running-based sports. On this basis, a more "golf specific" musculoskeletal measurement protocol referred to as the *Ten Test On Range* (The Golf Athlete, Brisbane, Australia) assessment protocol has been developed. This screening tool involves a series of tests designed to specifically test physical parameters thought to be important for golf and thus was adopted in this study [86]. While commonly used by many Australian golf professionals and physiotherapists, there is limited research on this screening tool.

Therefore, the aim of the current study was to investigate the effects of a short duration (i.e. seven week) exercise program comprising one exercise session per week on musculoskeletal measures and golf swing performance outcomes. It was hypothesised that the exercise program would result in improvements in both musculoskeletal screening scores and golf swing performance.

Methods

Participants

Forty-three golf students (7 females and 36 males, mean ± SD age 24 ± 8.9 years) volunteered to participate in the study (handicap, 8.6 ± 8.3 strokes). All students were enrolled in a Diploma of Golf Management at the PGA-IGI (Professional Golf Association of Australia– International Golf Institute), which is a full-time, one year golf management course. All participants had a minimum of one years' golf experience, and little if any previous experience with a golf-specific exercise program. Written consent was obtained prior to data collection and approval to conduct the study was given by the relevant institutions' ethics committees.

Overview of Experimental Design

The current project was a single-group based exercise study involving a pre-post design. Prior to the 7 week exercise program, participants completed assessments of musculoskeletal screening and golf swing performance across two testing sessions. At the first session, participants were asked to perform a series of 10 selected musculoskeletal screening tests [86], while at the second session participants performed a standardised, field based golf swing performance test which included 60 golf shots (Combine Test, TrackMan, ISG A/S, Denmark). Following baseline testing, all participants undertook a once weekly, seven-week golf specific exercise program consisting of muscular strength and endurance exercises. Following completion of the exercise program, all participants repeated the same musculoskeletal screening and golf swing performance tests performed at baseline.

Musculoskeletal Screening Assessments

The present study employed 10 musculoskeletal screening tests to examine flexibility, muscular endurance and movement competency of all participants. The testing sessions were conducted at a Country Club (Sanctuary Cove, Gold Coast), with each of the musculoskeletal screening sessions lasting ~one hour, whilst each Combine performance test taking ~45 minutes. An experienced Exercise Scientist, 2 experienced sports physiotherapists, 10 post-graduate physiotherapy students and a Master of Science student conducted the musculoskeletal testing sessions at the Country Club before and after the intervention. The Combine test was performed on the golf range under the supervision of a Master of Science student with the assistance of a golf lecturer at the Country Club. Table 3.1 provides a description and rationale of the musculoskeletal screening tests utilised in this study.

Table 3.1: A Description of the Musculoskeletal Screening Tests

Musculoskeletal Screening Test	Structures Assessment	Protocol
Side bridge	Challenges the muscles of the lateral trunk, the quadratus lumborum, external and internal obliques.	Participants laid on their side on the floor, with their forearm and feet supporting their weight. The elbow joint of the support arm flexed at 90°, with the opposite arm placed across their chest and legs extended. Participants then elevated their hips and kept a straight line with their whole body for maximum time, as assessed by a stopwatch [24, 70].
Front plank	Challenges the rectus abdominis, oblique and transverse abdominis muscles.	Participants were prone, placing their hands and elbows in front of them on the ground. Participants had to elevate their bodies to start the test, using their hands and toes as pivots whilst maintaining a straight, neutral body position where time taken was in seconds and participants were encouraged to maintain this for as long as possible.
Combined elevation	Global measure of the flexibility of the thoracic spine	Participants were prone on the floor, arms extended out in front of them with hands pointing forward, palms facing down and thumbs touching. Participants

(thoracic extension)		kept their chins on the floor, looking up at their thumbs with their chest, hips and feet kept on the floor during the test. They had to then lift up their arms slowly and as far as possible whilst keeping thumbs touching. The vertical distance from their hands to the floor was taken with a tape measure.
Hip Internal Rotation	Global measure of hip internal rotation movement	Participants were supine on a plinth, a belt was around their hips at the anterior superior iliac spine to stabilise their pelvis. The non-test leg was kept straight and the stretching leg was in 90° hip flexion. The assessor inwardly rotated the knee which outwardly rotated the foot until resistance. The stationary arm of the goniometer was in line with trunk and the movable arm in line with tibia. The COR was at the central patella tendon/inferior pole (central knee joint). This was repeated on the other leg.
Hip External Rotation	Global measure of hip external rotation movement	Participants were supine on a plinth, a belt was placed around their hips at the anterior superior iliac spine to stabilise their pelvis. With one leg straight, the other leg was at 90 degrees hip flexion. Their foot was outwardly rotated which inwardly rotated the hip until resistance. The stationary arm of the goniometer was in line with trunk and the movable arm in line with tibia. The COR was at central patella

		tendon/inferior pole (central knee joint). This was then repeated on the other leg.
Straight Leg Raise	Global measure of the flexibility of the hamstring muscle group	Participants were supine on a plinth with hands by their sides. One instructor lifted the test leg extended into hip flexion, keeping the knee extended until resistance was felt or pain initiated. The opposite leg and pelvis was kept straight by another instructor. An inclinometer was placed on the anterior part of the tibia, measuring the degrees of flexibility.
Thoracic Rotation	Global measure of the flexibility of the cervical & thoracic spine	Participants sat upright in a chair. A golf club was placed behind their backs for them to cradle the club in their elbows and maintaining club-spine contact. Participants kept knees, feet and hips facing forward. Participants rotated to one side as far as possible until club-spine contact was no longer maintained. A goniometer measured degrees of rotation by placing the stationary arm above the participants head with the moving arm in line with the leading shoulders direction and shaft direction. This was repeated on the other side.
Overhead squat	Global measure of upper back, hip and ankle mobility	Participants stood feet shoulder width apart, and were instructed to squat down until thighs were parallel to the floor. They had to keep the golf club above their head. Scoring was done with a 1, cannot get thighs to parallel with arms across

		chest, to 5, squat with thighs parallel and arms extended above head.
Single leg bridging lift	Global measure of hip strength and weight transference	Participants were instructed to lie supine on the floor, place feet apart, and lift their hips off the ground whilst extending one leg and holding it for 10 seconds. Participants were scored on a 1 – 5 scale, with 1 being the inability to straighten the leg and 5 is a steady 10 second hold with no cramping in the hamstring muscles
Single leg squat	Global measure of hip & trunk muscle strength	Participants folded their arms across their chest, stood on one leg with the other leg out in front. Participants were encouraged to do 6 controlled squats whilst aiming to reach 90° knee flexion. A scoring system of 1, significant dropping of hips, knees and losing balance, to 5, performed squat with good control to 90 degrees knee flexion, was used

Golf Swing Performance and Variables

Golf swing performance was measured using a Doppler Radar system, namely the TrackMan (TrackMan IIIe, Vedbaek, Denmark). This device is valid and reliable [87] and is commonly used by Australian golf coaches and on the USPGA and European PGA tours [40], Using this device enables participants to complete a field based golf swing performance test called the 'Combine Test' (TrackMan Performance Studio Version 3.0, TrackMan, Denmark), which involved 60 shots to 10 standardised targets. For each shot, the software provided a score from 0-100 based on distance from the target along the target line and lateral deviation from the target line. The lowest score for a shot equates to 0 and the highest 100. Distance markers were placed at 50, 100 and 150 metres, with the markers measured using a golf laser range finder (Bushnell Medalist, Overland Park, United States). The distance markers were placed in a line, providing each golfer with a target line to hit towards. All testing was performed on an outdoor driving range (150 × 300 metres), with each participant hitting shots from an artificial grass mat. Environmental conditions were similar on all testing days, with temperatures between 24 – 28 degrees Celsius and light winds between 10 – 20 km/h. The golf balls used were range balls (Srixon, Sydney, Australia), which generally travel ~80% of the distance of a standard competition ball. As seen in Figure 3.1, the TrackMan device was set up approximately 1.5 – 2.0 m behind the ball and in line with the target line similar to the recommendations of Robertson et al. [18].

Figure 3.1. A participant completing the Combine test using the TrackMan system.

Following a warm-up and familiarisation period of 15-20 minutes which included shots with a selection of clubs (i.e. self-selected), participants undertook the Combine Test. The test requires the golfer to hit shots using their club of choice (except the maximum distance shot where a driver is used) to distances along a target line at 65, 75, 85, 95, 105, 125, 145 and 165 metres, as well as a shot for maximum distance with the driver club. At each distance the golfer hits three shots starting at the 65 metre distance, followed by three shots to each subsequent distance thereafter. At the completion of these 30 shots, the process is repeated a second time until a total of 60 shots is completed. In the current study, participants were instructed to hit the ball as straight and close as possible to the target distance, except for the driver where participants were instructed to hit the ball as far and straight as possible. In addition to a score for each shot and an overall score out of 100, the TrackMan device allows for the measurement of other performance variables. No time constraints were implemented to perform the combine test, with rest periods between shots decided by participants. In the current study, the measurements we were interested in were club head speed (CHS), ball speed, carry distance, total distance, carry side (lateral deviation distance) and smash factor (ball speed / clubhead speed). A description of the variables is given in Table 3.2.

Table 3.2. Selected Golf swing Parameters as measured by the TrackMan.

Golf performance variables	Definitions
Club head speed (CHS)	The speed at which the club head is moving before impact
Ball Speed	The speed of the ball after impact is made
Carry Distance ("flat")	The distance the ball travels through the air
Carry Side (accuracy)	The measurement of where the ball lands in relation to the target line, either left or right of it.
Smash Factor	The ball speed divided by the club speed

Exercise Program

All participants were asked to complete one supervised exercise class per week for a 7 week period. The exercise program (see Table 3.3) was developed through consensus moderation between all researchers (all of which were trained exercise scientists or physiotherapists), with consideration given to the biomechanics and physical requirements of the golf swing, common injury sites of golfers, as well as the practicalities of the exercise facility and time available per class. The classes were held in a group exercise room and supervised by an experienced sports physiotherapist and a Master of Science student. The available equipment consisted of bikes, step-up boxes, a smaller barbell and weight plates up to 5kg. Each class ran for approximately 60 minutes which included a 5 minute warm-up and cool-down component. Consequently, the exercise program consisted of several traditional muscular endurance exercises as well as more golf specific movements involving rotational movements of the hips, torso and shoulders [41]. Exercises were adapted and progressed or alternatively regressed to suit the physical levels of each participant as determined using the baseline musculoskeletal screening assessment.

Table 3.3: A List of Exercises Implemented in the Seven-Week Exercise Program.

Body Part	Exercises Progressions	Sets	Reps	Rest between sets
Lower body	Bodyweight lunge Bodyweight Lunges with twist Weighted Lunges with twist Hockey jumps	3	8 - 12	45-60s
Upper push	Bodyweight push ups on knees Bodyweight push ups Dumbbell push ups	3	8 - 12	45-60s
Core	Prone hold Seated Russian twist Barbell woodchop	3	45 – 60 s 10 – 15 10 -15	45-60s
Upper pull	Prone 1-arm dumbbell rows Renegade row	3	8 - 12	45-60s
Sprints	Resisted band sprints	1	5	walk back to start

Statistical Analysis

As assumptions of normality were met for all outcomes based on the Shapiro-Wilks test, means and standard deviations were used as measures of centrality and spread. A repeated measures ANOVA was performed to evaluate pre-post differences in all outcomes for the entire group. In order to quantify the magnitude of these changes, effect sizes have been calculated. Effect sizes (d) were considered trivial if they were < 0.2; small if they were between 0.21 and 0.60; moderate if they were between 0.61 and 1.20 and large if they were greater than 1.20 [88]. However, because of considerable variation in the number of exercise sessions attended by some participants, a secondary analysis was performed comparing the training response of those who completed 6 or greater sessions (n = 11), those who completed 4 sessions (n = 8) and those who completed 2 or less sessions (n = 10). The three groups were referred to as the High, Medium and Low adherence groups, respectively. Given many of the outcomes for this sub-group analysis did not meet the assumptions of normality according to the Shapiro-Wilks tests, a Mann-Whitney U test was performed to compare the pre-post change scores between the sub-groups for all outcome measures. All statistical analyses were performed in SPSS Version 20, with significance set at $p < 0.05$.

Results

Thirty six of the original 43 (83%) participants completed baseline and post-testing and the data from these 36 participants are presented in Tables 3.4 – 3.5. Adherence data was also recorded for every exercise session, with a mean attendance rate of 55% (i.e. an average of 3.8 out of 7 sessions was attended by the whole group). As shown in Table 3.4, significant improvements in a number of musculoskeletal screening tests was observed for the entire group including: left leg bridging ($p = 0.024$); combined elevation (thoracic extension) ($p = 0.013$); right thoracic rotation ($p < 0.001$); and right and left single leg squat performance ($p = 0.012$ and $p = 0.001$ respectively). In contrast, no significant changes in any of the golf swing performance measures were observed for the entire group (see Table 3.5).

Table 3.4. Changes in Musculoskeletal Screening Test Scores after the Seven Week Exercise Program

Outcome		Baseline mean ± SD	Post mean ± SD	p - value
Side bridge (s)	Right	75 ± 34.8	87 ± 34.7	0.146
	Left	75 ± 30.9	93 ± 39.6	0.065
Bridging leg lift (1-5)	Right	4.6 ± 0.7	4.8 ± 0.5	0.570
	Left	4.5 ± 0.7	4.8 ± 0.4	0.024*
Straight leg raise (degrees)	Right	68 ± 11.5	69 ± 12.7	0.691
	Left	69 ± 11.3	70 ± 11.9	0.679
Hip internal rotation (degrees)	Right	27 ± 10.2	26 ± 6.8	0.625
	Left	28 ± 9.1	25 ± 7.8	0.224
Hip external rotation (degrees)	Right	40 ± 10.2	42 ± 12.6	0.553
	Left	39 ± 10.8	39 ± 14.4	0.796
Combined elevation (cm)		8 ± 6.7	13 ± 8.9	0.013*
Thoracic rotation (degrees)	Right	30 ± 6.2	37 ± 7.4	< 0.001**

	Left	31 ± 7.5	30 ± 9.6	0.860
Overhead squat (1-5)		3.8 ± 1.6	4.2 ± 1.2	0.354
Single leg squat (1-5)	Right	2.4 ± 0.7	2.9 ± 0.9	0.012*
	Left	2.4 ± 0.8	3.1 ± 0.8	0.001*
Front plank (s)		140 ± 69.7	152 ± 79.6	0.507

* Statistical significance level at $p < 0.05$; ** Statistical significance level at $p < 0.001$. The effect sizes for the significant improvements reported here were: Left bridging lift (d = 0.56, small effect size); Combined elevation (d = 0.64, moderate effect size) and Thoracic rotation (d = 1.03, moderate effect size).

Table 3.5. Changes in Golf Swing Performance after the Seven Week Exercise Program

Outcome	Baseline mean ± SD	Post mean ± SD	p - value
Combine test	66.0 ± 12.0	67.1 ± 9.4	0.681
Club head speed ($km.h^{-1}$)	162.1 ± 17.5	162.1 ± 17.0	0.995
Ball speed ($km.h^{-1}$)	225.7 ± 25.7	224.1 ± 24.0	0.773
Smash Factor	1.39 ± 0.05	1.38 ± 0.05	0.391
Driving Distance (metres)	234.6 ± 37.3	220.3 ± 31.1	0.072
Carry Side	0.6 ± 12.4	0.5 ± 13.2	0.718

* Statistical significance level at $p<0.05$. All exercise differences for all the outcomes reported were trivial with the exception of driving distance ($d = -0.34$, small effect size).

Table 3.6. Pre- and Post-Intervention Musculoskeletal Screening Scores for the Three Adherence Groups.

Outcome		High adherence		Moderate adherence		Low adherence	
		Baseline mean ± SD	Post mean ± SD	Baseline mean ± SD	Post mean ± SD	Baseline mean ± SD	Post mean ± SD
Side bridge (s)	Right	93.2 ± 27.5	107.0 ± 30.7	56.7 ± 22.3	85.4 ± 45.8	67.7 ± 20.2	81.6 ± 39.8
	Left	92.3 ± 24.7	122.4 ± 31.6	56.3 ± 24.1	74.4 ± 39.0	69.0 ± 22.6	75.6 ± 40.4
Bridging leg lift (1-5)	Right	4.7 ± 0.6	5.0 ± 0.0	4.7 ± 0.8	4.7 ± 0.5	4.5 ± 0.8	5.0 ± 0.0
	Left	4.4 ± 0.8	5.0 ± 0.0	4.9 ± 0.4	4.7 ± 0.5	4.6 ± 0.5	4.9 ± 0.4
Straight leg raise (^{o})	Right	68.6 ± 12.1	69.4 ± 10.7	64.7 ± 9.3	67.7 ± 4.1	68.1 ± 7.5	69.6 ± 6.3
	Left	70.5 ± 11.9	71.1 ± 12.4	65.4 ± 11.5	66.0 ± 5.7	70.6 ± 8.2	69.6 ± 3.9
Hip internal rotation (^{o})	Right	25.5 ± 11.4	26.5 ± 5.8	27.9 ± 12.4	27.0 ± 7.2	26.9 ± 3.9	23.5 ± 5.8
	Left	25.3 ± 8.8	24.8 ± 9.3	29.6 ± 12.6	27.1 ± 5.9	26.6 ± 4.6	22.3 ± 5.8
Hip external rotation (^{o})	Right	38.3 ± 10.5	40.4 ± 13.2	39.7 ± 8.1	40.3 ± 9.8	39.5 ± 12.6	38.6 ± 10.8
	Left	39.7 ± 9.8	38.3 ± 15.8	39.3 ± 9.8	35.1 ± 14.8	38.0 ± 13.7	35.6 ± 10.3
Combined elevation (cm)		8.0 ± 5.0	14.2 ± 7.3	10.3 ± 9.1	12.7 ± 9.4	5.3 ± 3.8	12.6 ± 11.8

Thoracic rotation (^{o})	Right	29.7 ± 5.5	35.3 ± 9.2	29.0 ± 5.3	38.9 ± 6.8	34.3 ± 6.6	39.1 ± 7.2
	Left	31.0 ± 6.8	25.5 ± 10.0	27.1 ± 7.9	26.9 ± 7.9	36.4 ± 7.1	36.6 ± 10.5
Overhead squat (1-5)		4.5 ± 0.9	4.5 ± 0.8	3.4 ± 1.6	4.6 ± 0.5	2.8 ± 2.0	3.5 ± 1.7
Single leg squat (1-5)	Right	2.6 ± 0.5	3.4 ± 0.8	2.3 ± 1.0	2.4 ± 0.8	2.0 ± 0.8	2.3 ± 1.0
	Left	3.0 ± 0.6	3.4 ± 0.8	2.3 ± 1.1	3.0 ± 0.6	1.9 ± 0.6	2.6 ± 0.7
Front plank (s)		142.1 ± 43.0	178.1 ± 64.7	122.0 ± 67.3	155.0 ± 133.7	146.9 ± 101.1	135.3 ± 55.1

Table 3.7. Pre- and Post-Intervention Golf Performance Assessment Scores for the Three Adherence Groups

Outcome	High adherence		Moderate adherence		Low adherence	
	Baseline mean ± SD	Post mean ± SD	Baseline mean ± SD	Post mean ± SD	Baseline mean ± SD	Post mean ± SD
Combine test	68.0 ± 7.3	68.7 ± 4.8	64.6 ± 17.9	64.6 ± 10.6	60.6 ± 15.7	63.7 ± 12.8
Club head speed ($km.h^{-1}$)	160.9 ± 15.5	160.8 ± 14.0	158.9 ± 23.5	158.2 ± 23.2	156.1 ± 16.8	157.1 ± 14.3
Ball speed ($km.h^{-1}$)	224.1 ± 21.2	222.5 ± 20.7	216.4 ± 40.1	217.3 ± 34.7	220.5 ± 24.0	218.9 ± 22.1
Smash Factor	1.4 ± 0.0	1.4 ± 0.1	1.4 ± 0.1	1.4 ± 0.0	1.4 ± 0.04	1.4 ± 0.05
Driving Distance (metres)	236.2 ± 30.0	221.7 ± 28.9	218.9 ± 50.1	207.9 ± 42.1	225.6 ± 39.7	216.8 ± 33.6
Carry Side	-4.1 ± 10.2	-0.9 ± 14.3	1.1 ± 12.1	-0.3 ± 18.0	0.3 ± 17.5	0.3 ± 12.9

Results of the Mann-Whitney U test for the effect of attendance on outcome measures revealed a small number of significant between-group effects (see Table 3.6 and 3.7). These included an improved left side bridge holding time for the High versus the Low group ($p = 0.003$); improved overhead squat performance for the High versus Moderate group ($p = 0.035$) and an improved left side bridge holding time for the Moderate versus the Low group ($p = 0.043$). For golf swing performance measures (i.e. Combine Test overall scores, clubhead speed, ball speed, driving distance, smash factor and carry side) no significant between-group differences in change scores were observed between the three attendance groups.

Discussion

The main findings of this study were that significant improvements were observed in several musculoskeletal screening tests including the left leg bridging lift, combined elevation test, right thoracic rotation, and right and left single leg squat performance. However, no significant improvements were observed for any of the golf swing performance variables. Additionally, Mann-Whitney U test results demonstrated no significant differences in the change scores between the three attendance groups for any of the golf swing performance measures, although more frequent training was associated with greater improvements in a few of the musculoskeletal screening tests including the left side bridge and overhead squat.

Improvements in a number of the musculoskeletal measures as a result of the exercise programs provides partial support for our first hypothesis. Such findings are consistent with several previous investigations, all of which found significant improvements in strength and range of motion outcomes when golfers engaged in a regular exercise program [12, 15-17]. For example, Doan et al. [12] assessed one-repetition maximum (1-RM) strength for the bench press, shoulder press, lat pulldown, and squat exercises which are well-known global exercises typical of strength training, and reported significant improvements in all these tests following an 11-week exercise program. A different approach was used by Lephart et al. [15] assessing strength of the torso, shoulders and hip muscle using a Biodex System III Multi-Joint testing and Rehabilitation System. Following the eight-week exercise program, Lephart et al. [15] reported significant improvements in torso rotational and hip abduction strength as well as all range of motion variables. An explanation for the greater number of improvements seen in the aforementioned studies could simply be due to the dose-response effect, whereby the greater the number of times an activity is performed (frequency), the more likely a response can be expected.

A unique feature of the current study was the one exercise session performed each week. Previous studies that have examined the effect of a single exercise session per week on previously untrained older adults found significant improvements in a range of physical qualities including muscular endurance and functional performance [21, 81, 82]. Similarly, we found improvements in several range of motion and movement competency tests (single leg bridging, thoracic rotation, thoracic extension and single leg squat performance) in younger, untrained collegiate golfers. Despite improvements in physical competency, this current study along with Lamberth and colleagues [14] observed no translation into improved golf swing performance, which is in contrast to the observed increases in both physical qualities (leg strength, core strength, range of motion) and CHS reported in previous studies [12, 13, 15-17, 36]. The most plausible explanation for the discrepancy, is that most previous golf specific exercise programs have utilised 2 – 3 sessions per week over 8 – 18 weeks, whereas our study consisted of only 1 session per week for seven weeks. Limited improvement in golf swing performance may reflect a minimum dosage effect, whereby a greater training duration might be required if the frequency is only once per week. This view is partially supported by the results of the sub-analysis comparing the High, Medium and Low attendance groups, whereby greater improvements were observed for multiple musculoskeletal screening tests for those who attended more exercise sessions.

There were several limitations that warrant acknowledgement in this study. First, no control group was used during the study as it was deemed unfair to participants who would have been excluded from the training group. Second, exercise program adherence rates were lower than previous studies, with a mean adherence rate of 55% for the whole group over the seven-week period. This is likely to have decreased the overall effectiveness of the program. Third, a lack of blinding of the assessors in which the same assessors were used for pre- and post-intervention musculoskeletal measurements, could potentially allow for a level of bias which may have skewed results. Lastly, while individualised training programs were considered, , they were deemed not to be feasible due to the intra-group variations in golf handicap, resistance training experience and movement competency, limitations in access to the training facility and the prohibitive cost of providing individual supervised sessions. Consequently, we utilised groups sessions that contained individually focussed exercises, which may have diluted the overall effectiveness of the program.

Conclusion

Our results indicate that although exercising once a week for seven weeks leads to no significant improvement in golf swing performance as assessed by the Combine test, it did result in significant improvements in several musculoskeletal screening tests. In relation to the wider golfing strength and conditioning literature, our results suggest that in relatively untrained golf populations some improvements in physical characteristics may occur with short duration, once a week training, but a longer duration or frequency of exercise may be needed to improve golf swing performance. However, the clinical relevance of these finding needs to be established regarding how useful this could be to practitioners. Future research should directly compare variations in exercise duration or frequency using randomised controlled trial designs to better elucidate the effect of manipulating exercise prescription variables on musculoskeletal screening and golf swing performance outcomes.

Chapter Four: Relationship between Training-Related Changes in Musculoskeletal Screening and Golf Swing Variables in Collegiate Golfers

Introduction

A number of studies have demonstrated significant relationships between measures of muscular strength, power or endurance and golf swing performance, as assessed by CHS and driving distance [6, 7]. For example, Keogh et al. [7] investigated the relationship between several physical measurements and CHS in 10 low and 10 high-handicap golfers. The results showed a correlation range of r = 0.43 – 0.71 for the muscular strength and endurance measures with CHS; but correlations of r = 0.00 – 0.34 between ROM measures and CHS. Similar findings were reported by Hellstrom [6] for 33 elite male golfers where a number of muscular strength and power measures were significantly correlated with club head speed (r = 0.36 – 0.61). As both of these studies were cross-sectional in design whereby these relationships were measured at a single point in time, it remains to be determined how changes in a variety of musculoskeletal measures may actually contribute to improvements in golf swing performance after the implementation of a strength and conditioning program [89].

A number of exercise studies have examined the effect of strength and conditioning programs on musculoskeletal and golf swing performance measures including CHS, ball speed or ball carrying distance [11-16]. The common finding has been significant increases in measures of muscular strength, trunk muscle endurance and range of motion, in addition to improvements in golf swing performance measures [11-16]. However, the exercise programs undertaken, as well as the skill level of the golfers, have varied quite considerably making it difficult to determine what aspects of the exercise program contributed to the improvements observed.

Therefore, the aim of this study was to gain further insight into the potential relationship between changes in a range of musculoskeletal measures (broadly classified as range of motion, abdominal muscular endurance and movement competency) and golf swing performance, as assessed by the TrackMan Combine test (TrackMan IIIe, Vedbaek, Denmark) Doppler Radar system. The Combine test was selected as a standardised measure of golf swing performance, in addition to measures such as CHS, ball speed, driving distance, carry side, smash factor, due to the wide variety of shots and distances the test involves and as it is currently extensively used in high performance golf programs. Using a series of tests designed as a musculoskeletal assessment tool for golfers, referred to as the *Ten Test On Range* (The Golf Athlete, Brisbane, Australia measure), physical parameters thought to be important for golf swing performance were measured [86]. It was hypothesised that the training-related changes in these musculoskeletal measures would correlate with changes in simulated golf swing performance as assessed by the TrackMan Combine test.

Methods

Participants

Forty three students (7 females and 36 males, mean ± SD age 24 ± 8.9 years) from the PGA-IGI (Professional Golfers Association – International Golf Institute) volunteered to participate in the study (handicap, 8.6 ± 8.3 strokes). All participants had a minimum of one year's experience playing golf, but no experience in performing a strength and conditioning programs for golf. Participants were all enrolled in a Diploma of Golf Management running for one year. Written consent was obtained from all participants and the study was approved by the Bond University Human Research Ethics Committee and Griffith University Human Research Ethics Committee.

Overview of Experimental Design

The study was designed as a single group, pre-post uncontrolled exercise study, with a full description of the methods of the larger study provided in Olivier et al. [90], as described in Chapter 3 of this thesis. Any relationships between the pre-and post-test changes in the musculoskeletal and golf swing performance measures were examined using Pearson's product moment correlations. No linear regressions were performed due to the insufficient sample size.

Musculoskeletal Screening Assessments

The present study employed the *Ten Test On Range* musculoskeletal measurement protocol which examined the flexibility, muscular endurance and movement competency qualities of all participants. All testing sessions were performed at a local golf club, with the musculoskeletal screening and Combine performance test assessments taking place on separate days within the same week. The musculoskeletal screening sessions took between 30 and 45 minutes while the Combine performance test assessments took between 45 and 60 minutes. The musculoskeletal measurements was performed indoors and the golf swing performance testing, i.e. Combine test, was performed on the driving range.

Golf Swing Performance and Variables

Golf swing performance was measured using a Doppler Radar system, more commonly known as the TrackMan (TrackMan IIIe, Vedbaek, Denmark). The TrackMan has previously been used by researchers [18, 90] and is commonly utilised by Australian golf coaches, the United States Professional Golfers Association (USPGA) and European PGA tours [40]. The TrackMan allows participants to complete a field based golf swing performance test called the Combine Test' (TrackMan Performance Studio Version 3.0, TrackMan, Denmark), which involves 60 shots to 10 standardised targets. Distance markers were placed at 50, 100 and 150 metres, with the markers measured using a golf laser range finder (Bushnell Medalist, Overland Park, United States). The Combine test was scored from 0–100, with greater scores indicative of greater ball striking performance. Each golfer was provided with a target line using the distance markers. All testing was performed on an outdoor driving range (150 × 300 metres), with each participant hitting shots from an artificial grass mat. Environmental conditions were similar on the pre-and post-testing days for all participants, with temperatures between 24–28 degrees Celsius and light winds between 10–20 km/h. The golf balls used were range balls (Srixon, Sydney, Australia), which generally travel ~80% of the distance of a standard competition ball. As recommended by Robertson et al. [18], the TrackMan device was set up approximately 1.5–2.0 metres behind the ball in line with the target line.

Participants completed the Combine test following a warm-up and familiarisation period of 15-20 minutes which included shots with a selection of clubs (i.e. self-selected). The Combine test required the golfer to hit shots using their club of choice (except the maximum distance shot where a driver is used) to distances along a target line at 55, 65, 75, 85, 95, 105, 125, 145 and 165 metres, as well as a shot for maximum distance with the driver club. The golfer started at the 55 metre distance, hitting three shots at each of the 10 consecutively longer distances. At the completion of these 30 shots, this process was repeated a second time until a total of 60 shots was completed. In our study, participants were instructed to hit the ball as straight and close as possible to the target distance, except for the driver where participants were instructed to hit the ball as far and straight as possible. The TrackMan device allows for the measurement of a score for each shot, an overall score out of 100 and other performance variables. In the current study, the measurements reported included club head speed (speed of club had at ball contact), ball speed (ball speed at the point the ball is hit into the air), carry distance (distance ball travels through the air before hitting the ground), total distance (distance ball travels from starting to finish position), carry side (lateral deviation distance the ball comes to rest from target line) and smash factor (ball speed / club head speed).

Exercise Program

All participants were asked to complete one supervised exercise class per week for a seven week period. The exercise program utilised was developed through consensus moderation between all researchers (all of which were trained exercise scientists or physiotherapists). In designing the training program, consideration of the biomechanics and physical requirements of the golf swing, common injury sites of golfers, as well as the practicalities of the exercise facility and time available per class were taken into account. All classes were conducted in a group exercise room, supervised by an experienced sports physiotherapist and a Master of Science student. Available equipment for use was limited to the following; spin bikes, step-up boxes, a smaller barbell and multiple weight plates up to 5 kg. Each class was approximately 60 minutes in duration including a 5 minute warm-up and cool-down. As such, the exercise program had to be adjusted accordingly, consisting of several traditional muscular endurance exercises as well as more golf related movements involving rotational movements of the hips, torso and shoulders [41]. Exercises progressions and/or regressions were made for each participant based on their level of competency as well as their baseline musculoskeletal screening tests.

Statistical Analysis

Prior to performing the analysis, assumptions of normality were assessed using the Shapiro-Wilks test. As the assumptions of normality were met, the change scores for each participant were calculated for all musculoskeletal and golf swing performance outcomes by calculating the difference between each individuals' pre-and post-test score for each outcome. The association between the musculoskeletal and golf swing performance outcomes change scores were assessed by the Pearson's product-moment correlation coefficient (r). Correlations < 0.10 were described as trivial; between 0.10-0.29 as small; between 0.30-0.49 as moderate; between 0.50-0.69 as large; between 0.70-0.89 as very large; between 0.90-0.99 as nearly perfect; and 1.00 as perfect. The 90% confidence interval and the likelihood that the correlation was substantial was also reported [88]. All statistical analyses were performed in SPSS Version 20, with significance set at $p < 0.05$.

Results

The change scores for the musculoskeletal and golf swing performance outcomes are provided in Tables 4.1 and 4.2, respectively. The correlations between the golf swing performance and musculoskeletal measurement change scores are presented in Tables 4.3, 4.4 and 4.5, respectively. In general, the correlations revealed relatively few significant ($p < 0.05$) relationships between the change scores for golf swing performance and musculoskeletal measures. Exceptions to this were the statistically significant negative correlations between; right bridging leg lift and driving distance ($r = -354$, $p = 0.040$) as well as left thoracic rotation and ball speed ($r = -0.358$, $p = 0.037$), driving distance ($r = -0.393$, $p = 0.021$) and side ($r = -0.381$, $p = 0.026$), respectively. Additionally, similar exceptions were noted between right thoracic rotation and smash factor ($r = -0.340$, $p = 0.049$), right single leg squat and ball speed ($r = -0.407$, $p = 0.017$) and left single leg squat and ball speed ($r = -0.411$, $p = 0.016$). On the contrary, a positive correlation was found between right side bridge and Combine test score ($r = 0.356$, $p = 0.039$). All statistically significant correlations were moderate in magnitude and were highly likely to be substantial according to the criteria of Hopkins [88].

Table 4.1. Musculoskeletal Screening Change Score Mean and SD scores

Musculoskeletal Screenings Tests	Change Score Mean ± SD
Right Side bridge (seconds)	12.2 ± -0.12
Left Side Bridge (seconds)	15.9 ± 8.6
Right Straight Leg Raise (degrees)	1.14 ± 1.13
Left Straight Leg Raise(degrees)	1.14 ± 0.66
Right Hip Internal Rotation (degrees)	-1 ± -3.3
Left Hip Internal Rotation (degrees)	-2.4 ± -1.3
Right Hip External Rotation (degrees)	1.6 ± 2.4
Left Hip External Rotation (degrees)	-0.78 ± 3.58
Right Bridging Leg Lift (1-5)	0.28 ± -0.29
Left Bridging Leg Lift (1-5)	0.31 ± -0.32
Combined Elevation (Thoracic Extension) (centimetres)	4.75 ± 2.23
Right Thoracic Rotation (degrees)	6.67 ± 1.28
Left Thoracic Rotation (degrees)	-0.36 ± 2.1
Overhead Squat (1-5)	0.31 ± -0.35
Right Single Leg Squat (1-5)	0.53 ± 0.27
Left Single Leg Squat (1-5)	0.69 ± -0.01
Front Plank (seconds)	11.75 ± 9.87

Table 4.2. Golf Performance Change Score Mean and SD Scores

Golf Performance Measurements	Change Score Mean ± SD
Combine Test	1.1 ± -2.6
Club head speed (km.h-1)	0 ± -0.5
Ball Speed (km.h-1)	-1.6 ± -1.7
Smash Factor	-0.01 ± 0
Driving Distance (metres)	-14.3 ± -6.2
Carry Side (metres)	-0.1 ± 0.8

Table 4.3. Correlations between Changes in Golf Swing Performance Variables and Abdominal Muscle Endurance Tests

Muscular Endurance tests	Combine Test		Driving Speed		Ball Speed		Driving Distance		Side		Smash Factor	
	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*
Right Sidebridge	0.356*	0.039	0.022	0.901	-0.024	0.893	-0.076	0.671	0.109	0.540	-0.165	0.350
Left Sidebridge	0.138	0.435	0.032	0.856	-0.072	0.684	0.018	0.919	-0.093	0.602	-0.263	0.133
Front Plank	-0.073	0.680	0.158	0.372	-0.040	0.820	0.084	0.637	-0.038	0.832	-0.333	0.054

* Significance level set at $p < 0.05$. The significant correlation between right side bridge and combine test has a mean value and 90% confidence interval of 0.36 (0.11 to 0.56), which is 95.7% likely to be substantial [88]

Table 4.4 Correlations between Changes in Golf Swing Performance Variables and Movement Competency Tests

Movement Competency Tests	Combine Test		Driving Speed		Ball Speed		Driving Distance		Side		Smash Factor	
	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*
Right Bridging Leg Lift	-0.300	0.084	-0.090	0.613	-0.171	0.333	-0.354*	0.040	-0.282	0.107	-0.093	0.602
Left Bridging Leg Lift	-0.090	0.614	0.003	0.985	-0.274	0.117	-0.136	0.442	-0.046	0.797	-0.198	0.262
Overhead Squat	-0.314	0.071	-0.062	0.727	0.039	0.829	0.058	0.747	-0.079	0.655	0.030	0.866
Right Single Leg Squat	0.027	0.881	-0.214	0.224	-.407*	0.017	-0.292	0.094	0.137	0.440	0.089	0.616
Left Single Leg Squat	-0.207	0.241	-0.175	0.322	-.411*	0.016	-0.141	0.426	-0.077	0.667	-0.212	0.229

* Significance level set at $p < 0.05$. The significant correlation between right bridging leg lift and driving distance has a mean value and 90% confidence interval of -0.35 (-0.56 to -0.11), which is 95.6% likely to be substantial. The significant correlation between ball speed and right single leg

squat has a mean value and 90% confidence interval of -0.41 (-0.6 to -0.17), which is 98.2% likely to be substantial. The significant correlation between ball speed and left single leg squat has a mean value and 90% confidence interval of -0.41 (-0.6 to -0.17), which is 98.3% likely to be substantial [88].

Table 4.5. Correlations between Changes in Golf Swing Performance Variables and Range of Motion Tests

Range of Motion Tests	Combine Test		Driving Speed		Speed		Driving Distance		Side		Smash Factor	
	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*	r	*p*
Right Straight Leg Raise	0.070	0.692	-0.335	0.053	-0.036	0.838	0.338	0.051	0.150	0.397	0.163	0.358
Left Straight Leg Raise	-0.083	0.640	-0.241	0.170	-0.103	0.561	0.162	0.359	0.286	0.102	0.099	0.576
Right Hip Internal Rotation	-0.119	0.501	0.044	0.807	-0.004	0.983	-0.089	0.616	-0.046	0.798	0.099	0.579
Left Hip Internal Rotation	-0.260	0.138	0.094	0.598	-0.125	0.481	0.127	0.473	-0.078	0.662	-0.114	0.520
Right Hip External Rotation	0.092	0.604	-0.165	0.351	-0.276	0.115	-0.014	0.936	0.143	0.421	-0.180	0.309
Left Hip External Rotation	0.052	0.769	0.107	0.548	-0.106	0.552	0.098	0.582	0.048	0.789	-0.151	0.393
Combined Elevation (Thoracic Extension)	0.066	0.710	0.005	0.977	-0.203	0.250	-0.052	0.771	0.145	0.414	-0.185	0.295
Right Thoracic Rotation	0.046	0.797	0.048	0.789	-0.205	0.244	-0.287	0.100	-0.261	0.136	-0.340*	0.049

Left Thoracic Rotation	-0.223	0.205	-0.303	0.081	-0.358*	0.037	-0.393*	0.021	-0.381*	0.026	-0.237	0.177

* Significance level set at $p < 0.05$. The significant correlation between right thoracic rotation and smash factor has a mean value and 90% confidence interval of -0.34 (-0.55 to -0.09), which is 94.6% likely to be substantial. The significant correlation between left thoracic rotation and ball speed has a mean value and 90% confidence interval of -0.36 (-0.56 to -0.11), which is 95.9% likely to be substantial. The significant correlation between left thoracic rotation and driving distance has a mean value and 90% confidence interval of -0.39 (-0.59 to -0.15), which is 97.7% likely to be substantial. The significant correlation between left thoracic rotation and side has a mean value and 90% confidence interval of -0.38 (-0.58 to -0.14), which is 97.1% likely to be substantial [88].

Discussion

The purpose of the study was to assess the relationship between training-related changes in musculoskeletal measures and golf swing performance following a 7 week exercise program consisting of 1 session a week. Such a study design was performed to gain insight into how improvements in a variety of musculoskeletal measurements may actually be related to improved golf swing performance. This is important as there has been little research investigating how changes in musculoskeletal screening measures that are a result of an exercise program may relate to improvements in golf swing performance.

The results from the present study demonstrated relatively few meaningful correlations in the change scores between the golf swing performance and musculoskeletal measures (abdominal muscular endurance, movement competency and range of motion) outcomes. While not consistent with the study's hypotheses, such results may reflect the wide variety of intrinsic (e.g. physical capacities and technical skills) as well as extrinsic (e.g. wind, temperature) factors that may influence golf swing performance on the driving range. However, the exceptions to this rule may provide important insights into the most important aspects of an exercise program with respect to improving golf swing performance.

A topic which has received considerable attention in golf research and practice is the "X-factor" or "X-factor stretch" [91, 92]. Golfers who exhibit a greater "X-factor" or "X-factor stretch" may have the ability to utilise a longer backswing that involves greater separation between torso and hips, which may then result in a greater angular velocity and a higher CHS [92]. It is believed that greater thoracic rotation during the backswing (right thoracic rotation) may allow for "X-factor" or "X-factor stretch" and ability to accelerate the club head during the downswing [92]. The correlation found between the changes in right thoracic rotation and smash factor ($r = -0.340$, $p = 0.049$) is the only significant correlation on the right side of the body, which at least on the surface does not seem to support the notion of the "X-factor stretch", in right handed golfers.

The majority of significant relationships in our study occurred on the left side of the body, as seen in the significant negative relationships for changes in left thoracic rotation and driving distance ($r = -0.393$, $p = 0.021$), ball speed ($r = -0.358$, $p = 0.037$) and carry side ($r = -0.381$, $p = 0.026$). The statistically significant negative correlation between the change in left thoracic rotation and carry side ($r = -0.381$, $p = 0.026$) was consistent with the hypotheses of the study. The carry side is defined as the lateral deviation distance the ball finishes at from the target line (TrackMan™, ISG A/S, Denmark) [40]. This negative relationship indicates that an increase in left thoracic rotation was associated with an improvement in shot accuracy. This result is consistent with perhaps the only other golf strength and conditioning study to examine the effect of an exercise program on ball striking accuracy. Specifically, Doan et al. [12] reported significant increases in thoracic rotation and putting accuracy in male golfers as a result of their 11 week exercise program. Collectively, the results of the present study and that of Doan et al. [12] support the continued incorporation of thoracic mobility exercises into a golfer's routine, as it may play a vital role in shot accuracy, and allowing a more comfortable follow-through for the golfer. Furthermore, with professional golfer's requiring both accuracy and distance, coaches may invest more quality time in improving such mobility characteristics as a greater thoracic rotation (i.e follow-through) may assist a player's shot accuracy. This could be particularly relevant to those golfers using the modern swing (whereby the magnitude of the trunk rotation and resulting "X-factor" is emphasised) to improve their accuracy of shots and reduce the spinal loading during the follow-through.

Alternatively, the negative relationship between changes in left thoracic rotation to driving distance and ball speed were inconsistent with the study's hypotheses as they suggest that increases in left thoracic rotation may actually be associated (albeit at a moderately low level) with decreases in ball speed and driving distance. These are somewhat unexpected outcomes which may be explained by the relative lack of changes in golf swing performance as outlined by Olivier et al [90]. In comparison to Olivier et al [90], Jones [37] demonstrated the efficacy of a short term proprioceptive neuromuscular facilitation (PNF) stretching regime on improving flexibility and golf swing performance measures, i.e. CHS. The potential between-study discrepancies in results may be explained by differences in the type of stretches (static vs PNF) used. Static stretching involves holding positions near end range for a set time, for example 30 seconds compared to the PNF method involving active contractions of 3-5 seconds against an object, followed by a relaxation of the muscle, repeating this process several times. Ultimately, improvements in range of motion at a particular joint may need to be examined in relation to the range of motion requirements for golf as well as how this change in range of motion may influence the coordination patterns if such physical improvements are to translate in to increased club head speed or ball striking distance.

In addition to muscular endurance and ROM, movement competency is considered critical in most sports as it enables athletes to move with greater efficiency while simultaneously providing pathways for developing appropriate strength and reducing risk of injury [22]. Our results showed statistically significant negative correlations between the changes in several movement competency tests and golf swing performance. Specifically, significant negative correlations were observed between changes in right bridging leg lift and distance (r = - 0.354, p = 0.040) as well as right and left single leg squat and ball speed (r = - 0.407, p = 0.017, r = 0.411, p = 0.016). It was hypothesised that improvements in these movement competency tests would be positively associated with improved golf swing performance results, however the results were inconsistent with this hypothesis. Collectively, the significant negative correlations between the changes in movement competency and golf swing performance outcomes suggested that over the course of a one session per week for seven weeks strength conditioning program that changes in golf swing performance may be unlikely to reflect changes in a particular movement competency exercise. Somewhat consistent with our results, Parchmann and McBride [66] reported that another common musculoskeletal screening assessment (Functional Movement Screen - FMS) was unable to predict a variety of measures of athletic ability or club head speed in 25 National Collegiate Athletic Association Division I golfers. Even though the *Ten Test On Range* screening test has been proposed to be a specific screening test for golfers, our results and that of Parchmann and McBride [66] still suggest that the validity and/or reliability of these musculoskeletal screening approaches in predicting golf swing performance remain somewhat questionable.

One result of particular interest that provides evidence of support for our hypothesis was the positive correlation between the change in right side bridge and Combine test score (r = 0.356, p = 0.039). An improvement in the right side bridge score may be indicative of greater muscular strength/endurance of the lateral trunk muscles, specifically the quadratus lumborum and oblique muscles. Such a result was consistent with the views of McGill [70] who described the importance of developing sufficient muscular endurance of the quadratus lumborum and oblique muscles to reduce the risk of LBP. These lateral trunk muscles may play an important role in stabilising the spine as well as contributing to the development of trunk angular velocity during the downswing phases of golf swing. Therefore, the continued implementation of exercises focusing on the lateral trunk flexors/trunk rotators into the regime of golfers is encouraged as it serves a role as a potential injury reduction as well as golf swing performance enhancing mechanism.

A number of limitations do exist within this study, including the short duration (seven weeks) and the low frequency (one session per week) of exercise performed. For example, because there were improvements in only a limited number of musculoskeletal assessments and as a result of relatively small sample size which invalidated the use of regression analyses, interpreting the outcomes need to be done cautiously and thus require further investigation. Likewise, because of the relatively poor adherence rate to the exercise program, the potential improvements from the exercise program were likely diluted. Further, the participants were not experienced in resistance training and somewhat heterogenous in terms of their golf ability and attendance at the training sessions. As a result, no significant changes in golf swing performance were observed at a group level, although the individual response exhibited by each participant varied. Therefore, the results of this study may not apply to that exhibited in longer training studies or in more elite golfers or those with greater strength and conditioning experience.

Conclusion

In conclusion, the results of this study appear to provide the first published data on how changes in a range of musculoskeletal screening exercises may relate to changes in golf swing performance. Although, some of the results were inconsistent with our hypotheses, this study may stimulate further research in this area that has the potential to inform the development of exercise programs that are better able to improve golf swing performance than the programs currently assessed in the golf exercise literature. Future studies of longer duration and exercise frequency that assess the changes in a wider variety of musculoskeletal and golf swing performance measures across other golfing populations may better identify these relationships, thereby allowing further refinements in these exercise programs.

Chapter 5: Discussion

While the literature indicates strength and conditioning programs can increase many musculoskeletal measures such as muscular strength, power and endurance as well as flexibility that contribute to increased golf swing performance, there are still many unanswered questions. Some of these questions relate to the minimal frequency of exercise required to improve physical qualities and golf swing performance as well as what components of the strength and conditioning programs are most important in terms of producing these adaptations. The studies performed in this thesis were conducted to answer these two related questions in collegiate golfers with limited resistance training experience as the majority of golfers worldwide also have limited resistance training background.

The first study sought to examine the effectiveness of a once a week strength and conditioning program; with the second study examining how changes in a range of musculoskeletal screening assessment tests may predict changes in golf swing performance. A major finding that emerged from the first study was that the performance of only one strength and conditioning session a week for a period of seven weeks was able to significantly improve a range of musculoskeletal screening assessments in collegiate golfers with limited resistance training experience. Although only a few musculoskeletal measures were improved, these benefits were observed with substantially less training sessions per week and a shorter duration of training than what has been routinely described for studies included in relatively recent reviews of the literature [1, 2]. However, these results appear consistent with a small number of studies examining reduced training frequency in relatively untrained golfers [79] and older adults [21, 81, 82], whereby significant improvements in muscular strength, power and/or endurance were observed with one exercise session per week performed for periods of up to eight weeks duration. The results of the current study when viewed in light of these reduced frequency and/or duration exercise programs, should therefore be of considerable interest to golfers, golf coaches and strength and conditioning coaches. Such results suggest that even the performance of one strength and conditioning session per week for seven weeks may result in a number of physical benefits that have the potential to improve golf swing performance and/or reduce the risk of injury. This may be especially important in the sport of golf as golfers from recreational to elite, professional status may have relatively little time or inclination to perform extensive strength and conditioning programs due to their preference to devote more time to the practice of a variety of golf shots as well as their family, work, study and/or travel commitments.

While the significant improvements in 5 of the musculoskeletal screening tests was a positive finding, the big question the first study sought to address was could the participation in once a week strength and conditioning program for only seven weeks result in improved golf swing performance? Unfortunately, no significant improvements in golf swing performance measures were observed, even when subgroup analyses between the High, Moderate or Low attendance groups were performed. While there was limited research to compare these results to, the lack of any significant improvements in golf swing performance was consistent with Lamberth et al. [79] who utilised a six-week program involving two strength and conditioning sessions per week. Collectively, the lack of significant improvements in golf swing performance resulting from this current study and that of Lamberth et al. [79] would indicate that there may be a minimum frequency and duration required for any significant improvement in golf swing performance to occur [11]. These results therefore would suggest merely performing one or even two strength and conditioning sessions per week for a short period (6-7 weeks) is unlikely to improve golf swing performance, even in golfers with limited resistance training experience.

The second question in this thesis sought to address was what aspects of a strength and conditioning program may most contribute to improved golf swing performance. This was thought to be an important question as most of the strength and conditioning programs evaluated in the peer-reviewed literature have been quite holistic in nature, involving a variety of muscular strength, power and endurance as well as some flexibility, stability and cardiovascular exercises. To answer this question, the second study sought to quantify how training-related changes in musculoskeletal screening assessment performance may be related to improvements in golf swing performance.

Results from the second study indicated a relative lack of many significant correlations between the changes in the musculoskeletal screening assessments and golf swing performance. Of those that were significantly correlated, the strength of these correlations were only moderately low to moderate. Moderate negative correlations reported between right bridging leg lift and driving distance ($r = -0.354$, $p = 0.040$), left thoracic rotation and ball speed ($r = -0.358$, $p = 0.037$), driving distance ($r = -0.393$, $p = 0.021$), and side ($r = -0.381$, $p = 0.026$). Further results showed similar trends, with moderate negative correlations detected between right thoracic rotation and smash factor ($r = -0.340$, $p = 0.049$), right single leg squat and ball speed ($r = -0.407$, $p = 0.017$) and left single leg squat and ball speed ($r = -0.411$, $p = 0.016$). The only significant positive correlation from this study was for the change scores between right side bridge and Combine test ($r = 0.356$, $p = 0.039$).

Thoracic rotation is a well-known topic of discussion in the golf industry largely because of its role in optimizing the “X-Factor stretch”. The X-factor stretch is better defined as the separation between the torso and hips during the backswing, which may allow for greater angular velocity to be generated in the downswing, resulting in a higher CHS [91, 92]. Carry side, as defined previously [40], “is the lateral deviation of the ball either left or right of the target line”. Thus, interpreting the results leads to the conclusion that incorporating regular thoracic mobility exercises may play some role in maintaining and improving the accuracy of a golfer’s driving shots. Addressing the positive correlation between change scores of the right side bridge and Combine test score seems relatively logical largely due to previous studies outlining the importance of muscular endurance of the lateral abdominal musculature in improving CHS and driving distance, both of which are predictors of successful golf performance [6, 9, 39].

The relative lack of correlation between the changes in individual musculoskeletal screening assessments and golf swing performance may not only reflect the low frequency and duration of the training program but also the multifactorial nature of golf performance. Compared to many athletic events such as sprinting or marathon running or even other ball sports, golf may require a wider range of physical, tactical, psychological and technical qualities. This is especially apparent when it is understood that elite golf performance requires the ability to accurately hit the ball distances of ~300 m during drives but also reading the putting green and bunker conditions to accurately putt or chip over distances of less than 10 m, respectively. Thus, additional work is still required to determine what aspects of an exercise program are the strongest contributors to improvements in a variety of golf performance parameters. Such a question may not be easily answered as it may be athlete-dependent, with insight into this answer provided by the results of musculoskeletal screening and strength/power assessments.

Practical Applications

This thesis presents the results of the research studies which investigated the effectiveness of implementing strength and conditioning programs into the overall training program of a golfer. More specifically, there was a focus on identifying whether a once per week, seven week long strength and conditioning program could improve musculoskeletal measures and golf swing performance as well as gaining some insight into which aspect of these programs were responsible for eliciting positive changes in golf swing performance. Such research was considered important as while, strength and conditioning programs have proved effective in improving musculoskeletal measures and golf swing performance, the question of the minimal exercise dose required for benefit not been thoroughly investigated. Further, the heterogeneity in the exercise prescriptions used in the studies limits our understanding of what aspects of these strength and conditioning programs contribute most to improving golf swing performance. As golfers from recreational to elite professionals often have limited time and access to a gym facility, it is even more imperative that only the most effective exercises, repetition and loading schemes are used.

Based on the results presented in the peer-reviewed literature and that obtained from the studies contained within the current thesis, the following recommendations can be made for both the golfer and their coaches:

1. Performing one exercise session per week for a period of seven weeks may be effective in significantly improving a number of musculoskeletal measures, however, no significant changes were noted in actual golf swing performance during this time;
2. For golf swing performance changes to be observed with just one exercise session per week, a longer duration of more golf-specific exercises may be required;
3. Limited associations were found between changes in the musculoskeletal screening measures and golf swing performance over the course of the seven week intervention. Nonetheless, changes in the right side bridge exercise performance was positively correlated with driving distance, suggesting that appropriate progressions of this and other exercises targeting the lateral trunk musculature may be important to include in golf exercise prescription;
4. The use of musculoskeletal screening assessments may assist strength and conditioning coaches to determine what physical qualities individual golfers need to improve in order to enhance their golf swing performance.

Limitations

The following limitations were identified by the authors throughout the two studies:

1. Participant attendance to the exercise sessions were quite mixed over the seven-week intervention, with only 11 of the 43 participants completing six

or more of the seven requested training sessions. This may have been related to the exercise sessions being embedded in the golf education program the participants were enrolled in, whereby motivational levels to attend the exercise sessions might have been affected by their study and golfing commitments;

2. Golf coaches or strength and conditioning coaches may need to develop strategies to improve exercise attendance rates if they wish to obtain greater changes in the musculoskeletal measures (and perhaps even golf swing performance);
3. The exercise program was relatively non-specific, with most resistance training exercises being strength and hypertrophy based. Access to standard gym equipment was also somewhat limited, meaning that certain participants may not have been sufficiently challenged during all exercises;
4. Progressing these exercise programs into more power based exercises might have had better simulated aspects of the golf swing and resulted in greater transfer to golf swing performance;
5. The sample of participants were inexperienced with resistance training but relatively heterogeneous with respect to age and handicap.
6. No a priori sample size calculation was performed, and the sample size was recognised as being insufficient to perform a regression analysis for Study Two.

Directions for Future Research

This thesis aimed to make a positive contribution to the current body of knowledge regarding minimum training dosage for individuals with limited time to devote to strength and conditioning as well as to gain some further insight into which aspects of the exercise prescription contributed most to improvements in the golf swing performance measures. While the results of this thesis demonstrated the potential for significantly improved musculoskeletal measures with only one resistance training session per week, there is still a need for greater understanding surrounding the most important aspects of the strength and conditioning program, as well as what changes in musculoskeletal measures may be most responsible for changes in golf swing performance. Therefore, the following areas are recommended to be investigated in future research studies:

1. Conduct a series of longitudinal studies which will compare a variety of exercise frequencies and durations so as to more clearly clarify the dose required to produce positive changes in both musculoskeletal measures and golf swing performance measures across golfers of a variety of genders, ages and handicap levels;
2. Utilise these longitudinal studies to better quantify the relationship between changes in musculoskeletal measures and golf swing performance across a variety of subgroups of golfers;
3. Continue to refine the development of golf specific musculoskeletal screening assessments, so to maximise the reliability and validity of these assessments in predicting golf swing performance and/or injury risk;
4. Conduct additional prospective studies which assess the golf swing performance benefits of an exercise program and its ability to reduce the risk of injuries over an extended period in a variety of golf subgroups.
5. Conduct a similar study design that includes a larger sample size and strategies to improve adherence to the training program.

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Appendix

The Golf Athlete booklet (Ten Test on-range)

1. Golf Single Leg Squat Test

Purpose:

This test assesses the strength and control of the each hip, knee and ankle to provide a stable base for the golf swing.

Golf Relevance:

Single leg control is essential for coordinated weight transference from the backswing to the follow through.

Procedure:

- The golfer stands on 1 leg
- Head remains up and chest out
- Hold both arms parallel to the floor (90 degree shoulder angle in standing)
- Keep unsupported leg in front of body
- Perform six slow single leg squats
- Attempt to maintain the knee over the second toe
- Maintain a level pelvis with no rotation (“square on”)
- The knee should bend to a 90 degree angle

Scoring:

1 = Performs single leg squat with significant shifting or dropping of the stance hip, knee falls in and loses trunk control

2 = Performs single leg squat, but with 2 of above 3 present

3 = Performs single leg squat, but with 1 of above 3 present

4 = Able to perform single leg squat with good control but unable to reach a 90 degree angle at the knee

5 = Able to perform six single leg squats with good control to 90 degree angle at the knee

2. Golf Single Leg Bridge Test

Purpose:

This test assesses the strength of the gluteal muscles and the ability of the golfer to control weight transference.

Golf Relevance:

Good functioning of the gluteals is essential to allow the golfer to maintain the stability of the trunk and pelvis during weight transference in the golf swing. This test assesses the relevant contribution of the principal muscles in the hip extensor group—namely the gluteals and the hamstring muscles. Good function would involve greater involvement of the gluteals in preference to the hamstrings.

Procedure:

- The golfer lies on the floor with arms folded across the chest
- Place the feet 15 cm apart
- Squeeze your buttock muscles and lift the hips off the ground
- Slowly march the feet up and down 5 times until comfortable with the 15cm separation
- Keep the spine in a neutral position – no rotation or dropping or excessive lower back arch
- Extend or straighten 1 leg out to take the weight through the opposite leg
- Keep the knees level and the hips steady
- Attempt to hold for 10 seconds
- Note any cramping or tightening in the hamstrings

Scoring - for each side:

1 = Unable to straighten leg

2 = Able to straighten the leg but immediate drop of unsupported hip or cramping of the hamstring

3 = Unsteadiness of the unsupported side or loss of alignment of the hips or cramping within 10secs

4 = Maintains a steady hold for 5 seconds but reports cramping/tightness in hamstring

5 = Steady hold for 10 seconds, no cramping or tightness in the hamstring with good alignment of the hips and low back

3. Golf Overhead Squat

Purpose:

This test assesses the ability of the golfer to squat correctly while maintaining good upper back posture.

Golf Relevance:

The ability to squat correctly at the three major joints of the lower half is essential to maintain posture throughout the swing. Maintenance of good squatting ability will decrease the rounding of the spine &/or the movement of the hips toward the ball. Elevation of the arms above the level of the shoulder should not affect the maintenance of the ideal golf posture. As the arms are raised at the top of the backswing the posture of the spine and the head should be maintained.

Procedure:

- The golfer stands with feet shoulder width apart
- Extend the arms above the head – holding a golf club in line of the ears
- Keep the head up and chest out
- Heels must be maintained on the ground
- Weight evenly distributed
- Attempt to squat with club maintained above the head so that the thighs are parallel to the ground
- If unable to maintain the correct line of movement repeat the above with the arms crossed on the chest.
- Repeat 5 times

Scoring

1 = Cannot get thighs to parallel with arms crossed on the chest

2 = Able to get thighs to parallel with arms crossed on the chest

3 = Cannot get thighs to parallel and/or maintain the arms extended above the shoulder the line of the ears without excessive forward inclination of the trunk

4. = Able to get thighs to parallel but unable to maintain the arms extended above the shoulder in line of the ears without excessive forward inclination of the trunk

5 = Able to get thighs to parallel with the arms extended fully above the head and in the line of the ears without excessive forward inclination of the trunk

4. Golf Seated Trunk Rotation Test

Purpose:

This test assesses the ability of the golfer to complete a full rotation of the shoulders (trunk or torso) in the golf swing.

Golf Relevance**:**

The ability to rotate the shoulders (trunk or torso) past the hips (pelvis) is important for storing energy, and for creating torque (rotational force). During transition, there is extra stretch created by this movement essential to high level ball striking and generating optimal club head speed. After impact the follow through allows the energy created, and not transmitted to the club head and ball, to be dissipated safely.

Procedure:

- The golfer should be in a seated position
- The seat height should be adjusted so that the thighs are parallel to the floor
- Cradle the club shaft in the crook of the elbows and behind the back
- Knees stay in contact with the wall
- Keep the chest up and back straight
- Head to remain horizontal
- Shoulder blades – down and back
- Ensure that the pelvis remains still – and does not rotate excessively
- Start with the club straight behind the back (pointing to 9 and 3 o'clock)
- The golfer turns the torso to the right until the club shaft lifts off the back on the right
- Observe where the shaft points to (on an imaginary clock face under the golfer) when the club lifts off the golfer's back
- Repeat to the left

Scoring:

Right

1 = Unable to turn without maintaining stable hips (pelvis) in sitting position

2 = Scores < than 4 o'clock on the clock face (30 degrees)

3 = Scores > 4 and less than 4.30 on the clock face (<45 degrees)

4 = Scores > 4.30 and less than 5 on the clock face (45 to 60 degrees)

5 = Scores > 5 on the clock face (>60 degrees)

Left

1 = Unable to turn without maintaining stable hips (pelvis) in sitting position

2 = Scores > than 8 o'clock on the clock face (30 degrees)

3 = Scores < 8 and greater than 7.30 on the clock face (<45 degrees)

4 = Scores <7.30 and greater than 7 on the clock face (45 to 60 degrees)

5 = Scores < 7 on the clock face (>60 degrees)

5. Golf Shoulder Lift Off Test

Purpose:

The test assesses the golfer's upper back and shoulder mobility and strength.

Golf Relevance:

Upper back mobility and strength – Spinal mobility and strength is important for the golfer to achieve a good set-up position and to achieve good rotation during the swing. Finally it underpins the generation of power/torque required to maximise club head speed.

Shoulder mobility – The golfer's shoulders require good flexibility to allow adequate shoulder turn while achieving the ideal position of the golf club at the top of the backswing. Maintenance of optimal trunk and shoulder posture through the backswing and follow through requires good shoulder mobility.

Shoulder blade strength – The golfer's ability to hold and control the shoulder blades allows the arms to stay "connected" during the golf swing.

Procedure**:**

- The golfer lies on the tummy on a firm surface
- Arms out straight in front of the head with the elbows straight
- Touch the thumbs together with palms facing downwards
- Look up at thumbs but keep the chin on the surface
- Keep feet, hips and chest on the surface throughout the test
- Raise straight arms slowly to the best height keeping the elbows straight
- Hold for 5 seconds
- Measure from wrist to the surface

Scoring**:**

1 = Unable to lift

2 = 0-5cm

3 = 5-10cm

4 = 10-15cm

5 = 15cm+